The Transmission of Commodity Price Super-Cycles

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Abstract

We examine two key channels through which commodity price super-cycles affect the economy. Higher commodity prices increase domestic demand (*wealth* channel), disproportionately benefiting non-exporters, and induce wage increases (*cost* channel) especially among unskilled workers, hurting unskilled-intensive industries. By exploiting regional variation in exposure to commodity price shocks and administrative firm-level data from Brazil, we empirically disentangle these transmission channels. We introduce a dynamic model with heterogeneous firms and workers to further quantify the mechanisms and evaluate welfare. The cost channel explains two-thirds of intersectoral labor reallocation, and the wealth channel explains two-thirds of the labor reallocation between exporters and non-exporters. Labor market frictions lead to persistent unemployment as the boom fades, eroding up to 50% of the accumulated welfare gains.

Keywords: Commodity shocks, local labor markets, skill premium, heterogeneous firms.

JEL classification: E32, F16, F41

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1 Introduction

Global commodity prices are a fundamental source of volatility for emerging markets. They explain a third of the variance in output [Fernández et al., 2017b], and cycle busts often cause recessions and slow recoveries [Reinhart et al., 2016]. A well established literature in international finance has studied the role of terms of trade [Mendoza, 1995] and commodity prices [Schmitt-Grohé and Uribe, 2015, Fernández et al., 2017b] as drivers of business cycles. This literature has typically abstained from micro-founding the transmission channels of these cycles to the economy and, consequently, overlooked their heterogeneous impact across firms and sectors. In this paper, we fill this gap by identifying and measuring two key transmission channels of commodity super-cycles.[1]

First, during a commodity boom, a *cost* channel operates through an increase in wages in response to an expansion in the labor demand of the commodity sector. Because the commodity sector is relatively unskilled-intensive, a commodity price boom lowers the skill premium, increasing the relative cost of less skill-intensive industries. Therefore, the impact of this channel on different industries is heterogeneous. Second, as prices and wages are higher during a commodity boom, the present value of domestic income increases, triggering a *wealth* channel. The responses to this channel are heterogeneous across firms as it benefits non-exporting firms more given that their demand is fully domestic, all else equal.[2]

Our empirical results are based on the case of Brazil during 1999-2013, which is an ideal setting for understanding the mechanisms behind the transmission of commodity price cycles. During this period, large price fluctuations struck the nation's economy, which has been historically characterized by massive regional differences in the composition of commodity production. Given the size of local production, any single Brazilian region cannot affect the world price of commodities. Therefore, the price of the local commodity basket is exogenous to any location. We exploit this exogenous regional variation and detailed administrative data for millions of firms to empirically identify the two channels. To identify the cost channel, we begin by documenting two auxiliary results. First, we show that the commodity sector is relatively unskilled-labor intensive. Second, increases in regional commodity prices reduce the skill premium in that particular location. These two results allow us to formulate the following hypothesis: If a cost channel exists, then firms operating in industries that are less skill-intensive should decrease employment more during a commodity boom than firms in more skill-intensive industries. Firm-level regressions confirm this hypothesis even within sectors. To identify the wealth channel, we focus on the manufacturing sector. In particular, we formulate the following hypothesis: If this channel exists, then exporting firms within this sector should decrease employment more during a commodity boom than

[1] Unlike regular business cycles, commodity super-cycles evolve at considerably lower frequencies. In fact, an expansionary boom can last more than a decade.

[2] The economic intuition behind these two channels can be traced back to Corden and Neary [1982]. To highlight the economic roots of the channels, we use the term *cost channel* instead of *resource movement effect* used in Corden and Neary [1982]. We extend the original spending channel to allow for consumption smoothing with an endogenous current account as in Alberola and Benigno [2017]. To account for this extension and avoid confusion with the static spending effect in Corden and Neary [1982] we denote it *wealth channel*.

non-exporting ones. This second hypothesis is also confirmed by our empirical analysis.[3]

The empirical identification of the channels provides the building blocks for our quantitative framework. We introduce a three-sector (commodity, manufacturing, and services) small open economy model, which extends the quantitative international finance literature in at least three dimensions. First, we deviate from the representative firm paradigm by including heterogeneous firms within each sector. This allows the model to capture intensive and extensive margin responses to changes in commodity prices. In particular, within manufacturing, an export productivity cutoff divides firms into exporters and non-exporters, which allows us to capture the differential exposure to the wealth channel within this sector. Second, because differences in skill intensity across sectors and movements in the skill premium play a key role in the transmission of commodity prices through the cost channel, we allow for skilled and unskilled labor as well as for differences in skill intensities across sectors. Third, because of the central role of labor markets and the pervasive rigidity in emerging economies' labor markets, we include downward wage rigidity in the model. This feature is key in generating the painful ending of a commodity cycle. The model is solved dynamically taking into account the consumption smoothing behavior of the representative household, featuring endogenous trade balance and current account dynamics that are critical to properly account for the wealth channel.[4]

We calibrate our model to the Brazilian economy. To discipline the wealth and cost channels, we explicitly target the heterogeneous skill intensity across sectors and the fraction of exporters in manufacturing, along with several other firm-level and macroeconomic moments. We test the validity of the model along a variety of non-targeted dimensions by making use of our rich firm and regional data. The model is able to replicate the dynamics of the regional skill premium, the reallocation of labor between sectors, and the differential effect of commodity prices on exporting firms in response to a commodity price super-cycle. We then use the calibrated economy to quantify the aggregate relevance of each channel. The cost channel explains approximately two-thirds of the reallocation of labor from manufacturing into services, while the second one explains approximately two-thirds of the reallocation of labor between exporters and non-exporters within manufacturing.

From an aggregate perspective, we show how labor market frictions imply that the efficient reallocation of labor during the commodity boom is transformed into inefficient misallocation of labor during the bust. In particular, an economy with a level of downward wage rigidity consistent with the frictions in the Brazilian economy experiences a 10% unemployment rate and a 5% decrease in real GDP at the end of the calibrated commodity cycle. This painful ending can consume more than half of the welfare gains

[3]The richness of the data allows us to controls for several alternative mechanisms that may have affected manufacturing firms during this period. These include regional trends of trade liberalization, regional variation on import penetration from China, commodity usage as an intermediate input in manufacturing, exchange rates, interest rates and financial conditions, among many others.

[4]We solve the model using global methods and without imposing a terminal condition for bonds. Consistent with Alberola and Benigno [2017] the wealth channel thus responds to changes in the present value of income. Through this mechanism temporary shocks can have permanent effects.

accumulated during the boom. In fact, a flexible economy exhibits a consumption equivalent welfare gain of 2.2% while a rigid economy only experiences a 0.9% gain. Consequently, the cross-country variation on the severity of commodity busts could be attributed in part to heterogeneity in labor market rigidity.

We build on the long-standing literature in international finance seeking to understand the impact of terms of trade on macroeconomic aggregates in emerging economies [Mendoza, 1995, Kose, 2002]. In particular, we contribute to the recent efforts to study and quantify the economic consequences of commodity price cycles [Reinhart et al., 2016, Shousha, 2016, Fernández et al., 2017a, Drechsel and Tenreyro, 2017, Alberola and Benigno, 2017].

Our main contributions to the literature are threefold. First, by allowing within-sector firm heterogeneity, we distance ourselves from the representative firm paradigm dominant in international finance. Therefore, our paper belongs to the recent literature that uses dynamic heterogeneous-firms models and/or firm-level information to study classical problems in international economics such as the transmission of business cycles [Ghironi and Melitz, 2005], the consequences of financial integration [Gopinath et al., 2015, Varela, 2015], the response of trade flows to devaluations [Alessandria et al., 2013], sudden stops [Ates and Saffie, 2016], and to measure news shock arising from commodity discoveries [Arezki et al., 2017]. In addition, recent models of commodity price transmission conceptualize these shocks as endowment changes to the economy, mainly highlighting the wealth channel [e.g., Fernández et al., 2017a].[5] Our empirical analysis shows that both the cost and wealth channels are relevant, and thus it is critical to include both in our model and quantitative analysis.

Second, while previous studies have focused on cross-country evidence [Fernández et al., 2017b, Sachs and Warner, 1995, Harding and Venables, 2016], we exploit variation in exposure to commodity price fluctuations across regions within a country to assess the empirical implications of our economic model. In this way, we are able to identify the distinctive effects of different transmission mechanisms of commodity price super-cycles allowing for heterogeneous effects across and within sectors. Therefore, on empirical grounds, we also speak to the literature examining the consequences of local economic shocks including import competition shocks [Autor et al., 2013, Dix-Carneiro and Kovak, 2017, Costa et al., 2016], natural resource abundance [Allcott and Keniston, 2014, Faber and Gaubert, 2016], or more broadly macroeconomic shocks [Blanchard and Katz, 1992].[6] We contribute to this literature in two main ways. First, not only do we measure spillovers to other sectors of the local economy, but we also identify specific transmission mechanisms. We are the first to empirically identify the two transmission channels in the classic work of Corden and Neary [1982]. To do so, recognizing and taking advantage of the heteogeneous

[5] An exception is Alberola and Benigno [2017] who embed the two channels of Corden and Neary [1982] in a small open economy model of a representative firm with endogenous growth (based on knowledge accumulation in the tradable sector) to study structural long-run changes driven by temporary commodity booms. Differently from Alberola and Benigno [2017], we focus on short and medium-run effects of commodity cycles abstracting from slow-moving phenomena such as knowledge accumulation. The two channels that we study are empirically identified, measured, and mapped into a rich quantitative framework.

[6] Also related to our work, with the different goal of quantifying the distributional effects of the sorting of workers across sectors, Adão [2015] exploits regional exposure to commodity prices in Brazil.

impact of each channel across firms and sectors is crucial to the empirical strategy. Second, we focus on the impact on firms, whereas this literature typically focuses on regional aggregates or on individuals.

Third, we show how labor market institutions, specifically downward wage rigidity [Schmitt-Grohé and Uribe, 2016], shape the response of the economy to these shocks. In this regard, our work speaks to the research examining how the relationship between commodity price volatility and output volatility depends on various institutional characteristics such as exchange rate regimes, political stability, and financial development [e.g., Céspedes and Velasco, 2012]. We show how these theoretical ingredients play key roles in the transmission of commodity cycles and their welfare implications.

The rest of the paper is structured as follows. Section 2 describes the data used in our empirical analysis. Section 3 documents the empirical findings that guide our theory. Section 4 outlines the model, and section 5 describes the results of our quantitative analysis. Section 6 concludes.

2 Data Description

Our empirical analysis is carried out using linked employer-employee data from Brazil for the period 1999-2013. This dataset - Relação Anual de Informações Sociais (RAIS) - is an administrative census collected for social security purposes by Brazil's Labor Ministry.[7] It encompasses the universe of formal-sector employees. The longitudinal information allows us to track both workers and firms over time.

We observe detailed worker characteristics including educational attainment, age, gender, and occupation. We observe firms' industry and their geographic location at the municipality level.[8] This allows us to exploit regional variation in exposure to commodity price changes in our empirical analysis.

For each job spell in each year, we observe the exact starting and ending day of a worker's employment in a firm. Based on this information, we compute quarterly indicators of employment. We observe individuals' mean monthly earnings in each job spell in each year, as well as earnings each December. In our analysis below, we use both annual earnings and monthly December earnings.

Skilled and Unskilled Workers. We divide workers into skilled and unskilled categories based on their educational attainment. In the raw data we observe nine groups of attainment ranging from no formal education to tertiary education. We classify as unskilled workers those with at most complete secondary education, and as skilled workers those with at least some tertiary education. Nationally, unskilled workers represent about 80 percent of total employment.

Regional Units. We define regional units that are a close approximation to the concept of local labor market. While in the raw data we observe the municipality of each worker's employer, these municipalities are geographically too small to be considered a local labor market.[9] Instead, we choose microregions as

[7] Differently than recent papers that have used worker-level records from this data [Alvarez et al., 2018, Dix-Carneiro and Kovak, 2017, Helpman et al., 2017] we use it to construct a comprehensive dataset of millions of firms in all sectors of the economy. No other such data exists for Brazil.

[8] Industry categories follow Brazil's National Classification of Economic Activities (CNAE).

[9] Brazil is divided into about 5500 municipalities, 558 microregions, 137 mesoregions, 27 states, and 5 macroregions

the regional unit that best reflects a local labor market. Throughout the paper we refer to these 558 microregions simply as regions. These regional units are defined by Brazil's Statistical Institute (IBGE) and are similar to U.S. commuting zones.[10] They are large enough such that interregional migration is fairly small. Aggregating the individual-level data, we compute sectoral and total regional employment, and regional measures of the skill premium.

Economic Sectors. The three sectors of interest to our paper are commodity, tradable, and nontradable. The commodity sector includes agriculture, mining, and fuels.[11] The tradable sector includes all manufacturing industries.[12] Nontradables include retail and wholesale trade, hospitality, construction, transportation, finance and real estate, among others.[13]

Firm-Level Panel. We construct a firm-level panel by aggregating our worker-level records. The panel consists of 2.3 million firms operating in the three sectors of interest. We compute firms' quarterly employment in the last month of each quarter.[14] We complement our firm-level panel with additional information on exporting and importing firms. This data on exporters and importers is obtained from Brazil's Secretariat of Foreign Trade (SECEX). We assign each firm in our panel a dummy variable for exporting and importing status at an annual frequency.

Descriptive Statistics. There is wide variation across regions and sectors in the number of firms, firm employment, and the share of exporting firms, as appendix table A1 shows. In all five Brazilian macroregions, commodity firms are fewer than those in the tradable and nontradable sectors and are also substantially larger. The share of exporters in the tradable sector varies from 3 percent in the *South* to 10 percent in the *North*.[15] Appendix table A2 illustrates the regional variation in the relative wage of skilled to unskilled workers, which ranges from 2.64 in the *Southeast* to 3.57 in the *South* in the middle of our sample period (2006).

Commodity Prices. We construct a regional commodity price index based on 14 commodity goods that capture a very large share of commodity employment in Brazil. These span agriculture, mining, and fuel industries and are chosen based on the following criteria: i) we must be able to match these categories to employment data to construct regional weights and ii) we must be able to match these categories to data on commodity prices in world markets. The list of 14 commodities consists of cereals, cotton, sugarcane, soybeans, citrus, coffee, cacao, bovine meat, ovine meat, poultry meat, coal, oil and

[10]Commuting zones have been widely used as approximations to local labor markets in the US for the analysis of regional shocks, such as in Autor et al. [2013].

[11]We verify later the robustness of our results to excluding fuel industries from the commodity sector.

[12]We show below that our results are robust to excluding manufacturing industries with an intensive use of commodities as inputs.

[13]We exclude from our analysis government and quasi-public sectors. This includes federal and local governments, education and healthcare. We also exclude domestic service.

[14]In the case of multiplant firms, we define a firm's sector as that in which the firm has a majority of employment. Similarly, we define a firm's region as that in which most of the firm's employment is concentrated.

[15]The shares of exporting firms reported in appendix table A1 are low in comparison to those reported in the literature for other countries. Part of the reason is that we restrict our sample to firms with 5 or more workers, whereas datasets used in the literature have a higher threshold. In addition larger economies typically have smaller shares of exporters.

gas, a basket of metallic minerals, and a basket of precious metals. The largest commodities in terms of employment are cereals, bovine meat, coffee, sugarcane, and soybeans. There is considerable variation in the geographic distribution of employment in these commodities across Brazil. There is also geographic variation in the share of employment in commodities in each region as is illustrated in figure A1 in the appendix.

We obtain commodity price data for the period 1999-2013 from the World Bank's Global Economic Monitor - Commodities. This dataset has the advantage of tracking commodity prices for a wide number of commodities over a long period of time and with systematic criteria to define the prices of all of them. The data is reported at a monthly frequency, and we construct quarterly price indices based on the last month of each quarter. These data are reported in nominal U.S. dollars, which we deflate using the U.S. Consumer Price Index.

We define a regional commodity price index as the weighted average of individual commodity prices. In each region, the weights are the base-period share of employment in each individual commodity in total employment in the commodity sector. Formally,

$$p_{rt} = \frac{\sum\limits_{c \,\epsilon\, C} p_{ct} \times e_{cr}}{\sum\limits_{c \,\epsilon\, C} e_{cr}}, \tag{1}$$

where p_{ct} stands for the price of commodity c in period t, and e_{cr} represents the base-year employment of commodity c in region r.[16] We obtain employment data for these weights from Brazil's Demographic Census of year 2000 - the earliest possible year that is close to the start of our sample period. By using the Demographic Census for these weights instead of RAIS, we are using a wider measure of employment - including informal employment.

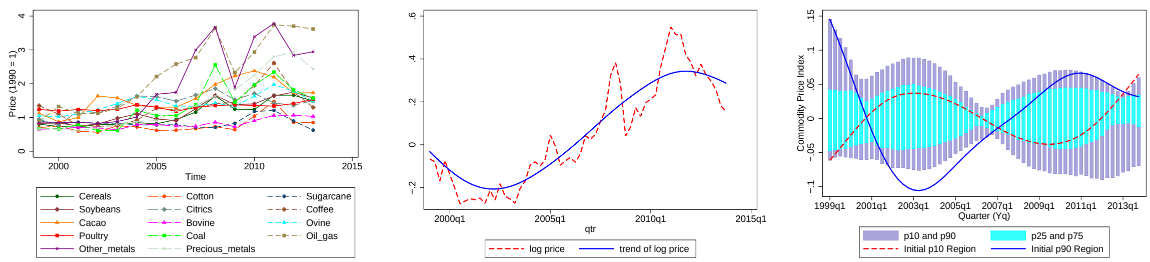
Commodity super-cycles are low frequency phenomena where most of the time series variation is explained by medium to long run movements. Therefore, to better capture super-cycles, we use the trend of this price index rather than the short run deviations from it.[17] We extract the trend for each region's price index using the Hodrick-Prescott filter, based on quarterly data for 1990-2015.

This regional price index varies across regions and time due to the interaction of (time-invariant) differences in the base-year composition of the commodity sector and of variation over time in the prices of individual commodities. Figure 1a depicts the evolution of the individual commodity price series over time. To a large extent this period has seen a commodity price boom, but there is widespread variation, with, for instance, large growth in metal prices and fairly stable prices in, for example, cotton or sugarcane. At the national level, our 1999-2013 window captures falling prices up to mid 2002 followed

[16] For each region, there is a fraction of employment in commodity-related activities that we cannot directly link to one of the 14 commodities for which we have price data. In these cases, we distribute those workers equally across the commodities for which we do have price data found within the same 2-digit industry.

[17] We discuss however in section 3.4 that our results are robust to using either the unfiltered commodity price index or both the trend and the cyclical component of the price index, and that it is the trend that drives our findings.

by a commodity price boom with the price index at its peak in 2011 and the start of a bust in the last two years of our sample. This is shown in figure 1b, which displays an aggregate commodity price index based on nation-wide employment weights. Figure 1c illustrates the variation in the residual regional price index after extracting region and period fixed effects, which is the source of our identification in the next section. The outer bars show the 10th and 90th percentiles of the residual price across regions in each quarter, and the inner bars show the 25th and 75th percentiles. The dashed (solid) line shows the path of the price for the region with the price at the 10th (90th) percentile in the initial period.



a) Individual Commodity Prices b) Commodity Price Index c) Regional Commodity Prices

Figure 1: Commodity Prices

NOTE: The graph on the left shows the path of the prices in real U.S. dollars of the 14 commodities included in our commodity price index. These prices are normalized to one in 1990. The graph on the middle shows the path of the commodity price index for Brazil (dashed line) and its trend (solid line). The graph on the right shows the percentiles of the distribution of the residual regional commodity price index after extraction region and period fixed effects. The outer bars mark the 10th and 90th percentiles and the inner bars mark the 25th and 75th percentiles. The dashed (solid) line marks the path of the residual price for the region at the 10th (90th) percentile in the initial period.

Additional Data Sources. We complement our data with information from multiple additional sources. These include the Brazil's household survey PNAD and Demographic Census, data on trade flows, import tariffs, and Brazil's input-output table. All of these are described in the appendix A.1.1 and are mostly used for robustness checks.

3 Empirical Characterization of Transmission Channels

We start with a brief conceptual discussion of the economic mechanisms behind the transmission of commodity price shocks throughout the economy and of our empirical framework. We disentangle the *cost* and *wealth* channels taking advantage of the fact that each of these has heterogeneous impacts across and within sectors.

Economic Intuition. An increase in commodity prices should lead to an expansion in the commodity sector's labor demand. Because the commodity sector is relatively unskilled-intensive, this implies an increase in the relative demand for unskilled labor, and consequently a decline in the skill premium.[18] These

[18]The negative correlation between commodity prices and the skill premium links our paper to a broader debate regarding to what extent the large decline in inequality observed in Brazil during this period (documented in Alvarez et al. [2018]) is a consequence of the commodity price boom of the 2000's rather than to structural policies.

changes in wages and prices reallocate labor away from the tradable and nontradable sectors and towards the commodity sector. The tradable sector is relatively unskilled-intensive in comparison to nontradables, so it faces a larger negative cost shock. Further, in both tradables and nontradables there is heterogeneity in skill intensity across narrow industries. This heterogeneity allows us to empirically identify the cost channel. Note that the wealth channel has a homogeneous impact across nontradable industries, so any variation in the impact of commodity prices on employment as a function of industries' skill intensity can be attributed to the cost channel. We document that firms in relatively unskilled-intensive industries within the tradable and nontradable sectors suffer larger employment losses in response to increases in commodity prices.

A positive commodity price shock also triggers a wealth effect increasing the local demand for goods. This wealth channel benefits firms that sell their goods domestically: firms in the nontradable sector and non-exporters in the tradable sector. We thus identify the wealth channel based on its heterogeneous impact on exporters vs. non-exporters within the tradable sector, showing that exporters suffer larger employment losses than non-exporters.

Parameters of Interest and Identification. Given these mechanisms, we consider the following model to establish the link between commodity prices and firm-level employment leading to the detection of the cost channel:

$$\log(\text{Emp})_{ft} \quad = \quad \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \gamma_f + \delta_t + \epsilon_{ft} \,, \tag{2}$$

where Emp_{ft} denotes employment of firm f in period t, Price_{rt} is the commodity price index of region r in period t, Skill Intensity_i is the skill intensity of firm f's industry measured in the baseline period, γ_f and δ_t denote firm and time (quarter) fixed effects, respectively; and ϵ_{ft} is the error term. We allow time fixed effects to vary by state to control for confounding time-varying shocks. To control for seasonality we include dummies for each of the four quarters. We estimate equation (2) separately for firms in the tradable and nontradable sectors. The parameter of interest is α_c. The cost channel implies $\alpha_c > 0$.

We take advantage of within sector heterogeneity, to detect the wealth channel. In particular, we examine the following linear regression model:

$$\log(\text{Emp})_{ft} \quad = \quad \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_w \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] + \gamma_f + \delta_t + u_{ft} \,, \tag{3}$$

where Exporter_{ft} is a dummy variable taking a value of one if the firm exports in period t, and u_{ft} is the error term. We estimate (3) only for the tradable sector. We also control for firm and state-by-time fixed effects, as well as for seasonality with quarter dummies. The parameter of interest is β_w. The wealth channel implies $\beta_w < 0$.

Our empirical strategy is based on reduced form OLS regressions of the regional commodity price index on firm-level outcomes. In this context, the identification of the parameters of interest critically depends upon the exogeneity of the commodity price index, Price_{rt}, relative to firm's employment in equations (2) and (3). This identifying assumption holds as long as firm-level outcomes do not influence commodity prices in international markets. Two facts we document in detail in appendices A.1.4 and A.1.5 provide evidence supporting this logic. First, Brazil holds a relatively small world market share in each of the commodities used in the construction of this index. Second, employment in each of these commodities is regionally dispersed: in each commodity, even regions at the right tail of the distribution represent a small share of aggregate employment. In section 3.4 we show our results are robust to a large set of confounding shocks and alternative mechanisms.[19]

3.1 The *Cost* Channel

The cost channel refers to the increase in (primarily unskilled) wages (a result of commodity booms) that raises firms' labor cost and affects employment. In this section we provide evidence supporting this transmission channel, but before doing so we must document two important facts: heterogeneity in skill intensity across sectors and across industries within sectors and a negative association between regional skill premia and commodity prices.

Heterogeneous Skill Intensity. We first document the distribution of skill intensity across industries within the commodity, tradable, and nontradable sectors. This allows us to observe both the relative ordering of sectors as well as the variation in skill intensity within sectors. We measure an industry's skill intensity as the share of skilled workers in total employment. As discussed in Section 2, we define skilled individuals as those with at least some tertiary education. We use cross-sectional data in year 2000.[20, 21] The distribution of skill intensity across industries for each sector is displayed in figure 2 and moments of this distribution are reported in appendix table A5. Two observations emerge. First, the commodity sector is the most unskilled-intensive, followed by tradables and then nontradables. Second, while the distribution of skill intensity in commodity industries is fairly homogeneous, it varies substantially within tradables, and especially, within the nontradable sector. This wide variation within sectors is used in our subsequent analysis to identify the transmission channels of commodity price cycles.

[19]Our approach resembles Bartik [1991] as we construct regional shocks weighting individual commodity price time series with regional employment shares. Work in progress by Goldsmith-Pinkham et al. [2018], Jaeger et al. [2018], and Adão et al. [2018] explores the identifying assumptions and the correct computation of standard errors in this class of regressions. Adão et al. [2018] study inference when regression residuals are correlated across regions with similar sectoral shares. In our empirical specification, technological shocks to specific commodities could increase the standard errors of our estimates under the assumption these omitted shocks also had an impact on firm level outcomes outside of the commodity sector. The fact that p-values in the coefficients that are key to identifying the cost and wealth channel results are an order of magnitude below 1% imply that even a large correction to our standard errors would not change our conclusions.

[20]We have verified that these statistics are stable over time.

[21]While we report these distributions using data from RAIS, data from Brazil's demographic census show a similar pattern.

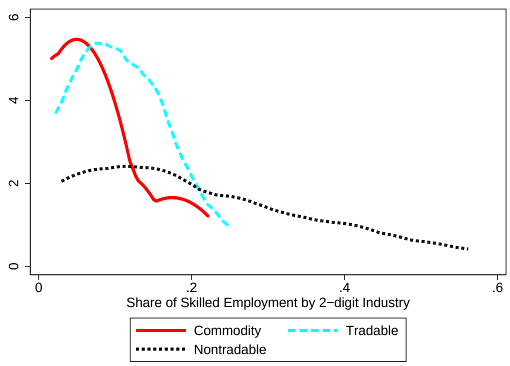


Figure 2: Skill Intensity Across Industries

NOTE: This figure displays kernel density estimates of the distribution of skill intensity (measured as the share of skill workers in year 2000) of two-digit industries in the commodity, tradable, and nontradable sectors.

Skill Premium and Commodity Prices. To establish the relationship between commodity prices and the regional skill premium we estimate the following equation:

$$\mathrm{SP}_{rt} = \pi_1 \cdot \mathrm{Price}_{rt} + \gamma_r + \delta_t + v_{rt} \,, \tag{4}$$

where SP_{rt} denotes the skill premium in region r at time t and v_{rt} is an error term.

We use annual observations for each region during the period 1999-2013, with commodity prices measured in the last month of the year. The regional commodity price index is the HP filtered trend of the employment weighted index defined in equation (1).[22] We measure the skill premium as the (log) difference in mean skilled and unskilled earnings in each region, for workers employed in the last month of the year. We report our results using both annual and monthly (December) earnings.[23] The regression includes region fixed effects, as well as macroregion-by-year fixed effects.[24]

The results are reported in table 1. A one log point increase in the regional commodity price index is associated to a 0.14 log point decline in the skill premium based on annual wages (column 1) and a 0.13 log point decline based on monthly wages (column 2). These are large elasticities; an increase in commodity prices such as that seen in Brazil between the second quarter of 2002 and the last quarter of 2011 (a 55 log point trough-to-peak increase) would lead to a 7 log point decline in the skill premium (based on column 2).

[22]As we argued in Section 2, we use the filtered trend of the regional commodity price index because our analysis is not concerned with high-frequency fluctuations in commodity prices. Our results, however, are very similar when using unfiltered price indices as seen in table A13 in section A.2.4 in the appendix.

[23]We estimate this regression on the skill premium with annual observations given the nature of how wage data is reported. As described in more detail in Section 2, we observe the annual earnings per job spell in each year as well as December earnings. Employment regressions below are estimated using quarterly data.

[24]A limitation of this regression stems from the changing composition of employment in response to commodity price shocks. If a commodity price increase attracts unskilled workers into employment, this will bias our estimates of the impact on the skill premium towards zero. Autor et al. [2013] acknowledge the same type of bias when measuring the impact of Chinese import competition on wages in U.S. local labor markets. Note that we do find an increase in total regional employment in response to commodity price shocks, as shown in appendix A.1.7.

Table 1: Commodity Prices and Skill Premium

	(1) Annual	(2) Monthly
(log) Price$_{rt}$	-0.140**	-0.128***
	(0.057)	(0.058)
Observations	8363	7912
R^2	0.694	0.687

Note: This table reports the results of the estimation of equation (4). Column 1 and, 2 correspond to annual and monthly (December) earnings respectively. Each regression includes region as well as macroregion-by-time (year) fixed effects. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Main Results. In what follows we document that higher commodity prices lead to larger employment losses in relatively unskilled industries (cost channel) within the tradable and the nontradable sectors separately.

We use the quarterly firm panel described in Section 2. This is an unbalanced panel with a maximum of 60 observations per firm during the period 1999-2013. These firms are located across 558 local labor markets. The dependent variable is (log) firm employment.[25] We include firm fixed effects as well as state-by-time (quarter) fixed effects. We cluster standard errors at the region level.

Consider first the total impact of the regional commodity price index on firm-level employment in each sector, resulting from the superposition of both channels. These results are reported in the first four columns in table 2 and correspond to excluding the interaction term between skill intensity and the commodity price index in equation (2). The results in the first column indicate that for firms in the commodity sector (column 1), a one log point increase in the regional commodity price index is associated to a 0.13 log point increase in employment. Columns 2 and 3 display the results from the tradable sector for all industries and excluding firms in three tradable industries with an intensive use of commodities as inputs, respectively.[26] In both cases, commodity prices are negatively correlated with firm employment. Based on column 3, a one log point price increase leads to a 0.14 decline in firm-level employment. Finally, in the nontradable sector (column 4) the impact is small and not statistically different from zero. Again, these responses result from the superposition of the cost and wealth channels and are consistent with the idea that in response to rising commodity prices the cost channel hurts the tradable sector relatively more, while the wealth channel benefits the nontradable sector relatively more. Our next results help us disentangle both channels.

Columns 5 through 8 in table 2 display the results after adding the interaction between skill intensity

[25] Employment and commodity prices are measured in the last month of each quarter.

[26] Appendix A.2.9 describes the construction of commodity usage by industries based on Brazil's input output table, and the criterion used to exclude commodity-intensive industries from the sample in column 3.

and the regional commodity price index. Given that in this case we demean the commodity price index and the measure of skill intensity, the estimated coefficients associated with the price index are similar in magnitude compared to those reported in the first four columns, although for the nontradable sector the coefficient becomes statistically significant. Regarding the interaction term, for the tradable sector (column 6), we find a statistically significant and positive interaction term, that translates into an elasticity of -0.170 and -0.127 for firms at the 25th and 75th percentiles of skill intensity respectively. The results for the tradable sector in column 7, which excludes industries with an intensive use of commodities as inputs, are similar. Within the nontradable sector (column 8), we find a positive and statistically significant coefficient on the term capturing the interaction between commodity prices and skill intensity. The elasticity of firm employment to commodity prices for firms at the 25th and 75th percentiles of skill intensity is -0.039 and 0.005 respectively. This difference illustrates the relevance of heterogeneity within the nontradable sector in terms of skill intensity. Overall, our findings confirm that higher commodity prices lead to larger employment losses in relatively unskilled industries, a result consistent with the cost channel.[27,28]

3.2 The *Wealth* Channel

As explained above, the impact of commodity price shocks within the tradable sector might also differ depending on firms' exporting status. Exporters benefit the least from the positive local demand shock caused by rising commodity prices. Comparing the impact of commodity price shocks on exporting and non-exporting firms within industries allows us to provide evidence on the wealth channel of transmission.

Columns 1 and 2 in table 3 display the results for equation (3). Given the well-documented link between exporting status and firm size, we additionally include interaction terms between firm-size-bin dummies and the price index.[29]

We find a much larger negative elasticity of firm employment to commodity prices for exporters (-0.10) than non-exporters (-0.042) in the tradable sector (see column 1).[30] This large and statistically significant difference illustrates the relevance of the wealth channel in the transmission of commodity price shocks. These results are robust to including the interaction between commodity prices and the skill intensity share of each tradable industry (see appendix A.2.1), the interaction between the exchange rate and the

[27] This result also holds for the commodity sector (see column 5 in table 2).

[28] While all nontradable industries rely entirely on domestic demand, heterogenous income elasticities of demand could generate heterogenous responses to commodity price shocks. In this context, a non-zero correlation between skill intensity and income elasticities of demand would pose a threat to our identification strategy of the wealth channel. To explore the robustness of our argument to this concern, we exploit variation within broader two-digit industries. Intuitively, within these broader industries differences across three-digit industries in income elasticities would be much smaller. Table A11 (column 2) in the appendix presents these results. Consistent with our main findings, higher regional commodity prices lead to larger employment losses in relatively unskilled-intensive three-digit industries.

[29] We include the interaction between the regional commodity price index and the following firm-size dummies: 0 to 50 workers, 50 to 100 workers, 100 to 500 workers, 1000 and more workers.

[30] The results are similar when we exclude tradable industries with an intensive use commodities as inputs, as shown in column 2.

exporter dummy (see appendix A.2.3), as well as a number of other robustness checks discussed below.

Table 2: Commodity Prices and Firm-Level Employment: The *Cost* Channel

	Total Impact				Cost Channel			
	Commodity	Tradable		Nontradable	Commodity	Tradable		Nontradable
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(log) Price_{rt}	0.131**	-0.136***	-0.140***	0.010	0.100*	-0.136***	-0.138***	0.014
	(0.065)	(0.030)	(0.032)	(0.021)	(0.056)	(0.030)	(0.033)	(0.021)
Skill Intensity_i x (log) Price_{rt}					3.467***	0.795***	0.943***	0.845***
					(0.476)	(0.205)	(0.220)	(0.114)
Observations	1,007,633	8,086,964	6,960,963	30,453,468	1,007,570	8,007,422	6,881,423	30,453,457
R^2	0.907	0.873	0.867	0.849	0.908	0.873	0.866	0.849

NOTE: This table reports the results of the estimation of equation (2) by sector. The first four columns exclude the interaction between the regional commodity price index and industries' skill intensity. Column 1 corresponds to the commodity sector. Column 2 and 3 corresponds to the tradable sector. Column 3 excludes commodity-intensive industries. Column 4 corresponds to the nontradable sector. Columns 5 to 8 include the interaction term, which allows the identification of the cost channel. Column 5 displays the results for the commodity sector. Columns 6 and 7 (excluding commodity-intensive industries) display the results for the tradable sector. Column 8 presents point estimates for the nontradable sector. Each regression includes firm and state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Note we estimate equation (2) demeaning the commodity price index and skill intensity variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Table 3: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	All industries	Excluding commodity-intensive industries
	(1)	(2)
(log) Price_{rt}	-0.042*	-0.049**
	(0.022)	(0.023)
Exporter_{ft}	0.141***	0.138***
	(0.005)	(0.005)
Exporter_{ft} x (log) Price_{rt}	-0.058***	-0.056***
	(0.015)	(0.015)
Observations	8,086,964	6,960,963
R^2	0.909	0.903

NOTE: This table reports the results of the estimation of equation (3). Column 1 includes all industries in the tradable sector. Column 2 excludes commodity-intensive industries. Each regression includes firm and state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. We include (but do not display) the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 0 to 50 workers, 50 to 100 workers, 100 to 500 workers, 1000 and more workers. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Our results indicate a commodity boom leads to a negative impact on manufacturing firms, resulting from the superposition of the cost and wealth channels. This coincides with the classic *Dutch Disease* literature [Harding and Venables, 2016]. Two recent papers however, in very different contexts, find seemingly different results. Allcott and Keniston [2014] use geographical variation to study the impact of oil and gas endowments in the U.S. on local manufacturing revenue, employment and productivity. Faber and Gaubert [2016] use geographic variation to examine the long-term economic consequences of a shock to nontradable industries - the expansion of tourism in Mexican coastal regions. Both papers exploit agglomeration externalities triggered by the boom with long-run productivity and demand implications. Their positive effects on manufacturing could be interpreted as evidence against the *Dutch Disease* hypothesis.

Interestingly, our framework provides a complementary interpretation of those findings. The key economic insight is that the relative skill intensity of sectors can define the transmission of a shock to one sector of the economy to others through skill prices, highlighting the importance of an endogenous skill premium. Therefore, in the case of Allcott and Keniston [2014], the result that oil booms do not reduce employment in the tradable sector is not necessarily opposed to the predictions of our model as oil production is a relatively skill-intensive activity. Likewise, in the case of Faber and Gaubert [2016], increases in tourism, which lead to increases in manufacturing GDP, can be explained by different relative skill intensities across sectors. In addition we focus on short and medium run effects, while these papers focus on long-run effects in which agglomeration externalities can play a role.

3.3 Additional Results

Two additional sets of empirical findings are reported in our appendix A.1.7. First, when analyzing regional employment, we document that commodity price fluctuations reallocate regional employment across sectors. In particular, a one log point increase in the regional commodity price index is associated with an increase of 0.0687 percentage points (p.p.) in the regional share of commodity employment, a 0.0272 p.p. decline in the share of tradable employment, and a 0.0116 p.p. positive but not statistically significant change in the share of nontradable employment (see table A6). These responses result from the superposition of the cost and wealth channels and are consistent with the firm-level results discussed earlier.[31]

Second, we use the rich firm-level information in RAIS to determine the impact of regional commodity prices on the extensive margin (entry and exit of firms) and on export status within the tradable sector. For firms in the commodity sector, we report that a one log point increase in the regional commodity price index in period t is associated with a 0.133 percentage point higher probability the average firm reports being active in the same period. In the tradable sector, commodity prices are negatively correlated with the probability of firms being active. A one log point price increase is associated to a 0.052 p.p. lower probability a firm is active. In the nontradable sector, a one log point increase in the regional commodity price index is associated with a 0.0297 percentage point lower probability. Again, these results are

[31] Table A8 in the Appendix show that these results are driven primarily by the response of unskilled labor to commodity price variation.

consistent with the idea that the cost channel hurts the tradable sector more than the nontradable sector, while the wealth channel benefits primarily the nontradable sector. Finally, higher commodity prices are correlated with a lower probability of exporting. A one log point increase in the price index is associated with a 0.011 p.p. lower probability a firm in the tradable sector exports (see table A9). In a commodity boom, exporters in the tradable sector face higher costs, but export sales do not benefit from the wealth channel. As a result, the incentives to export diminish.

3.4 Robustness Checks

We verify the robustness of these findings to alternative definitions of our regional commodity price index and to contemporaneous regional shocks faced by Brazil. In addition, we analyze the role of informality, interregional mobility, exchange rates, firms importing status, interest rates and financial conditions and potential political economy mechanisms.

Trade Shocks. As many other countries, Brazil faces a large increase in imports from China in the period under study. The impact of this shock is concentrated in regions with large shares of employment in tradables. To show that our estimates are not confounded by this shock, we estimate a version of equations (2) and (3) including an interaction term between the regional commodity price index and a measure of regional exposure to the increase in Chinese competition. This verifies that our estimates above are not driven by a spatial correlation between exposure to the China shock and the regional concentration of industries by skill intensity (in the case of the cost channel) or the regional concentration of exporting firms (in the case of the wealth channel). The details on the estimation are shown in appendix A.2.7. We find that the impact of commodity prices on firm employment in each sector and their interaction with industry skill intensity or with firms' exporting status are very similar to those obtained earlier (see tables A15 and A16). Additionally, in the late 1980's and early 1990's, Brazil reduced its import tariffs substantially [Dix-Carneiro and Kovak, 2017]. While this occurred earlier than our sample period, the impacts could potentially be long-lasting. To evaluate the sensitivity of our results to this policy change, we create a regional measure of exposure to trade liberalization and estimate equations (2) and (3) including an interaction term between commodity prices and this measure. Details are provided in appendix A.2.8. Once again we find negligible differences in our estimates when including this term, as we report in tables A15 and A16.

Informality. While Brazil has a large share of informal labor, our data is limited to the formal sector of the economy. Because informality is more common among unskilled workers, a transition of informal workers towards the formal sector in response to an increase in commodity prices would bias our results against finding a decline in the skill premium. Thus, we interpret our results for the skill premium, and the consequent reallocation of labor away from manufacturing, as a lower bound. Despite this point, we verify whether ignoring informal employment impacts our results by estimating versions of equations (2) and (3) including an interaction term between the commodity price index and the regional informality share. This demonstrates that our estimates above are not driven by a spatial correlation between the degree of regional informality and the regional concentration of industries by skill intensity (in the case of the cost channel) or the regional concentration of exporting firms (in the case of the wealth channel). We compute regional informality shares based on the Demographic Census of 2000 and details are provided in appendix A.2.6. The results (shown in tables A15 and A16) indicate that the impact of commodity prices on firm employment and the differential effects as a function of skill intensity or exporting status are robust to controlling for this alternative.

Geographic Spillovers (including Interregional Mobility). We extend our empirical strategy to capture geographic spillovers through general equilibrium effects. These spillovers could occur due to trade linkages, migration, or other geographic linkages. Following Allcott and Keniston [2014] we assume that these spillovers are mostly local, meaning that a given region is only impacted by commodity price shocks to other regions within a certain radius. In appendix A.2.4 we construct a broader commodity price index that estimates the absolute effect of commodity price shocks including these geographic spillovers, taking into account the prices faced by nearby regions. The impact of commodity prices on employment we estimate is very similar to that reported earlier, which suggests the magnitude of these spillovers is small. Further, we show in appendix A.2.5 that there is no statistically significant impact of regional commodity prices on the share of workers previously employed in other regions.

Exchange Rates. Exchange rate fluctuations could impact employment of exporting and nonexporting firms in the tradable sector differentially. Several conditions would have to be met for exchange rate fluctuations to confound our estimates of the impact of regional commodity prices on firm-level employment in equation (3). Our regressions include time fixed effects that capture aggregate shocks. Spatial correlation between the share of exporters and the local composition of commodity baskets, however, could lead to results being driven by exchange rate movements. (Note that this spatial correlation would have to occur within states, as we include state-by-time fixed effects). We show in appendix A.2.3 that this is not the case, by estimating equation (3) adding an interaction term between the exchange rate and the exporter dummy variable.

Exporting and Importing Firms. In response to rising commodity prices, the cost of importing firms in the manufacturing sector would increase by less than that of non-importers, leading to larger employment losses in non-importers. A well established fact is that exporting firms are more likely to be importers [Bernard et al., 2009]. In (3), used to identify the wealth channel, not controlling for importing firms would cause the exporter dummy to also capture the differential impact of commodity prices on importers. This implies that we can interpret our estimates in table 3 as a lower bound. In appendix A.2.3 we estimate equation (3) but now adding a dummy for importing firms. Consistent with our hypothesis, the coefficient on the interaction term between the regional commodity price index and the exporter dummy is more negative than in the baseline results (see column 2 in table A12), while importers do better than non-importers in response to an increase in the regional commodity price. In addition, exchange rate movements could also impact exporters and importers differentially. Thus, we also add an interaction term between both the exporter and importer dummy variables and the exchange rate, obtaining very similar results.

Interest Rates and Financial Conditions. Shousha [2016] and Fernández et al. [2017a] suggest that commodity cycles can affect the economy through an interest rate channel as spreads seem to be lower during booms and higher during busts. Although we see this as a complementary channel, we can rule out that our main findings are driven by it. While we control for economy-wide shocks using time fixed effects, the pass-through of interest rates to firm-level employment could have a differential impact depending upon firm's size. Although our data does not include financial information, the literature on financial frictions has documented that borrowing constraints are strongly tied to firm size (Gopinath et al. [2015]); small firms are more likely to be constrained and therefore less likely to benefit from the boom. However, a non-zero spatial correlation between the share of small firms and the local composition of commodity baskets could pass on the effects of interest rate fluctuations, threatening our analysis.[32] Tables A11 and 3 for the cost and wealth channels respectively confirm our findings hold even after we control for the interaction between firm-size- bin dummies and the regional commodity price index. Our results are robust to an interest rate (or more in general a financial) channel.

Note also that including these firm-size-bin dummies controls as well for differences across firms in skill intensity, which can be correlated with firm size.

Regional Commodity Price Index: Trend vs. Cyclical Component. Our baseline empirical analysis is carried out using the trend of the regional commodity price index obtained with the Hodrick-Prescott (HP) filter. Table A13 in the appendix shows our results are similar when using the raw price index instead of its trend. Moreover, by including both the trend and cyclical components simultaneously, we conclude that the price index's trend is the source of variation driving our main findings.

Political Economy. Commodity prices could potentially impact labor market outcomes through various political economy mechanisms. A first such channel could consist in increased revenue by local governments leading to increases in social transfers or a larger demand for employment associated to public works. Caselli and Michaels [2013] find a small (if at all) increase in social transfers and public good provision to increases in oil-related revenue to regions. A second channel is that local governments could adjust the minimum wage in response to commodity prices. The following facts suggest our results are robust to this mechanisms. First, while oil resources might lead to local government revenue, other commodities do not, and we find that our results are robust to excluding oil and gas from the commodity price index (appendix A.2.4). Second, in Brazil the minimum wage is primarily defined at the national level, although a handful of states have state-level minimum wages (that must be higher

[32] This spatial correlation would have to emerge within states as we control for state-specific time fixed effects.

than the national-level minimum).[33] Our firm-level regressions include state-by-time fixed effects, which would absorb changes in state-level minimum wages, alongside any other policies determined at this level of regional aggregation.

4 Model

To separately quantify the transmission mechanisms of commodity prices throughout the economy and the welfare cost of commodity price fluctuations, we develop a three-sector small open economy model. Because our focus is on slow moving and persistent commodity super-cycles, the model has no uncertainty and is solved under perfect foresight.

The economy consists of commodity, tradable, and nontradable sectors. In the perfectly competitive commodity sector, heterogeneous firms produce a homogeneous good using skilled and unskilled labor and a scarce natural resource. The commodity good has an exogenous price determined in the world market. In the competitive nontradable sector, heterogeneous firms produce a homogenous good using skilled and unskilled labor. Finally, in the tradable sector, heterogeneous firms use skilled and unskilled labor to produce differentiated varieties in a context of monopolistic competition. As a consequence of a fixed cost of exporting, higher-productivity firms sell to both the domestic and international markets, while lower-productivity firms sell exclusively to the domestic market. Skilled and unskilled labor is supplied inelastically by a representative household. This household demands the commodity good, the bundle of tradable varieties, the nontradable good, and an imported good. This household can borrow freely from the world.[34] Figure A7 in appendix B shows a diagram of the model economy.

Finally, a key feature of labor markets in emerging economies is their rigidity. Thus, we include in our framework downward wage rigidity, modeled as in Schmitt-Grohé and Uribe [2016]. This friction triggers important implications for the model's dynamics. In particular, it transforms efficient sectoral reallocation during the boom into inefficient unemployment during the bust, generating important welfare consequences for commodity price super-cycles.

4.1 Representative Household

The representative household consumes imported (M), commodity (C^d), nontradable (N) and tradable (T^d) goods. It supplies skilled (L_t^s) and unskilled (L_t^u) labor inelastically. Lifetime utility is:

[33] Engbom and Moser [2017], for instance, argue that minimum wages vary little across (some) states.

[34] The commodity, tradable and nontradable sectors are modeled extending heterogenous firms models such as Hopenhayn [1992] and Melitz [2003]. The international aspect of the model is similar to Mendoza [1995]. The commodity sector differs from the nontradable sector in that commodity producers export part of their production. The commodity sector differs from the tradable sector in that it faces a perfectly elastic foreign demand. This means changes in the commodity price lead to larger changes in quantities in the commodity than in the tradable sector. These large changes in quantities in response to changes in the commodity price can lead to strong general equilibrium spillovers to the other sectors. A version of the model with a representative commodity producer and a continuum of tradable and non tradable varieties with monopolistic competition is available upon request.

$$U = \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\nu} \left(\left(M_t^\theta + \alpha^N N_t^\theta + \alpha^T \left(T_t^d\right)^\theta + \alpha^C \left(C_t^d\right)^\theta \right)^{\frac{1}{\theta}} \right)^{1-\nu} ,$$

where $\theta \in (0,1)$ controls the elasticity of substitution between goods and $\nu > 1$ is the intertemporal elasticity of substitution.

Let P_t^C be the exogenous commodity price of the commodity good, P_t^R the price of the fixed resource, P_t^N the price of the nontradable good, and P_t^T the price of the tradable bundle. Let the exogenous price of the imported good be normalized to one and used as the numéraire. The representative household budget constraint is then:

$$M_t + P_t^N N_t + P_t^T T_t^d + P_t^C C_t^d + B_{t+1} \leq w_t^s L_t^s + w_t^u L_t^u + P_t^R \bar{R} + (1+r^*) B_t + \Pi_t ,$$

where $L_t^s \leq \overline{L}^s = (1-\kappa)\overline{L}$ and $L_t^u \leq \overline{L}^u = \kappa \overline{L}$, with $\kappa \in (0,1)$ governing the scarcity of skill workers in the economy. This notation anticipates potential unemployment due to a frictional labor market. Bonds are in units of the imported good and the interest rate (r^*) is exogenous. Π_t collects total profits from firms in the commodity, nontradable, and tradable sectors. The tradable bundle consumed by the household is:

$$T_t^d = \left[\int_{\zeta \in \mathfrak{Z}} q_{d,t}(\zeta)^\rho d\zeta \right]^{\frac{1}{\rho}} ,$$

where ζ is an index for individual varieties, and $\mathfrak{Z}$ is an index set for individual varieties sold in the domestic market. The price of the tradable bundle is given by the following aggregation of the prices of individual varieties:

$$P_t^T = \left[\int_{\zeta \in \mathfrak{Z}} p_t(\zeta)^{1-\sigma} d\zeta \right]^{\frac{1}{1-\sigma}} ,$$

where $\sigma = \dfrac{1}{1-\rho} > 1$. Finally, it is useful to use the Euler equation for bonds to define the household's stochastic discount factor $\Lambda_{t,t+1}$:

$$\Lambda_{t,t+1} = \frac{1}{1+r^*} , \tag{5}$$

where $\Lambda_{t,t+1} = \beta \left(\dfrac{\lambda_{t+1}}{\lambda_t} \right)$ and $\lambda_t = \left[M_t^\theta + \alpha^N N_t^\theta + \alpha^T \left(T_t^d\right)^\theta + \alpha^C \left(C_t^d\right)^\theta \right]^{\frac{1-\theta-\nu}{\theta}} \times M_t^{\theta-1}$. Note that when equation (5) holds, $\Lambda_{t,t+1}$ is constant. When the household is surprised by a new sequence $\left\{P_t^C\right\}_{t=\tilde{t}}^{\infty}$ revealed at period $\tilde{t}$, expression (5) does not hold in that period and the marginal utility experiences a discrete jump before reaching a new constant level in $\tilde{t}+1$. In other words, the permanent income hypothesis holds implying that the household decides a new constant level of consumption immediately after a change in the present value of its income. This optimal re-balancing of consumption is critical for characterizing the *wealth* channel.

4.2 Production

Labor input. Every sector $r \in \{C, N, T\}$ combines skilled and unskilled labor according to the following CES function:

$$l_i^r\left(l_{i,t}^{u,r}, l_{i,t}^{s,r}\right) \equiv \left[(\phi^r)^{\frac{1}{\gamma}}(l_{i,t}^{u,r})^{\frac{\gamma-1}{\gamma}} + (1-\phi^r)^{\frac{1}{\gamma}}(l_{i,t}^{s,r})^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}} ,$$

where $l_{i,t}^{s,r}$ and $l_{i,t}^{u,r}$ are the skilled and unskilled labor inputs respectively. We assume that the relative use of these two types of labor varies across sectors (ϕ^r), while the elasticity of substitution between skill types is constant across them. We can define the effective labor cost of sector r as:

$$\hat{w}_t^r = \left[\frac{\phi^r}{(w_t^u)^{\gamma-1}} + \frac{1-\phi^r}{(w_t^s)^{\gamma-1}}\right]^{-\frac{1}{\gamma-1}} .$$

Note that as the skill premium falls, sectors with higher skill intensity (lower ϕ^r) see a decrease in their effective labor cost relative to low skill intensity sectors.

Commodity sector. The commodity good is produced by heterogeneous firms with the following technology:

$$C_{i,t} = C(z_i^C) = z_i^C \times R_{i,t}^{\xi} \times \left(l_{i,t}^C - f^C\right)^{\eta} \qquad \text{with} \quad 0 < \{\xi, \eta\} < 1 \quad \text{and} \quad \xi + \eta < 1,$$

where z_i^C is a permanent idiosyncratic productivity draw, $l_{i,t}^C$ the total effective labor input, and $R_{i,t}$ is the resource input used by firm i. There is a fixed operating cost f^C in units of effective labor so total labor employed in production is $l_{i,t}^C - f^C$. The resource input supply is fixed at $\bar{R}$. Profits of firm i in period t are:

$$\pi_{i,t}^C(z_i^C) = P_t^C\left[z_i^C R_{i,t}^{\xi}\left(l_{i,t}^C - f^C\right)^{\eta}\right] - \hat{w}_t^C l_{i,t}^C - P_t^R R_{i,t} .$$

The commodity sector faces an exogenous international price and no exporting costs.

Nontradable sector. The nontradable good is homogeneous and produced by heterogeneous firms with the following technology:

$$N_{i,t} = N(z_i^N) = z_i^N \times \left(l_{i,t}^N - f^N\right)^{\alpha} \qquad \text{with} \quad 0 < \alpha < 1 ,$$

where f_N is the fixed operating effective labor cost. Profits are:

$$\pi^N(z_i^N) = P_t^N \left[z_i^N \left(l_{i,t}^N - f^N \right)^\alpha \right] - \hat{w}_t^N l_{i,t}^N \,.$$

Tradable sector. Firms in the tradable sector are heterogeneous in their productivity z^T. They produce differentiated varieties indexed by ζ using the following technology:

$$q_t(z^T) = z^T \times \left(l_t^T - f^T \right) \,.$$

Domestic production is subject to a fixed cost $f^T = f_d^T$ measured in terms of effective labor units. Production for the foreign market faces a higher fixed cost $f^T = f_x^T > f_d^T$.

Firms that produce only for the domestic market face the following demand:

$$q_{d,t}(\zeta) = T_t^d \left[\frac{p_t(\zeta)}{P_t^T} \right]^{-\sigma} \,,$$

while exporting firms face a larger demand given by:

$$q_{ex,t}(\zeta) = q_{d,t}(\zeta) + q_{x,t}(\zeta) = \left[T_t^d (P_t^T)^\sigma + \gamma_0 \right] p_t(\zeta)^{-\sigma} \,,$$

where γ_0 denotes the size of the foreign market. We assume the same price elasticity for domestic and foreign demand. Therefore, regardless of their productivity, firms face a residual demand curve with constant price elasticity σ and, as a consequence, choose the same markup $\sigma/(\sigma-1) = 1/\rho$ over marginal cost $\hat{w}_t^T/z^T$. This yields the following pricing rule:

$$p_t(z^T) = \frac{\hat{w}_t^T}{\rho z^T} \,.$$

Finally, firms' optimal profits are:

$$\pi_t\left(z^T\right) = \begin{cases} \pi_{d,t}\left(z^T\right) = \dfrac{\left(P_t^T\right)^\sigma T_t^d}{\sigma} \left[\dfrac{\rho z^T}{\hat{w}_t^T} \right]^{\sigma-1} - \hat{w}_t^T f_d^T & \text{for nonexporters.} \\ \pi_{ex,t}\left(z^T\right) = \pi_{d,t}\left(z^T\right) + \dfrac{\gamma_0}{\sigma} \left(\dfrac{\rho z^T}{\hat{w}_t^T} \right)^{\sigma-1} - \hat{w}_t^T f_x^T & \text{for exporters.} \end{cases}$$

Note that if a commodity boom increases domestic demand (T_t^d) for the tradable good, this increases domestic but not export sales. Therefore, a commodity price super-cycle has heterogeneous effects even within firms in the tradable sector depending on their exporting status.

4.3 Entry, exit and Exporting Decisions

Let optimal profits in sector $r \in \{C, N\}$ be denoted by $\pi^r_{i,t}$. Firms are subject to an exogenous exit probability δ^r each period. They also exit endogenously when the discounted present value of profits turns negative. A firm's value is:

$$W^r_{i,t}(z^r) = \max\left\{0,\ \pi^r_{i,t}(z^r) + (1-\delta^r)\Lambda_{t,t+1} W^r_{i,t+1}(z^r)\right\}.$$

The operational productivity cut-off $\underline{z}^r_t$ is implicitly defined by the productivity level that solves $W^r_{i,t}(\underline{z}^r_t) = 0$.

In the tradable sector, given an exogenous exit rate of δ^T, a firm's value depends on its exporting status $j = \{d, ex\}$, and it is given by:

$$W^T_{j,t}\left(z^T\right) = \max\left\{0\,, \pi_{j,t}\left(z^T\right) + \left(1-\delta^T\right)\Lambda_{t,t+1} W^T_{t+1}\left(z^T\right)\right\}\ ,$$

where the continuation value is:

$$W^T_{t+1}\left(z^T\right) = \begin{cases} W^T_{d,t+1} & , \text{if } \underline{z}^T_{t+1} \leq z^T < \underline{z}^T_{x,t+1} \\ W^T_{ex,t+1} & , \text{if } z^T \geq \underline{z}^T_{x,t+1} \\ 0 & , \text{otherwise} \end{cases}$$

The operational $(\underline{z}^T_t)$ and exporting $(\underline{z}^T_{x,t})$ cut-offs are implicitly defined by the conditions:

$$W^T_{d,t}\left(\underline{z}^T_t\right) = 0 \quad \text{and} \quad \pi_{ex,t}\left(\underline{z}^T_{x,t}\right) = 0.$$

Entry and firms' productivity distributions. Potential entrants in sector $r \in \{C, N, T\}$ draw their permanent productivity z^r from a distribution with probability density function $g(z^r)$ and cumulative density function $G(z^r)$. Denote by $\tilde{M}^r_t$ the mass of entrepreneurs that pay a sector-specific fixed cost $\hat{f}^r_e$ to observe a sector specific productivity z^r. We define a convex entry cost function of the form:

$$\hat{f}^r_e(\tilde{\mathcal{M}}^r_t) = f_e + \gamma_e\left[\exp\left(\frac{\tilde{\mathcal{M}}^r_t - \tilde{\mathcal{M}}^r}{\tilde{\mathcal{M}}^r}\right) - 1\right],$$

where f_e and γ_e are common across sectors, and $\tilde{\mathcal{M}}^r$ is sector-specific. This cost function is consistent with the firm dynamics literature and captures congestion externalities or competition for a fixed resource at entry.[35] Entry costs are measured in units of effective labor. Therefore, for a given operational

[35] This assumption is standard in dynamic models of heterogeneous firms [see, for example, Jaef and Lopez, 2014]. From a practical perspective, this assumption helps us avoid corner solutions in entry and excess volatility in the entry margin.

productivity threshold $\underline{z}_t^r$ the free entry condition is:[36]

$$\hat{w}_t^r \hat{f}_e^r \left(\tilde{\mathcal{M}}_t^r\right) = \int_{\underline{z}_t^r}^{\infty} W_t^r(z_t^r) g(z^r) dz^r .$$

The time-varying distribution of entrants' productivity is:

$$\tilde{\mu}_t^r\left(z^r\right) = \begin{cases} \frac{g(z^r)}{1-G(\underline{z}_t^r)} & \text{if } z^r \geq \underline{z}_t^r. \\ \\ 0 & \text{otherwise.} \end{cases}$$

Denoting $\mathcal{M}_t^r$ the mass of active producers in sector r, the time-varying distribution of producers is:

$$\mu_{t+1}^r(z^r) = \begin{cases} \dfrac{\left(1-\delta^r\right)\mathcal{M}_t^r \mu_t^r(z^r) + \tilde{\mathcal{M}}_{t+1}^r g(z^r)}{\mathcal{M}_{t+1}^r} & \text{if } z^r \geq \underline{z}_{t+1}^r. \\ \\ 0 & \text{otherwise.} \end{cases}$$

The law of motion that characterizes the evolution of the mass of incumbent producers in sector r is then:

$$\mathcal{M}_{t+1}^r = \left(1-\delta^r\right)\mathcal{M}_t^r \int_{\underline{z}_{t+1}^r}^{\infty} \mu_t^r(z^r) dz^r + \tilde{\mathcal{M}}_{t+1}^r \int_{\underline{z}_{t+1}^r}^{\infty} g(z^r) dz^r \ .$$

4.4 Labor Market Frictions

Labor-market rigidity is a key feature of many commodity producer economies. Because of the central role that labor markets play in the model, we include this feature by imposing the following restriction on the evolution of wages:

$$w_t^k \geq \chi w_{t-1}^k \quad \forall k \in \{u, s\} \quad \text{where} \quad 0 < \chi < 1 \, , \tag{6}$$

and the slackness condition emphasizing that unemployment is demand determined:

$$\left(w_t^k - \chi w_{t-1}^k\right)\left(L_t^k - \bar{L}^k\right) = 0 \quad \forall k \in \{u, s\} \ .$$

Note that, for any skill level, either restriction (6) is not binding and the economy is at full employment or it binds and there is involuntary unemployment. This is a tractable way of capturing the role of labor market frictions in emerging markets, particularly in the context of commodity cycles. For instance, a commodity boom is associated with massive labor flows to that sector. When the boom is over, wages have to decrease in order for labor to be reallocated again to the other sectors. The larger χ is, the more likely it is that the constraint binds during the bust, and therefore, the more likely it is to observe a

[36]The parameter $\tilde{\mathcal{M}}^r$ is calibrated to ensure that in the initial steady state the only entry cost is f_e.

painful end to the commodity boom with unemployment and a recession [Reinhart et al., 2016].

Importantly, wages in the model are denominated in units of the imported good. Under a fixed exchange rate regime, as in Schmitt-Grohé and Uribe [2016], nominal wage rigidity automatically translates into real wage rigidity. Under a flexible exchange rate, on the other hand, downward nominal wage rigidity implies real wage rigidity only in the presence of wage indexation. As explained in the next section, the assumption of real wage rigidity in Brazil is supported by the evidence.

5 Quantitative Analysis

We calibrate the model with two main objectives: to quantify the importance of the *cost* and *wealth* transmission channels that propagate commodity price super-cycles throughout the economy, and to evaluate the welfare implications of commodity price fluctuations under flexible and downwardly rigid wages. First, we describe the calibration of the model to the Brazilian economy. We then validate the calibration by simulating data from the model and replicating non-targeted empirical regressions. Finally, we use the calibrated model to decompose the transmission channels and evaluate welfare.

5.1 Calibration

A first set of parameters is externally calibrated using values obtained both from the literature and from the data described in Section 2. A second set of parameters is internally calibrated to match macroeconomic ratios and sectoral and firm-level outcomes computed from our data. The calibration is done at an annual frequency and uses data for year 2001.[37,38]

Externally Calibrated Parameters. Table 4 shows a first set of 11 externally calibrated parameters that are consistent with the literature and a set of regional outcomes computed using the data described in Section 2. The discount factor (β) is consistent with an annual interest rate of 4%. The parameters governing risk aversion (υ), substitution between final goods (θ), substitution between tradable varieties (σ), and substitution between skilled and unskilled labor (γ) are taken from the international trade and international finance literature.[39] The exogenous sectoral exit rates (δ^C, δ^N, and δ^T) are computed from RAIS.

The degree of downward wage rigidity (χ) is calibrated to be consistent with the macroeconomic evidence described in appendix A.1.9. Following Schmitt-Grohé and Uribe [2016] we obtain this parameter by analyzing the dynamics of wages in an episode of low inflation, a crawling peg and rising unemployment. Between 1996 and 1998, unemployment in Brazil increased by 29% while real wages, after adjusting by long-run inflation and economic growth, only decreased at an annual rate of 0.01%. We therefore calibrate

[37] We choose 2001 because it is the year right before the start of the boom.

[38] The model is calibrated to the exact same sample used in the empirical analysis.

[39] The elasticity of substitution between tradable varieties falls within the range provided in Simonovska and Waugh [2014] The elasticity of substitution between skilled and unskilled labor is obtained from Katz and Murphy [1992].

χ to 0.99. This value is consistent with Schmitt-Grohé and Uribe [2016]'s calculation for Argentina. Sections 5.3 and 5.4 illustrate the impact of downward wage rigidity in the economy by varying this rigidity parameter.[40]

Table 4: Externally-Calibrated Parameters

Parameter	Description	Value	Source
r^*	World interest rate	0.04	Macroeconomic Data
β	Time discount factor	0.9615	$\beta = \frac{1}{1+r^*}$
ν	Risk aversion	1.5	Literature
θ	Substitution consumption bundle	0.80	Literature
ρ	Tradable sector D-S aggregator weight	0.75	Literature
σ	Tradable sector substitution	4	$\sigma = \frac{1}{1-\rho}$
γ	Substitution skilled/unskilled labor	1.41	Literature
δ^C	Exit rate (C sector)	0.08	Microeconomic Data
δ^N	Exit rate (N sector)	0.13	Microeconomic Data
δ^T	Exit rate (T sector)	0.11	Microeconomic Data
χ	Downward wage rigidity	0.99	Macroeconomic Data

Note: This table shows the values and sources of the externally-calibrated parameters.

Internally-Calibrated Parameters. Table 5 displays the set of 12 parameters that are either normalized or calibrated to perfectly match macroeconomic ratios of the Brazilian economy. We set $P^C = P^T = P^M$ in the initial steady state. The aggregate labor supply is adjusted to normalize GDP to 100 in the initial steady state. Because this is a small open economy that faces an exogenous interest rate, an initial condition for bond holdings is needed to solve the model. Without loss of generality we assume that the economy starts with zero net foreign assets.

The stock of natural resources is used to match the commodity output share. The size of the foreign market (γ_0) is used to target the export to GDP ratio of the Brazilian economy. This parameter determines the differential response of exporters and nonexporters to changes in domestic demand originating from the wealth channel. The preference parameters in the commodity and nontradable sectors (α^C and α^N) are used to target the consumption shares in each of these sectors. The intensity in the use of skilled and unskilled labor in each sector (ϕ^C, ϕ^N, and ϕ^T) and the abundance of unskilled workers (κ) are jointly calibrated to match the fraction of skill intensity in each sector and the skill premium of the economy. These parameters are critical to quantify the differential impact of the cost channel across sectors.

[40] Appendix A.1.9 provides both microeconomic and macroeconomic evidence of wage rigidity in Brazil, a country with crawling peg regime until 1999 and a floating exchange rate thereafter. Interestingly, as documented by Messina and Sanz-de Galdeano [2014], the incidence of downward real wage rigidity did not decrease after the liberalization of the exchange rate. The fraction of workers subject to downward real wage rigidity remained high, even after the introduction of the inflation-targeting regime and inflation stabilization in the mid and late 1990s. The highly unionized Brazilian labor market, the automatic correction of the minimum wage by inflation, and a history of endemic inflation, have lead to persistent indexation of labor contracts [Messina and Sanz-de Galdeano, 2014]. This is consistent with the ranking in Campos and Nugent [2012], which positioned Brazil within the top 10% most rigid labor markets in 2000 (out of 144 countries).

Table 5: Internally-Calibrated Parameters: Normalizations and Macroeconomic Ratios

Parameter	Description	Value	Target	Value
P^C	Commodity price	1.0	Normalization	$P^C = 1$
$\bar{L}$	Labor supply	31.4	Normalization	$Y = 100$
$\bar{B}$	Steady state bond	0	Trade-balance/GDP	$TB/Y = 0$
$\bar{R}$	Resource supply	5.3	Commodity output share	$C/Y = 0.12$
γ_0	Size of foreign market	12.8	Exports/GDP	$X/Y = 0.15$
α^C	Preference (C sector)	0.8	Consumption share (C sector)	$C^d/Y = 0.04$
α^N	Preference (N sector)	2.7	Consumption share (N sector)	$N/Y = 0.59$
α^T	Preference (T sector)	1.1	Normalization	$P^T = P^C$
κ	Share unskilled labor, aggregate	0.83	Skill Premium (%)	$(w^s/w^u - 1) * 100 = 225$
ϕ^C	Skill intensity (C sector)	0.69	Unsk. to skilled labor (C sector)	$L^{u,C}/L^{s,C} = 0.92$
ϕ^N	Skill intensity (N sector)	0.42	Unsk. to skilled labor (N sector)	$L^{u,N}/L^{s,N} = 0.79$
ϕ^T	Skill intensity (T sector)	0.58	Unsk. to skilled labor (T sector)	$L^{u,T}/L^{s,T} = 0.88$

NOTE: This table shows the values of internally-calibrated parameters used for normalization (top three), calibrated to match macroeconomic ratios for the Brazilian economy (next five), and set to match sectoral skill intensity (bottom 4).

Finally, we jointly calibrate the remaining 11 parameters to match salient features of our data. Despite the complex relationship between parameters and moments, table 6 presents a set of strong associations. The technology parameters (ξ, η, and α) are disciplined by the share of labor of the nontradable and commodity sectors and the share of firms in the commodity sector. The fixed costs of production (f^C, f^N, and f_d^T) are used to match the share of labor of the smallest 50% of firms in each sector. The fixed cost of exporting (f_x^T) pins down the fraction of exporters in the tradable sector. The common fixed component of the entry cost is calibrated to match the share of firms in the nontradable sector. The congestion externality parameters (γ_e and $\tilde{\mathcal{M}}^r$) are set to avoid any externality in the initial steady state and to match the volatility of the entry rate in the commodity sector during the calibrated commodity price super-cycle.[41] Finally, the underlying productivity distribution is assumed to be log normal and its mean and variance (μ and Σ) are used to match the share of labor of the 25% largest firms in each sector.

As table 6 shows the commodity sector in the Brazilian economy concentrates a modest share of firms and workers (commodity production represents only 12% of output). This means powerful internal amplification and propagation mechanisms must be present to generate the aggregate effects of a commodity price super-cycles documented in the literature.[42]

In the following exercises we assume that the economy starts in a steady state in period 0. In period 1 a commodity price super-cycle is revealed to the agents in the economy. As figure 3 shows, the price of the commodity good increases steadily for ten years (darker gray area in each graph) and reaches a cumulative increase slightly above 50%. This trough-to-peak amplitude is obtained from the increase in commodity prices observed in Brazil between 2002 and 2011, as measured with employment-weighted prices at a national level. It then decreases steadily for another ten years (light gray area in each graph)

[41] Details on the calibration procedure are provided in appendix B.3.4.

[42] Appendix B.3.4 provides further details of the calibration procedure behind the parameters in tables 6 and 5.

Table 6: Internally-Calibrated Parameters

Parameter	Description	Value	Target	Data	Model
ξ	Resource share (C sector)	0.34	Share of firms (C sector)	0.025	0.024
η	Labor share (C sector)	0.48	Share of labor (C sector)	0.088	0.084
α	Labor share (N sector)	0.62	Share of labor (N sector)	0.617	0.607
f^C	Fixed cost (C sector)	0.13	Unsk. Labor 50% Low (C sector)	0.007	0.007
f^N	Fixed cost (N sector)	0.10	Unsk. Labor 50% Low (N sector)	0.010	0.011
f_d^T	Fixed cost (T sector - domestic)	0.12	Unsk. Labor 50% Low (T sector)	0.012	0.012
f_x^T	Fixed cost (T sector - foreign)	1.47	fraction of exporters (T sector)	0.16	0.15
f_e	Common fixed entry cost	4.0	Share of firms (N sector)	0.79	0.73
γ_e	Common congestion elasticity	16	Entry volatility (C sector)	0.0145	0.0146
			Unsk. Labor 25% Upp (C sector)	0.85	0.94
(μ, Σ)	Mean and Std prod. dist.	(0.50, 0.60)	Unsk. Labor 25% Upp (N sector)	0.89	0.83
			Unsk. Labor 25% Upp (T sector)	0.85	0.87

NOTE: This table displays the values for the 11 internally-calibrated parameters.

back to its initial level.

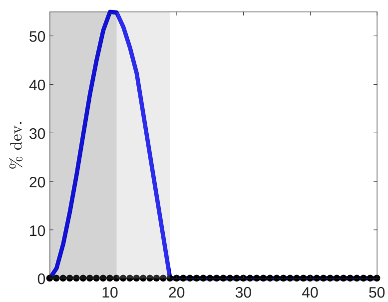


Figure 3: Commodity Price Super-Cycle

NOTE: This figure shows the path of the price of the commodity good used in the quantitative analysis.

5.2 Model Validation

Prior to quantifying the dynamics of the model we perform a validation exercise along key non-targeted elements. Using simulated data based on the model's response to the price sequence used in our quantitative analysis (shown in figure 3), we estimate regressions that are analogous to those estimated in the empirical section.

First, we show that the model can replicate the evolution of the skill premium, the main driver of the cost channel of transmission. We estimate the following regression of the (log) skill premium on the (log) commodity price sequence using the simulated data.

$$\text{SP}_t = \beta_1 \cdot \text{Price}_t + \epsilon_t \tag{7}$$

This equation is analogous to the skill premium regression in equation (4) in the empirical section.

Since our model does not have regional variation, we exclude the regional fixed effects from equation (4) when using the simulated data. The results are displayed in column 1 of table 7, alongside the earlier results reported in the empirical section (but using annual data, which is the frequency at which the model is calibrated). This comparison indicates that the model matches very closely the skill premium dynamics triggered by the commodity price super-cycle.

The intersectoral reallocation of labor between the tradable and nontradable sectors lies at the core of the transmission of commodity price super-cycles in the model. Therefore, this is another important dimension along which to test the calibrated model. To this end we estimate the following equation of sectoral employment shares on the commodity price sequence, which includes the interaction between the price and a tradable sector dummy, and sector and time fixed effects. [43] In the regression estimated with the raw data, we replace the sector and time fixed effects by a set of region-sector, region-time and sector-time fixed effects.

$$\text{Emp. Share}_{st} = \beta_1 \cdot \text{Price}_t \cdot T_s + \gamma_s + \delta_t + \epsilon_{st} \tag{8}$$

We compare the estimated parameters obtained using the simulated data with those obtained based on the raw data. The results are reported in columns 3 and 4 of table 7. We observe a close match between model and data in the reallocation of employment across sectors.[44]

Finally, we compare the model-generated firm-level employment responses to the commodity price super-cycle to those estimated from the raw data in Section 3. We estimate the following equation that distinguishes between the impact of prices on exporting and nonexporting firms in the tradable sector:

$$\log(\text{Emp})_{ft} = \beta_1 \cdot \text{Price}_t + \beta_2 \cdot \text{Exporter}_{ft} + \beta_3 \cdot \text{Exporter}_{ft} \cdot \text{Price}_t + \gamma_f + \epsilon_{ft} \tag{9}$$

This equation is analogous to equation (3) estimated in the empirical section. The results are shown in columns 1 and 2 in table (8), and again show a close parallel between the behavior of the model and the empirical results.

5.3 Transmission Channels

The cost and wealth channels transmit commodity price super-cycles throughout the economy. We use the calibrated model as a tool to quantify the strength of each of these transmission channels. We find, first, that the cost channel is quantitatively the main driver of the reallocation of labor between the tradable and nontradable sectors. Second, it is the wealth channel that primarily determines the reallocation of labor serving domestic versus export sales within the tradable sector.

[43] We estimate this equation jointly for the tradable and nontradable sectors because we are concerned in our quantitative results later in this section with the reallocation of employment between these sectors.

[44] We estimate equation (8) with data at an annual frequency since this is the frequency at which the model is calibrated.

Table 7: Model Validation: Regional-level Regression Analysis

	(1)	(2)	(3)	(4)
	Skill Premium		Regional Employment	
	Model	Data	Model	Data
(log) Price_t	-0.0647***	-0.128***		
	(0.0078)	(0.058)		
(log) $\text{Price}_t \cdot T_s$			-0.0730***	-0.0455***
			(0.0031)	(0.0133)
Observations	25	8363	200	16740

NOTE: This table reports the results of the estimation of equations (7) and (8) using raw data (columns 2 and 4) and simulated data (columns 1 and 3). When using raw data, the regression includes fixed effects to account for regional variation as described in the text. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Table 8: Model Validation: Firm-Level Employment Regression Analysis

	(1)	(2)
	Tradable	
	Model	Data
(log) Price_t	-0.2406***	-0.04293***
	(0.0011)	(0.0125)
Exporter_{ft}	0.4208***	0.1391***
	(0.0119)	(0.0031)
Exporter_{ft} x (log) Price_{rt}	-0.1153***	-0.0848***
	(0.0048)	(0.0110)
Observations	67,133	1,971,049

NOTE: Column 1 in this table reports the results of the estimation of equation (9) using the simulated data. Column 2 reports the results of equation (3) using annual data (hence the small difference in the coefficients in comparison with the results in section 3. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

The cost channel is driven by changes in wages that interact with the differential skill intensity of the tradable and the nontradable sectors. To illustrate this mechanism, figure 4a plots the relative effective labor cost between the tradable and the nontradable sector. Because the nontradable sector is relatively intensive in skilled labor, the rise of the skill premium during the boom reduces the relative labor cost of firms in the nontradable sector.

The wealth channel is driven by changes in income and the heterogeneous dependence of firms on domestic demand. To illustrate the operation of this second channel we focus on the tradable sector given that in this sector some firms (nonexporters) rely on the domestic demand more than others (exporters), while all firms within this sector are equally skill-intensive. Figure 4b shows how the fraction of exporters decreases during the boom, with a 50 percent drop in this share. Consequently, the model results in larger firms, that sell part of the production in the foreign market, being more affected by the commodity boom than smaller firms that operate only locally.

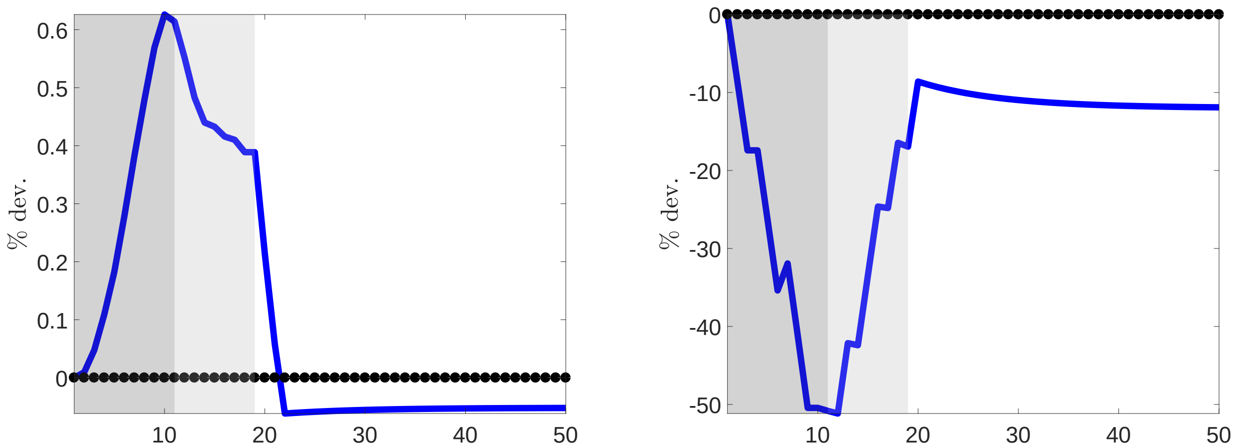
To compare the strength of each channel we generate counterfactuals that shut down one channel at a time. To isolate the wealth channel, silencing the cost channel, we force wages to remain constant. To isolate the cost channel and suppress the wealth channel we keep constant the price of the nontraded good, the price index of tradable varieties, the marginal utility of income, and the price of the natural resource. In this way, firms in each sector adjust their supply only due to changes in wages and not to the movement in prices that reflect higher demand. To build each counterfactual, we forgo market clearing conditions focusing only on the aggregation of individual firm decisions.[45]

Figure 5a plots the response of the ratio of employment in the tradable to employment in the non-tradable sector in response to the simulated commodity price super-cycle. In the baseline scenario, which superposes both transmission channels, the tradable sector contracts by 20 percent relative to the non-tradable sector. With the wealth channel muted (green dashed line) the cost channel implies a larger increase in the wage of unskilled labor, which is a larger negative cost shock for the tradable sector. The decline in relative employment in the tradable sector is thus much stronger (50 percent). With the cost channel muted (red crossed line), the wealth channel by itself raises relative tradable employment by 35%. Two effects lead to this outcome. First, all firms in the nontradable sector benefit from the increase in the domestic demand, while only a share of sales in the tradable sector do. Second, the employment response of firms in the tradable sector is stronger than that of firms in the nontradable sector (as a result of the environment of monopolistic competition in the tradable sector). Overall, the cost channel is quantitatively the main driver of the reallocation of labor between the tradable and nontradable sectors, explaining approximately two-thirds of this reallocation.[46]

Figure 5b illustrates the response of the ratio of tradable sector employment hired to serve the domestic demand to employment hired to serve the foreign demand. In the baseline case, this ratio increases up to 50% during the boom. With the wealth channel in isolation (red crossed line) this increase is more than twice as large, because the increase in local demand applies only to domestic sales. The cost channel (green dashed line) reduces the ratio of employment serving domestic (relative to foreign) demand. This second result is more nuanced and depends on the relative magnitude of the fixed costs paid to serve the domestic and foreign markets. In sum, the wealth channel explains most of the labor reallocation within the tradable sector, explaining approximately two-thirds of this reallocation.

[45] In each counterfactual we allow for entry, operation, and exporting decisions to adjust. Therefore, we consider the response of both the extensive and intensive margins in each case.

[46] To see this point, focus on the summit of the boom. Activating the wealth channel implies a change of 25p.p. (from -45 to -20) while activating the cost channel implies a 50 p.p. change (from 30 to -20).

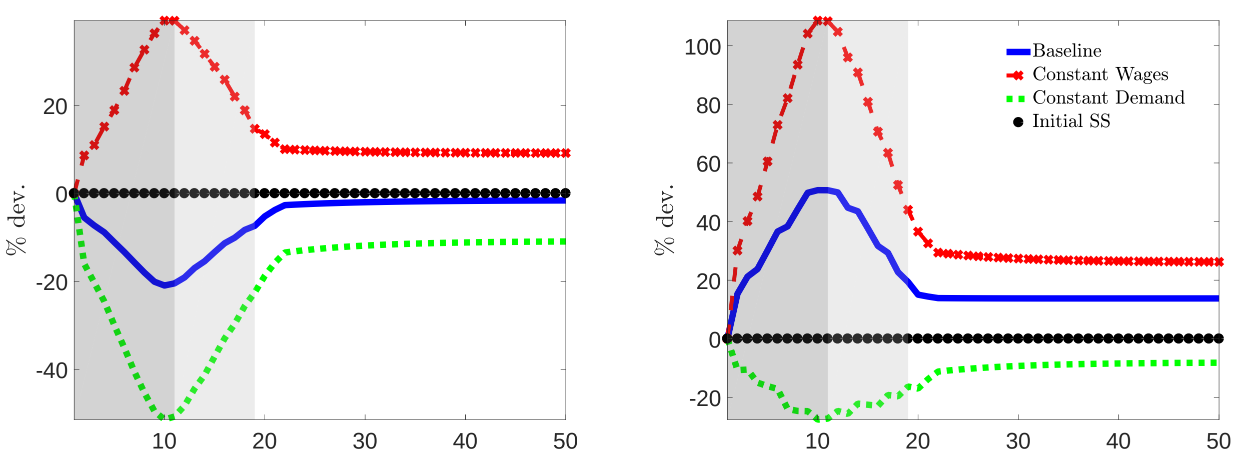


a) Effective Wage Differential $\left(\frac{\hat{w}^T}{\hat{w}^N}\right)$

b) Fraction of Exporting Firms in the Tradable Sector

Figure 4: Effective Wage Differential and Fraction of Exporters

NOTE: This figure shows the response of the effective wage differential between the tradable and nontradable sectors (left) and the fraction of exporters in the tradable sector to the commodity price super-cycle shown in figure 3. The blue solid line corresponds to the baseline case and the black circled line corresponds to the initial steady state.



a) Relative Tradable to Nontradable Sector Employment $\frac{L^T}{L^N}$

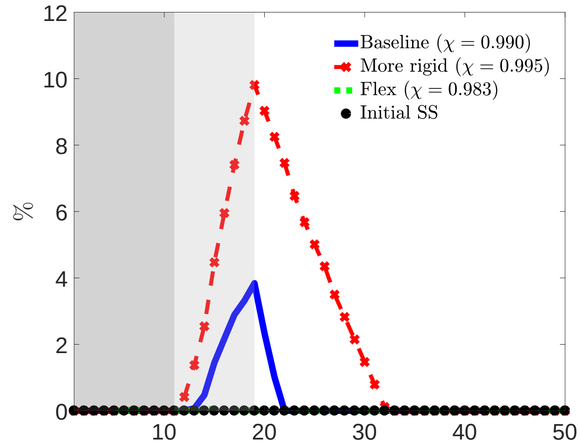
b) Relative Employment in Domestic to Exported Production in the Tradable Sector $\frac{L_d^T}{L_x^T}$

Figure 5: Counterfactuals

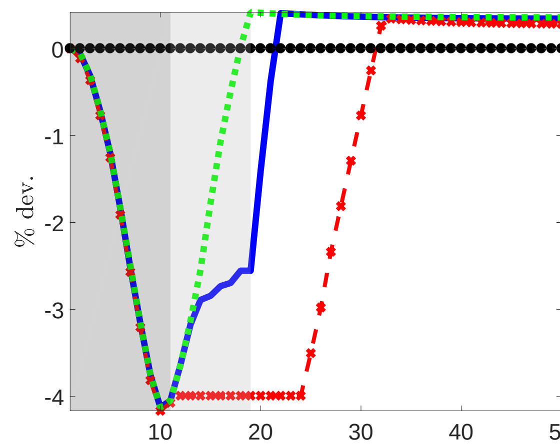
NOTE: This figure shows the response of the relative tradable to nontradable sector employment (left) and the ratio of labor employed in the production of tradables for the domestic market to labor employed in the production of tradables for the foreign market (right) to the commodity price super-cycle shown in figure 3. The blue solid line corresponds to the baseline case, the red crossed line corresponds to the case with constant wages, the green dashed line corresponds to the case with constant demand and the black circled line corresponds to the initial steady state.

5.4 Aggregate Impacts and Welfare

We now evaluate the macroeconomic effects of a commodity price super-cycle and assess the welfare cost of downward wage rigidity during these episodes. To this end we simulate the behavior of the following three economies that differ only in their degree of wage rigidity: a flexible economy ($\chi = 0.983$), an economy with an intermediate degree of rigidity ($\chi = 0.990$) which was the case used in the previous sections, and a highly-rigid economy ($\chi = 0.995$).



a) Unemployment Rate

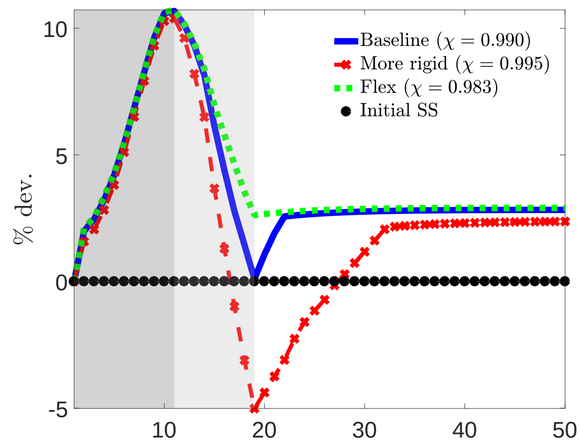


b) Skill Premium

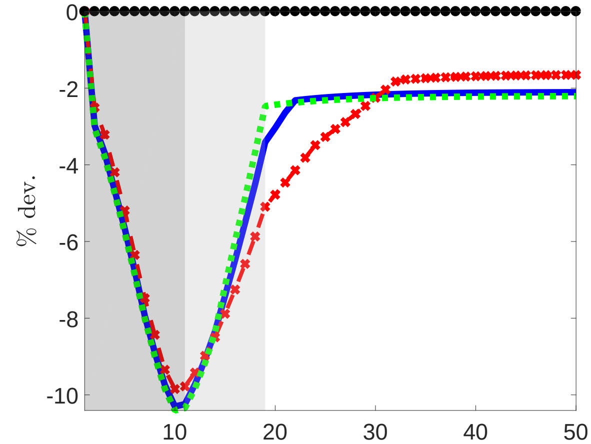
Figure 6: Response of the Unemployment Rate and the Skill Premium to a Commodity Price Super-Cycle

Note: This figure shows the response of the unemployment rate (left) and the skill premium (right) to the to the commodity price super-cycle shown in figure 3. The different lines correspond to the i) economy with flexible wages (green dashed line) ii) baseline (moderately rigid) economy (solid blue line) iii) highly rigid economy (red crossed line) and iv) steady state level (black circled line).

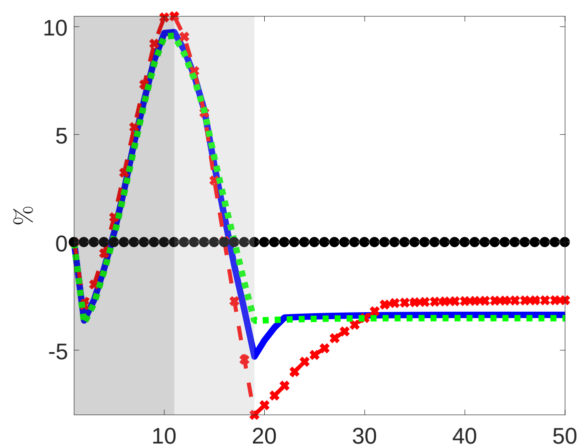
Figure 6a plots the evolution of the unemployment rate. Both the peak of the unemployment rate and the number of years with positive unemployment increase with the level of wage rigidity. The intermediate and especially the most rigid economy suffer unemployment for several years following the end of the super-cycle. Figure 6b in turn shows the evolution of the skill premium, which declines during the boom to a similar extent in all three cases. During the bust, the skill premium in the flexible economy rises quickly, while in the most rigid economy, it stays at its lowest level for several periods even after the commodity price is back to the initial steady state. The decline in the skill premium during the boom implies that the downward wage rigidity constraint is more likely to be binding for unskilled than for skilled labor, since the optimal downward adjustment of unskilled wages would be larger under flexible wages. Consistently, we observe that in the flexible economy only the constraint for unskilled labor is binding while in the most rigid economy, the constraints for both worker types bind. As a consequence, the skill premium remains persistently low during and following the bust, and the relative labor misallocation between the tradable and nontradable sectors lasts longer.[47,48]



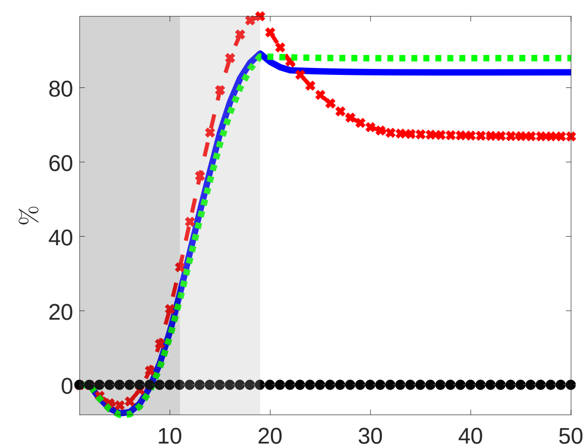
a) GDP (Consumption deflated)



b) Real Exchange Rate



c) Trade Balance to GDP ratio



d) Net Foreign Assets to GDP ratio

Figure 7: Response of Macroeconomic Outcomes to a Commodity Price Super-Cycle

Note: This figure shows the response of consumption-deflated GDP (top left), the real exchange rate (top right), the trade balance to GDP ratio (bottom left) and the net foreign assets to GDP ratio (bottom right) to the to the commodity price super-cycle shown in figure 3. The different lines correspond to the i) economy with flexible wages (green dashed line) ii) baseline (moderately rigid) economy (solid blue line) iii) highly rigid economy (red crossed line) and iv) steady state level (black circled line).

The response of GDP to the commodity price super-cycle in each of these economies (in figure 7a) shows how high degrees of downward wage rigidity generate a recession at the end of the cycle. This

[47] Appendix figure A9 shows that in the economy with intermediate rigidity the cycle generates unemployment only among unskilled workers, while in the highly rigid economy both types face unemployment (and the peak and duration are higher for unskilled workers). Besides the unemployment effect, figure A10 shows that more rigid economies have a persistently lower share of labor in the tradable sector and a higher share in the nontradable sector. The persistent distortion in the skill premium is associated to a persistent effect on the intersectoral allocation of labor.

[48] Note than in the long-run the skill premium remains higher than in the initial steady state. This is a consequence of the permanent trade deficit generated by the boom, which implies a higher long-run ratio of nontradable to tradable production. Because the nontradable is relatively skill intensive, this leads to a higher steady-state skill premium.

corresponds to the empirical observations documented by Reinhart et al. [2016] regarding the painful end of commodity super-cycles. The most rigid economy experiences persistent unemployment of up to 10% and real (consumption-deflated) GDP falling by up to 5%. Appendix B.5 shows that the real effects of downward wage rigidity also hold when we follow Kehoe and Ruhl [2008]'s suggestion and use a chained Fisher index to construct real GDP.

Figures 7b, 7c, and 7d plot the behavior of the real exchange rate, the trade balance, and net foreign assets. Consistently with the empirical cross-country literature, the real exchange rate appreciates persistently (domestic prices increase as the economy is permanently wealthier).[49] The more rigid economies face a larger appreciation in the short run but less long-run appreciation due to the smaller capitalization of the commodity boom. In line with the permanent income hypothesis, households adjust their permanent consumption level on impact and choose a new and higher level of consumption. The path of the trade balance and net foreign assets are consistent with countercyclical trade balance and current account dynamics. The permanent effect of this transitory cycle can be seen in the long-run level of the net foreign assets to GDP ratio and the trade balance to GDP ratio. The flexible economy converges to a new steady state with 20 percentage points more foreign assets than the most rigid economy.[50] Note that less rigid economies accumulate more foreign assets and can therefore afford a larger trade balance deficit following the end of the commodity price super-cycle.

Finally, we illustrate how the peak unemployment rate, the number of periods with unemployment, the long-run net foreign assets to GDP ratio, and the consumption-equivalent welfare vary as a function of the intensity of downward wage rigidity.[51] We choose a range for the rigidity parameter that spans from the fully flexible economy ($\chi = 0.983$) to the highly rigid economy ($\chi = 0.995$). Our ($\chi = 0.990$) estimate (discussed in Appendix Section A.1.9) lies within this range. Figures 8a and 8b show that the intensity and the duration of unemployment are convex functions of the degree of downward wage rigidity. Similarly, figures 8c and (8d) illustrate how the long-run net foreign assets to GDP ratio and the consumption-equivalent welfare gain decrease at increasing rates with the degree of rigidity. The cost of wage rigidity can be as large as to reduce the 2.2% consumption-equivalent welfare gain from the cycle

[49] The real exchange rate is defined as the inverse of the price of the final consumption bundle ($P_t = \omega^M \cdot P_t^M + \omega^{C^d} \cdot P_t^C + \omega^N \cdot P_t^N + \omega^{T^d} \cdot P_t^T$, with weights ω given by steady-state consumption shares of each good).

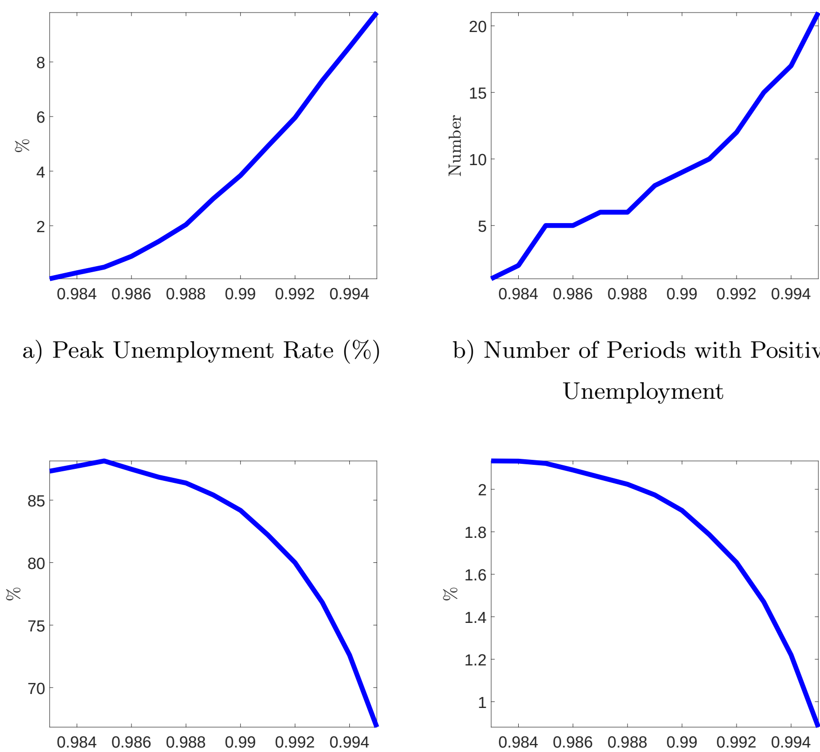
[50] Note that the level of asset accumulation in figure 7d is quite large. The model does not feature fiscal expenditure. For this reason, in practice, one might observe lower levels of asset accumulation following commodity booms. During the commodity price boom observed between 2002 and 2011 Brazil's fiscal expenditure increased at a similar rate than GDP, mantaining the expenditure to GDP ratio stable (the general government expenditure to GDP ratio was 34.5% in 2002 and 35.1% in 2011).

[51] To assess the impact of the commodity price super-cycle on welfare we calculate the consumption-equivalent welfare gain from the episode. This is the difference between the welfare gain of an economy exposed to the cycle W_{cycle} versus that of one not exposed W_0, measured as the amount of consumption the representative household would have to receive to be indifferent between experiencing the cycle and remaining in the initial steady state. This is:

$$\text{Consumption-Equivalent Welfare Gain} = \left(\frac{W_{cycle}}{W_0}\right)^{\frac{1}{1-\upsilon}} - 1\,. \tag{10}$$

in the flexible economy to 0.9% in the most rigid economy.

In a nutshell, the quantitative model illustrates how the superposition of the cost and wealth channels explains the transmission of a commodity price super-cycle. Downward wage rigidity amplifies its impact, generating deep and persistent recessions at the end of the cycle and producing cross-sectoral labor misallocation and unemployment.



a) Peak Unemployment Rate (%)

b) Number of Periods with Positive Unemployment

c) Long-Run Net Foreign Assets to GDP ratio

d) Consumption-Equivalent Welfare (%)

Figure 8: Aggregate Consequences of Downward Wage Rigidity

Note: This figure shows the peak unemployment rate (top left), the number of periods with positive unemployment (top right), the long-run net foreign assets to GDP ratio (bottom left) and the consumption-equivalent welfare gain from the cycle (bottom right) under different values of the downward wage rigidity parameter.

6 Conclusions

This paper analyzes the transmission of commodity price cycles throughout the economy. We identify two main channels - *cost* and *wealth* - , both of which have heterogeneous impacts across and within sectors. Following a commodity price boom, the cost channel, which operates through an increase in wages in response to an expansion in the labor demand of the commodity sector, reallocates labor away from the tradable and nontradable sectors. Its impact on different sectors depends upon their skill intensity. Because the commodity sector is relatively unskilled-intensive a commodity price boom lowers the skill premium and is especially distressing for less-skilled tradable and nontradable industries. The wealth channel is driven by the general increase in income and benefits sectors and firms selling their products locally (i.e., the nontradable sector and non-exporters in the tradable sector).

To confirm the economic intuition behind these channels, we exploit quasi-experimental regional variation in the exposure to commodity price fluctuations in Brazil during the period 1999 and 2013 and examine rich longitudinal administrative employee-employer data for the same period. We uncover heterogeneous responses coming from both channels and document the empirical association between commodity prices and firm- and sector-level employment, the skill premium, firm entry and exit, and firm-level exporting status. We empirically identify the cost channel exploiting differences in skill intensities across industries within sectors, and the wealth channel from differences between exporters and non-exporters in the tradable sector.

Guided by this novel evidence, we introduce a dynamic three-sector model of heterogeneous firms with skilled and unskilled labor that captures these transmission channels and the associated margins of adjustment, including the role of downward wage rigidity. We calibrate our model to moments of our microeconomic data to quantify the strength of the cost and wealth channels, and the welfare and unemployment implications of commodity price super-cycles. Our findings show that the cost channel explains two-thirds of intersectoral labor reallocation and the demand channel explains two-thirds of the reallocation of labor between exporters and non-exporters within the tradable sector. We show how labor market frictions, prevalent in commodity-dependent emerging economies, reduce the welfare gains obtained from a commodity price super-cycle. This result highlights the relevance of policies aimed at reducing labor market rigidity in these countries.

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Index of Online Appendices

A Empirical Appendix

A.1 Data

A.1.1 List of Data Sources.

In what follows we describe each of the additional data sources used in the paper. Our two main data sources (RAIS and commodity prices from the World Bank's Global Economic Monitor - Commodities) are described in the main text.

Demographic Census. We use the long forms of Brazil's Demographic Census in year 2000 to i) construct weights for the commodity price index as defined in section 2; ii) construct regional informality shares as described in appendix A.2.6; iii) create the map of regional specialization in commodities in appendix A.1.3; iv) construct weights for the import penetration measures in appendix A.2.7; and v) compute shares of commodity employment concentration examine in appendixA.1.5. Additionally we use the 1991 Census to construct weights for regional tariffs as described in section A.2.8. Weights are constructed based on employed individuals aged 20-60.

PNAD (Pesquisa Nacional por Amostra de Domicílios). We use the household survey PNAD to construct annual measures of unemployment that are representative of the entire country, used in appendix A.1.9. We also compute mean aggregate wages from PNAD. PNAD contains information for between 330 and 350 thousand individuals each year during the period 1996-1999. Note that an alternative to PNAD would be the PME employment survey (Pesquisa Mensual de Emprego) but it collects information for only 12 major urban areas. Unemployment is computed as the ratio between the number of unemployed individuals and searching for a job to the sum of those employed and those unemployed and searching for a job.

Trade Flows. We use the United Nations' COMTRADE database to construct measures of Chinese imports used in appendix A.2.7 and to compute Brazil's market shares in commodities in world markets examined in appendix A.1.4. Industry-level trade data is originally reported in COMTRADE according to the ISIC revision 3 classification, and converted to three-digit level CNAE industries using a cross-walk provided by Brazil's Statistical Institute (IBGE).

Firm-level Exporter Status. We obtain the universe of exporting firms from Brazil's Secretariat of Foreign Trade (SECEX), which we match to RAIS. This is available at yearly frequency.

Import Tariffs. We obtain industry-level tariffs in 1990 and 1995 from Kovak [2013]. We compute the change in industry-level tariffs as described in appendix A.2.8.

Input-Output Table. We use Brazil's 2005 input-output table with 56 sectors and 110 products, which we use to define tradable industries with an intensive use of commodities as inputs in appendix A.2.9. This input-output table is produced by Brazil's Statistical Institute (IBGE).

Geographic data. We obtain data on administrative regional units from Brazil's Statistical Institute (IBGE). These allow us to match municipalities to microregions, macroregions and states.

A.1.2 Descriptive Statistics.

This section reports a set of descriptive statistics on the firm panel across macroregions and sectors and on the skill premium across macroregions.

Table A1: Summary Statistics by Macroregion and Sector - Firm Panel

Macroregion	Sector	Number of Firms	Mean Employment	Share of Exporters
North	Commodity	1088	68.3	0.04
	Tradable	4144	53.9	0.10
	Nontradable	18416	27.0	0.00
Northeast	Commodity	3312	81.3	0.06
	Tradable	14909	46.5	0.04
	Nontradable	69301	25.6	0.00
Central-West	Commodity	7647	116.9	0.03
	Tradable	71720	46.9	0.09
	Nontradable	262454	29.3	0.01
Southeast	Commodity	3490	73.5	0.02
	Tradable	36754	45.4	0.09
	Nontradable	88162	22.1	0.01
South	Commodity	1782	138.3	0.02
	Tradable	7467	34.3	0.03
	Nontradable	37178	24.7	0.00

Note: This table reports the number of firms, mean firm employment, and the share of exporting firms, by macroregion and sector in the first quarter of 2006, which is the year in the middle of our sample. These statistics are computed within the sample of firms with at least 5 workers used in the firm-level regressions in the text.

Table A2: Summary Statistics by Macroregion: Wages and Skill Premium

Macroregion	Mean Skilled Wage	Mean Unskilled Wage	Skill Premium
North	1541.66	517.82	2.98
Northeast	1229.50	412.70	2.98
Central-West	1707.46	582.50	2.93
Southeast	1396.16	528.77	2.64
South	2120.77	594.73	3.57

Note: This table reports the mean monthly wage for skilled and unskilled workers and the skill premium by macroregion in 2006, which is the year in the middle of our sample. Wages are reported in real *Reais* of 2000.

A.1.3 Regional Specialization in Commodities.

Figure A1 illustrates the regional variation in the degree of specialization in commodity production. For each region, we compute the share of employment in the commodity sector as a share of regional employment using Brazil's Demographic Census in year 2000. The map shows four shades of blue that correspond to quartiles of the distribution of the share of regional employment in the commodity sector. Darker shades reflect a larger share of employment in commodities. As the figure shows, we find a larger degree of specialization in commodities in the *North* and *Northeast*, and a lower degree of commodity specialization in the *Southeast*.

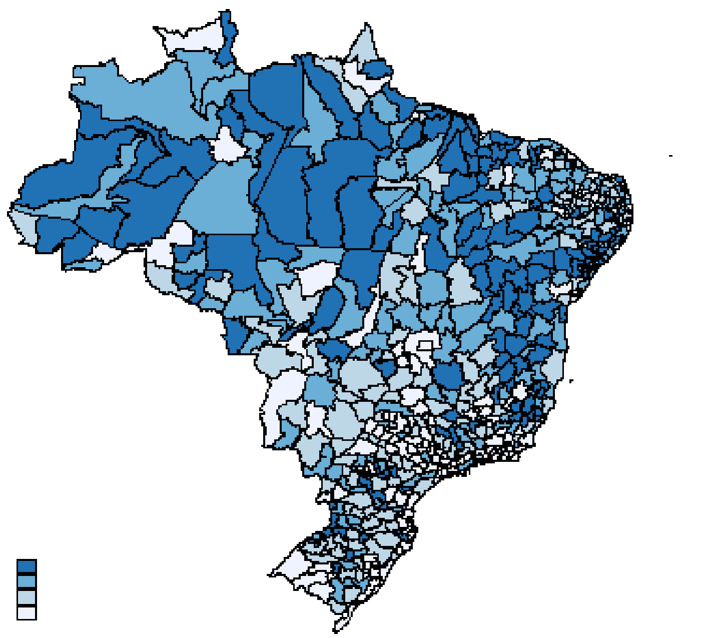


Figure A1: Regional Specialization in Commodities

A.1.4 Market Share of Brazil in World Commodity Markets.

Here we report the market share of Brazil in world markets for the largest 5 commodities (in terms of employment) used in the construction of our regional commodity price index. Due to the lack of comparable production data, we report market shares of Brazilian exports in total world exports. We obtain data on Brazil's and World exports by commodity from the United Nations' COMTRADE database for year 2000. Table A3 reports the results.

A.1.5 Geographic Concentration of Commodity Employment.

In this section we report statistics on the distribution of employment shares across regions for each of the largest 5 commodities (in terms of national employment) included in our regional commodity price index. Table A4 reports the employment share of various percentiles of this distribution. The coffee industry

Table A3: Export Shares of Brazil by Commodity

	Share (%)
Bovine Meat	3.60
Cereals	5.19
Coffee	17.19
Soybeans	24.01
Sugarcane	23.75

NOTE: This table reports the share of value exported by Brazil as a fraction of world exports by commodity in year 2000, for the largest 5 commodities in terms of national employment. The data is obtained from COMTRADE.

(region at the 99th percentile), for instance, concentrates 2.95 percent of national employment. These ratios show that even the most specialized regions represent a small fraction of commodity employment.

Table A4: Distribution of Employment Share by Commodity Across Regions

Percentile	Cereals	Sugarcane	Soybeans	Coffee	Bovine Meat
p1	0.0000	0.0000	0.0000	0.0000	0.0000
p5	0.0000	0.0000	0.0000	0.0000	0.0001
p10	0.0001	0.0000	0.0001	0.0000	0.0002
p25	0.0003	0.0001	0.0001	0.0000	0.0005
p50	0.0008	0.0003	0.0006	0.0002	0.0010
p75	0.0023	0.0014	0.0040	0.0020	0.0025
p90	0.0046	0.0047	0.0124	0.0088	0.0045
p95	0.0066	0.0091	0.0256	0.0150	0.0061
p99	0.0142	0.0374	0.0492	0.0295	0.0085

NOTE: This table reports various percentiles of the distribution of regional shares of national employment by commodity, for the largest 5 commodities in terms of national employment. The data is based on the Demographic Census of year 2000.

Tables A3 and A4 suggest that none of Brazil's regions display the market power needed to set international prices. This supports our assumption that, when it comes to commodities, Brazilian regions are price takers.

A.1.6 The Distribution of Skill Intensity across Sectors.

Table A5 represents the means, standard deviations, and various percentiles of the distribution of skill intensity across two-digit industries for the commodity, tradable, and nontradable sectors.

Table A5: Distribution of Skill Intensity Across Industries

	Commodity	Tradable	Nontradable
Mean	0.074	0.107	0.199
St. Dev.	0.075	0.064	0.162
p10	0.017	0.028	0.033
p25	0.025	0.052	0.057
p50	0.048	0.105	0.146
p75	0.127	0.149	0.307
p90	0.221	0.185	0.398

NOTE: This table reports the mean, std. deviation, and various percentiles of the distribution of skill intensity across two-digit industries for the commodity, tradable, and nontradable sectors..

A.1.7 Regional Employment and Commodity Prices

In this section we report additional results on the impact of commodity prices on regional employment. First, we show that commodity price fluctuations reallocate regional employment across sectors. Second, we measure the impact on a region's total employment in all sectors.

To measure how commodity price fluctuations reallocate regional employment across sectors we estimate equation (A1) for each sector at a time.

$$\text{Emp. Share}_{rt} = \beta \cdot \text{Price}_{rt} + \gamma_r + \delta_t + \epsilon_{rt} \tag{A1}$$

We take advantage of the availability of quarterly employment data and use 60 observations for each of our 558 regions. Employment and commodity prices are measured in the last month of each quarter. The dependent variable is the share of employment in each sector in total regional employment. Using these shares rather than total sectoral employment prevents our results to be driven by an impact of commodity prices on total regional employment.[52]

As in the skill-premium regression earlier, we include region fixed effects as well as macroregion-by-time (quarter) fixed effects. In addition, we include fixed effects for each quarter of the year to control for seasonality. We cluster standard errors by region.

The results are reported in table A6. A one log point increase in the regional commodity price index is associated to an increase of 0.069 percentage points (p.p.) in the regional share of commodity employment (column 1), a 0.027 p.p. decline in the share of tradable employment (column 2), and a 0.012 p.p. positive but not statistically significant change in the share of nontradable employment. The 55 log

[52] We show in appendix A.1.7 that in fact commodity prices are positively correlated with total regional employment. Further, we show that most of the increased regional employment comes from workers previously employed in the formal sector in the same region, and not from workers previously employed in the formal sector in other regions, or from workers not previously employed in the formal sector.

point in commodity prices in Brazil during 2002q2 and 2011q4 would then be associated to a 3.78 p.p higher share of employment in the commodity sector, and a 1.5 p.p. lower share in the tradable sector. The reallocation of labor across sectors is driven primarily by changes in unskilled employment shares, as we show below.

Table A6: Commodity Prices and Shares of Sectoral Employment

	(1) Commodity	(2) Tradable	(3) Nontradable
(log) Price_{rt}	0.069***	-0.027*	0.012
	(0.018)	(0.017)	(0.020)
Observations	33480	33480	33480
R^2	0.895	0.916	0.875

NOTE: This table reports the results of the estimation of equation (A1). Column 1 corresponds to the commodity sector. Column 2 corresponds to the tradable sector. Column 3 corresponds to the nontradable sector. Each regression includes region as well as macroregion-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

To measure the impact on employment levels, we re-estimate equation (A1) but using total regional employment as the right-hand side variable. We find a large increase in regional employment: a one log point increase in the regional commodity price index is associated to a 0.288 log point increase in employment.

Table A7: Total Regional Employment

	(1)
(log) Price_{rt}	0.288***
	(0.068)
Observations	33480
R^2	0.986

NOTE: This table reports the results of the estimation of equation (A1) using total regional employment as the dependent variable. This regression includes region as wel as macroregion-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Finally, to quantify the impact on sectoral employment by skill category we repeat the analysis but now separately by sector and skill type. The results are displayed in table A8. As suggested by the economic channels studied in the main text, across all sectors, the impact of commodity prices is much larger for unskilled employment.

Table A8: Regional Employment by Skill Category

	(1)	(2)	(3)	(4)	(5)	(6)
	Commodity		Tradable		Nontradable	
	U	S	U	S	U	S
(log) Price_{rt}	0.0767***	0.0127	-0.0341*	0.0185	0.0353*	-0.0723***
	(0.0192)	(0.0107)	(0.0183)	(0.0127)	(0.0209)	(0.0266)
Observations	33480	33455	33480	33455	33480	33455
R^2	0.898	0.671	0.916	0.850	0.887	0.683

NOTE: This table reports the results of the estimation of equation (A1). Columns 1 and 2 correspond to unskilled and skilled employment in the commodity sector. Columns 3 and 4 correspond to unskilled and skilled employment in the tradable sector. Columns 5 and 6 correspond to unskilled and skilled employment in the nontradable sector. Each regression includes region as well as macroregion-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.1.8 Heterogeneous Responses at the Extensive Margin

We can use the rich firm-level information to determine the impact of regional commodity prices on the extensive margin (entry and exit of firms). To this end, we construct a balanced panel of all firms present at any point in our sample, and construct the categorical variable Present_{ft} which equals one when we observe firm f in the data in period t, and zero otherwise. We estimate a regression of commodity price shocks on this categorical outcome:[53] This procedure using firm-level regressions follows Bustos [2011], who examines the impact of trade barriers on export participation.

$$\text{Present}_{ft} = \beta \cdot \text{Price}_{rt} + \gamma_f + \delta_t + \epsilon_{ft} \tag{A2}$$

Equation (A2) is estimated separately by sector. The empirical strategy, exploiting regional variation and including firm and state-by-period fixed effects, follows that used earlier for firm-level employment. We cluster standard errors by firms. We estimate this equation using annual data.[54]

Table A9 shows the results. In the commodity sector (column 1), a one log point increase in the regional commodity price index is associated to a 0.133 percentage point higher probability a firm is active. In the tradable sector, column 2 shows the results for firms in all industries, while column 3 excludes firms in three tradable industries with an intensive use of commodities as inputs. In both cases, commodity prices are negatively correlated with the probability a firm is active. Based on column 2, a one log point price increase is associated to a 0.052 p.p. lower probability a firm is active. Finally, in the nontradable sector (see column 4), a one log point increase in the regional commodity price index is associated to a 0.0297 percentage point lower probability a firm is active.

[53] We estimate a linear probability model rather than a probit model to avoid the incidental parameters problem given the large set of fixed effects included.

[54] We find very similar effects at quarterly frequency.

Similarly, to quantify the impact of regional commodity prices on firms' exporting status in the tradable sector, we estimate a regression model in the same spirt of (A2) but with a dummy variable taking a value of one if the firm's exports in period t, and zero otherwise.

Table A9 reports the results. As its column 5 indicates, higher commodity prices are correlated with a lower probability of exporting. A one log point increase in the price index is associated to a 0.011 p.p. lower probability a firm in the tradable sector exports.[55] These results are consistent with the combined effect of the cost and wealth channels.

Table A9: Commodity prices, Entry/Exit and Export Status

	Outcome: Present$_{ft}$				Outcome: Export$_{ft}$
	Commodity	Tradable		Nontradable	Only Tradable
	(1)	(2)	(3)	(4)	(5)
(log) Price$_{rt}$	0.133***	-0.0519***	-0.0582***	-0.0297***	-.0107**
	(0.0194)	(0.00724)	(0.00782)	(0.00321)	(0.00537)
Observations	681,915	5,709,000	4,920,345	26,339,445	1,763,929
R^2	0.535	0.470	0.469	0.433	0.756

NOTE: This table reports the results of the estimation of equation (A2). Column 1 corresponds to the commodity sector. Column 2 and 3 corresponds to the tradable sector. Column 3 excludes commodity-intensive industries. Column 4 corresponds to the nontradable sector. Column 5 corresponds to the equation with export status as the dependent variable, estimated for firms in the tradable sector. Each regression includes firm as well as state-by-time fixed effects. Standard errors are clustered by firm. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.1.9 Downward Wage Rigidity in Brazil

In what follows we provide evidence on the nature of wage adjustments in Brazil.[56] We first provide macroeconomic evidence of downward real wage rigidity. Next we document the distribution of individual wage changes, showing that wage cuts are significantly more infrequent in Brazil than in the US.

[55]To compare the magnitude of the effect of commodity prices on net entry and net entry into exporting, note that a moving from the 25th to the 75th percentile in the regional commodity price is associated to a 0.042 standard deviation lower probability of being active, and a 0.013 standard deviation lower probability of being an exporter.

[56]A brief introduction to labor market institutions is useful. From the 1960's to the mid-1990s, wage adjustments in Brazil were highly centralized, with adjustments to all formal sector workers set by law annually. While this centralized adjustment law was abandoned, hyperinflation in the early 1990's led to indexation of wages to the minimum wage. The period under study in this paper (1999-2013) is one of somewhat larger flexibility and where wage-setting decisions are more likely to take place at the firm level. On the other hand, following Brazil's new constitution in 1988, in the context of a transition from military to civilian rule, unions were allowed more freedoms and labor costs generally increased. During the last two decades, pressure for reform in the direction of a more flexible labor market has led to several minor attempts at reducing firing costs and allowing temporary contracts. As a result of this historical process, Brazil's labor market nowadays is more rigid than that of most countries as measured by international indices. Campos and Nugent [2012] rank Brazil within the top 10% most rigid labor markets in 2000 within a sample of 144 countries. See Paes De Barros and Corseuil [2004] and Amadeo and Camargo [1993] for details on Brazil's labor market institutions in recent decades.

Macroeconomic Evidence of Downward Real Wage Rigidiy. In addition to the micro-level results, in this section we discuss macroeconomic evidence of downward wage rigidity. We study two episodes in which real wages would be expected to fall but remain flat, which is indicative of downward real wage rigidity.

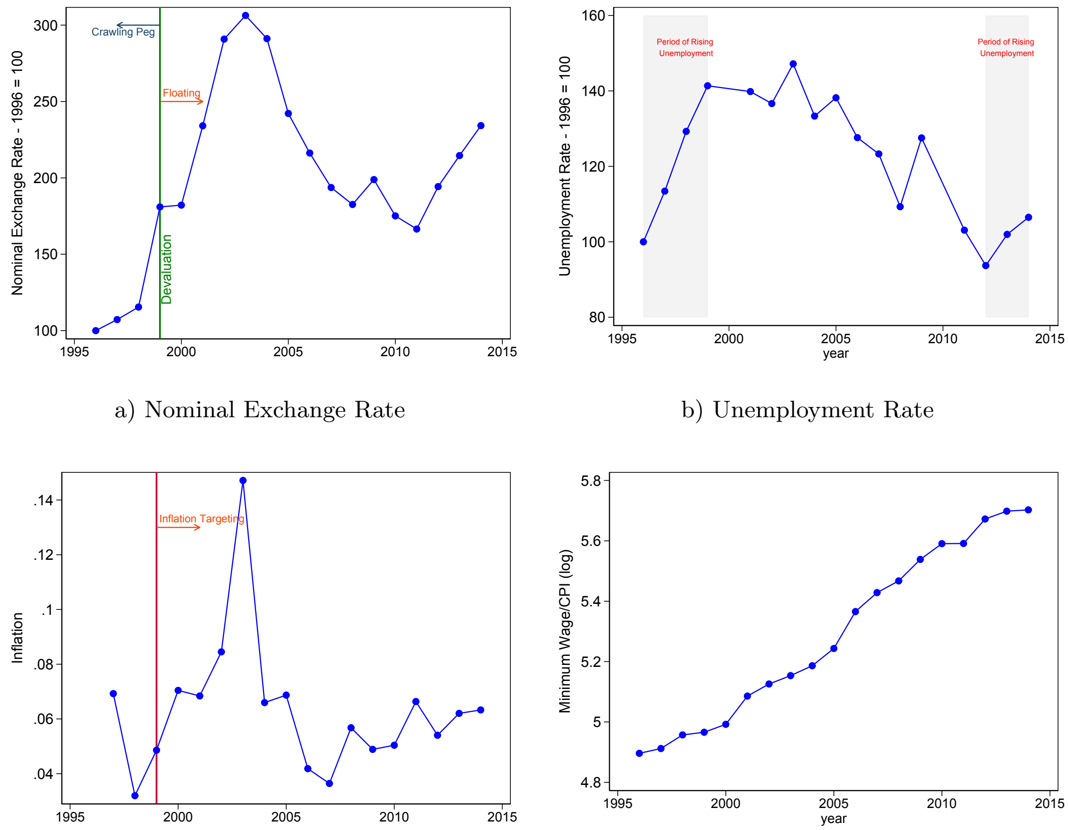
First, following the analysis in Schmitt-Grohé and Uribe [2016], during the 1996-1998 period of increasing unemployment and an exchange rate regime characterized by a crawling peg, one would expect flexible wages to fall. Real wages, however, remain constant or even increase, only falling in dollar terms as a consequence of the unexpected devaluation in early 1999. Second, during 2012-2014, again under rising unemployment, but this time under a floating exchange rate regime, once again real wages are unable to adjust. Figure A2 plots the path of the nominal exchange rate, unemployment, inflation, and real minimum wage. Figure A3 and A4 plot the path of nominal wages, real wages in dollar terms, and CPI-deflated real wages in each of these episodes.

This analysis is consistent with the analysis in Messina and Sanz-de Galdeano [2014] who estimate the incidence of wage rigidity in the Brazilian economy between 1996 and 2004 using microeconomic data and document that a large fraction of individuals were subject to downwardly rigid real wages in Brazil during this period, without there being a structural change following the devaluation. This suggests that only monetary or exchange rate surprises can impact the real wage.

The 1996-1998 episode is used to identify the wage rigidity parameter in the model. We compute the wage rigidity parameter as the annual growth rate in nominal wages between 1996-1998 adjusted by foreign inflation and by the long-term growth rate of Brazilian real per capita GDP. The annual growth rate of nominal wages is $\left(\frac{w^{1998}}{w^{1996}}\right)^{1/3} = 1.075$. We use the U.S. GDP deflator as a proxy for foreign inflation, which in this period equals 1.5 percent annually. The growth rate of Brazil's real per capita GDP between 1980 and 2010 is 1.95 percent per year. In the context of our economic framework, this implies:

$$\chi = \frac{\left(\frac{w^{1998}}{w^{1996}}\right)^{1/3}}{[1.0195 \times 1.015]} = 0.990\,. \tag{A3}$$

Different values of foreign inflation can lead to different estimates of χ. In our simulations in the main text, we use a wide range of values for χ.



a) Nominal Exchange Rate

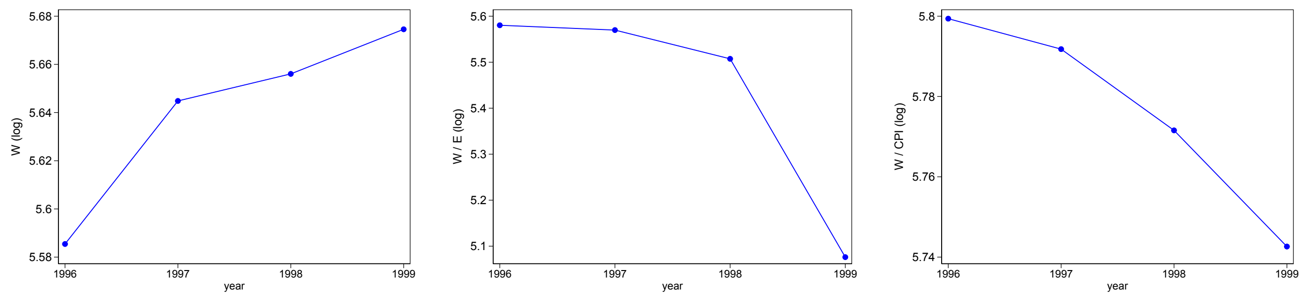
b) Unemployment Rate

c) Inflation

d) Real Minimum Wage

Figure A2: Nominal Exchange Rate, Unemployment Rate, Inflation, and Real Minimum Wage: 1996-2014

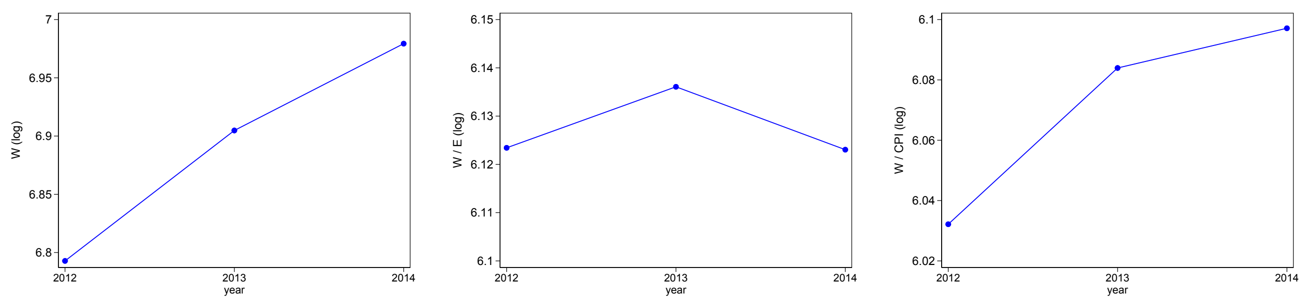
Note: This figure shows the path of the nominal exchange rate (in panel (a)), the unemployment rate (in panel (b)), inflation (in panel (c)), and the minimum wage deflated by the CPI (in logs, in panel (d)). Unemployment is computed from the household survey PNAD as explained in the text. The nominal exchange rate and unemployment rate are indexed to 100 in 1996.



a) Nominal Wage b) Real Wage in Dollar Terms c) Real Wage (Nominal Wage / CPI)

Figure A3: Nominal and Real Wages in Brazil: 1996-1999

Note: This figure shows the path of nominal wages (in panel (a)), real wages in dollar terms (in panel (b)), real wages deflated by the CPI (in panel (c)). All series are in logs and are computed from the household survey PNAD as explained in the text.



a) Nominal Wage b) Real Wage in Dollar Terms c) Real Wage (Nominal Wage / CPI)

Figure A4: Nominal and Real Wages in Brazil: 2012-2014

Note: This figure shows the path of nominal wages (in panel (a)), real wages in dollar terms (in panel (b)), real wages deflated by the CPI (in panel (c)). All series are in logs and are computed from the household survey PNAD as explained in the text.

Microeconomic Evidence on the Distribution of Wage Changes. In this section we document properties of the distribution of individual wage changes. Our goal is to show that wage cuts are significantly more infrequent in Brazil than in the US. We compare our findings to those in recent work by Kurmann and McEntarfer [2017] who document the distribution of wage changes for the U.S.

We focus on year-to year changes in individuals' mean monthly wages. We restrict the sample to individuals aged 20 - 60 employed in the commodity, tradable, or nontradable sector. To make the results as comparable as possible to the earlier literature we restrict the sample to *stayers* - workers employed the two entire and consecutive years in the same firm, and we define wages that stay constant as those that change less than 0.5% [see Kurmann and McEntarfer, 2017]. We pool all year-to-year wage changes over the period 1999-2013.

To make our results comparable to recent findings for the U.S. [Kurmann and McEntarfer, 2017], we focus on nominal wages. We find nominal wage cuts are rare, even in low-growth years or in regions facing downturns. Figure A5 shows the kernel density of the pooled distribution of wage changes.[57] We find that 16.0 percent of wages fall from one year to the next, 2.7 percent stay constant, and 81.3 percent rise.[58] As a comparison, Kurmann et al. [2016] report that 30 percent of hourly wages fall in the U.S. private sector in a 30-state sample during 1999-2011.

Figures A6a and A6b show that the distribution of wage changes is similar for skilled and unskilled individuals, as well as across sectors.[59] Additionally we document that the asymmetry in the distribution and the small frequency of nominal wage cuts holds in both high and low growth years, as figure A6c shows. We also classify region-year pairs into quartiles according to the intensity of regional commodity price shocks. As figure A6d shows, there is very little impact of these price shocks on the asymmetry of the wage change distribution and on its left tail. Various percentiles and statistics of the pooled distribution of wage changes are shown in figure A6e.

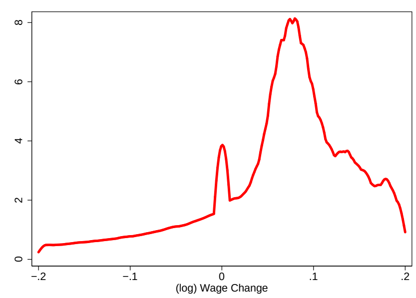


Figure A5: Distribution of Nominal Wage Changes

NOTE: This figure displays the distribution of nominal wage changes pooled over 1999-2013.

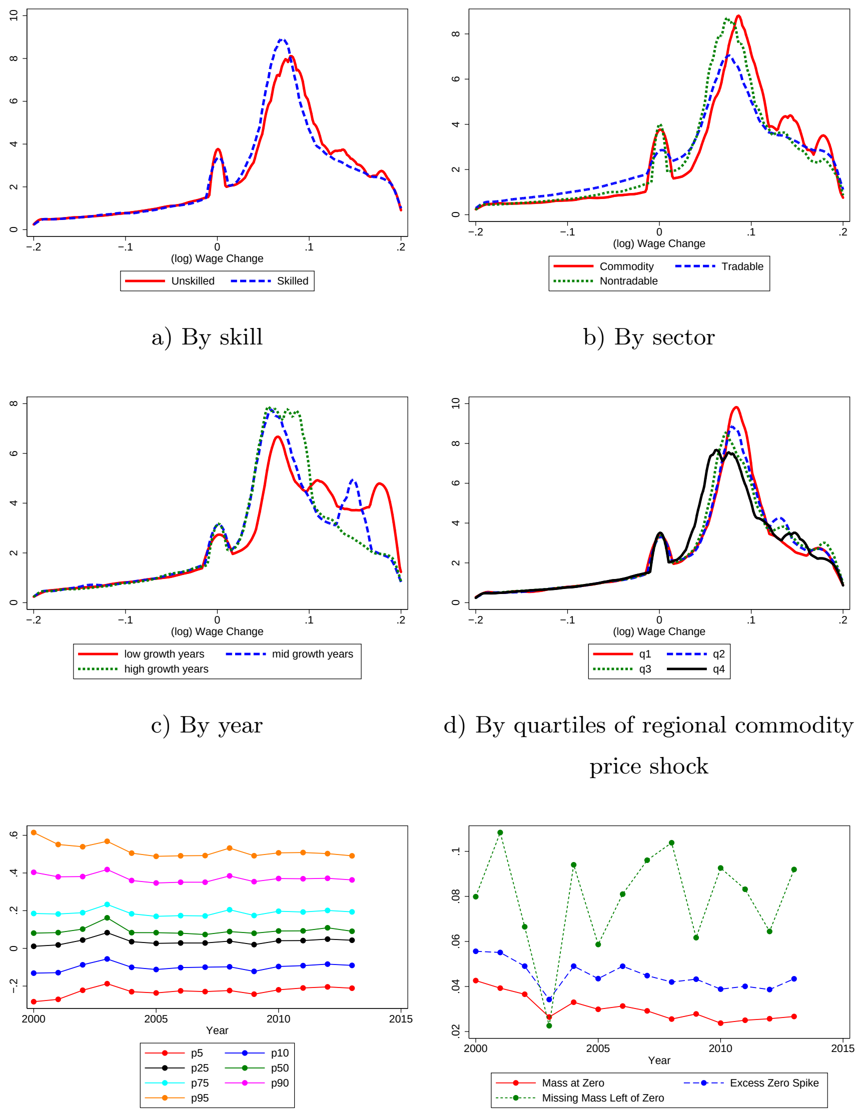
We also compute three measures used in the literature that capture asymmetries in the wage change distribution. Following Kurmann and McEntarfer [2017] we define the mass at zero as $M_0 = F(0.005) - F(-0.005)$, the excess zero spike as $ES_0 = [F(0.005) - F(-0.005)] + [F(2 \times median + 0.005)] -$

$[F(2 \cdot median - 0.005)]$, and the missing mass left of zero as $MM_0 = 1 - F(2 \times median + 0.005) - F(-0.005)$. The path over time of each of these measures is shown in figure A6f. All of these are indicative of downward wage rigidity.

[57]The path over time of the percentiles of this distribution are shown in figure A6e.

[58]Following Kurmann and McEntarfer [2017] we define wages that stay constant as those that change less than 0.5%.

[59]This justifies why in the model we impose the same downward wage rigidity restriction to skilled and unskilled labor. This similar behavior of wage changes for skilled and unskilled workers is also consistent with a labor code that treats these two types of workers similarly.



a) By skill

b) By sector

c) By year

d) By quartiles of regional commodity price shock

e) Percentiles

f) Statistics

Figure A6: Distribution of Nominal Wage Changes

Note: Panel (a) shows the distribution of nominal wage changes for skilled and unskilled workers pooled over 1999-2013. Panel (b) shows the distribution of nominal wage changes for workers in the commodity, tradable, and nontradable sector pooled over 1999-2013. Panel (c) shows the wage change distribution for high-growth years (the two years with highest GDP growth: 2007 and 2010); mid-growth years (the two years with the closest to the median GDP growth: 2005 and 2006); and low-growth years (the two years with lowest GDP growth: 2003 and 2009). Panel (d) shows the wage-change distribution separately for quartiles of intensity of commodity price shocks in region-year pairs (see text). Panel (e) shows the evolution of the percentiles of the wage change distribution over time. Panel (f) shows evolution over time of the following statistics of the wage change distribution: the mass at zero, the excess zero spike, and the missing mass left of zero (all defined in the text).

A.2 Robustness Checks

A.2.1 Wealth Channel: Controlling for Skill Intensity

We verify the robustness of equation (3) to including the interaction between commodity prices and the skill intensity share of each tradable industry. The results, shown in table (A10) below, are very similar to the baseline results in the main text.

Table A10: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	(1)
(log) Price$_{rt}$	-0.042*
	(0.022)
Exporter$_{ft}$	0.134***
	(0.004)
Exporter$_{ft}$ x (log) Price$_{rt}$	-0.063***
	(0.014)
Skill Intensity$_{i}$ x (log) Price$_{rt}$	0.263**
	(0.107)
Observations	8,007,443
R^2	0.909

NOTE: This table reports the results of the estimation of equation (3). Column 1 includes the interaction of the regional commodity price index and each industry's skill intensity. Each regression includes firm as well as state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Note we demean the commodity price index and skill intensity variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.2 Cost Channel

Controlling for Firm-Size Bin Dummies. We verify the robustness of our main results to different specifications of equation (2). Specifically, we first control for firm-size bin dummies and their interaction with the regional commodity price index. The results, shown in column 1 in table A11 below, are similar to the baseline results discussed in the main text.

Identification *Within* Two-Digit Industries. In addition, we control for the interaction between the regional commodity price index and two-digit industry dummies. Here the identification of the cost channel is based on the variation in skill intensity across 3-digit industries (but *within* two-digit industries). The results, shown in column 2 in table A11 below, are again similar to the baseline results discussed in the main text.

A.2.3 Exporters, Importers and the Exchange Rate.

We verify the robustness of our results to the following alternative specifications of equation (3):

Table A11: Commodity Prices and Firm-Level Employment: The *Cost* Channel

	Nontradable	Nontradable
	(1)	(2)
(log) Price_{rt}	0.033*	0.056
	(0.018)	(0.056)
Skill Intensity_i x (log) Price_{rt}	0.485***	0.430***
	(0.069)	(0.094)
Observations	30,453,457	30,453,457
R^2	0.891	0.850

NOTE: This table reports the results of the estimation of equation (2) for the nontradable sector. Column 1 includes (but do not display) the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 0 to 50 workers, 50 to 100 workers, 100 to 500 workers, 1000 and more workers. Column 2 includes the interaction between the regional commodity price index and two-digit industry dummy variables. Each regression includes firm and state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Note we estimate equation (2) demeaning the commodity price index and skill intensity variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

1. Baseline regression plus the interaction between the exchange rate and the exporter dummy;
2. Baseline regression plus an importer dummy in addition to the exporter dummy;
3. Baseline regression plus the interaction between the exchange rate and the exporter and importer dummies.

The results, shown in table (A12) below, confirm the robustness of our main findings.

A.2.4 Alternative Commodity Price Index Definitions.

We consider the following three alternative definitions of the regional commodity price index:
Excluding Oil and Gas. The first alternative definition excludes fuels (oil and gas), since this is a regulated sector, and computes the price index based on the 13 remaining commodities. We estimate equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, using this alternative regional commodity price index. The results for the cost channel (eq. (2)) are shown in columns 1 and 2 in table A15. The results for the wealth channel (eq. (3)) are shown in column 1 in table A16. These results are very similar to the baseline results in the main text. This is to be expected as employment in the oil and gas industry is small, so leaving it aside from the commodity price index results in minor changes.
Accounting for shocks to neighboring regions. The second alternative definition takes into account the commodity price shocks to each region's neighboring regions. It is possible that regional employment could depend on commodity prices of other regions to the extent that there is some degree of interregional linkages, including interregional trade or migration.[60] These linkages could lead to geographic spillovers.

[60]Note however that we show in appendix A.2.5, regional commodity price are not correlated with the share of a regions' workers coming from other regions.

Table A12: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	(1)	(2)	(3)
(log) Price$_{rt}$	-0.040*	-0.042*	-0.041*
	(0.022)	(0.022)	(0.022)
Exporter$_{ft}$	0.155***	0.138***	0.137***
	(0.007)	(0.004)	(0.008)
Exporter$_{ft}$ x (log) Price$_{rt}$	-0.068***	-0.135***	-0.135***
	(0.015)	(0.012)	(0.013)
Exporter$_{ft}$ x Exchange Rate$_t$	-0.017**		0.001
	(0.007)		(0.007)
Importer$_{ft}$		0.077***	0.091***
	(0.006)	(0.008)	
Importer$_{ft}$ x (log) Price$_{rt}$		0.195***	0.186***
		(0.017)	(0.018)
Importer$_{ft}$ x Exchange Rate$_t$			-0.017***
			(0.006)
Observations	8,086,964	8,086,964	8,086,964
R^2	0.909	0.909	0.909

NOTE: This table reports the results of the estimation of equation (3) for the tradable sector. In addition to the baseline specification in table 3 in the main text, column 1 includes the interaction between the exchange rate and the exporter dummy; column 2 includes an importer dummy, and column 3 includes the importer dummy and the interaction between the exchange rate and both the exporter and importer dummies. Each regression includes firm as well as state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by firm. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Following Allcott and Keniston [2014] we assume these spillovers are mostly local, implying that it is shocks to regions within a certain radius that are the most relevant. Under this assumption, the broader commodity price index we construct estimates the absolute effect of commodity price shocks including these geographic spillovers, taking into account the prices faced by nearby regions.

For each region, this alternative regional commodity price index is defined as the mean of the regional commodity price indices of all regions (including itself) within a radius of 100 kilometers. We compute distances between regions as the distance between their centroids.[61] We estimate equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, using this alternative regional commodity price index. The results for the cost channel (eq. (2)) are shown in columns 3 and 4 in table A15. The results for the wealth channel (eq. (3)) are shown in column 2 in table A16. These results are also robust to i) assigning lower weight to more distant regions and ii) modifying the 100 km. radius.

Regional Commodity Price: Trend and Cyclical Components We verify the robustness of our main results to alternative definitions of the regional commodity price index. In particular, we estimate

[61] The median region has 6 neighboring regions with centroids within this 100 kilometer radius (in addition to itself).

equations (2) and (3) using i) the unfiltered regional price index, and ii) both the trend and cyclical components of the regional price index. The results, shown in table (A13) below, indicate that it is the trend component (which we use in our empirical analysis in the main text) that drives the results. The cyclical component has a small and statistically insignificant impact on the outcomes of interest. These result also indicate that using the unfiltered price index leads to very similar results than using the trend.

Table A13: Firm-Level Employment: *Cost* and *Wealth* Channels

	(1)	(2)	(3)	(4)
(log) Price$_{rt}$	0.010		-0.004	
	(0.008)		(0.009)	
(log) Price Trend$_{rt}$		0.013		-0.043**
		(0.021)		(0.022)
(log) Price Cycle$_{rt}$		0.005		0.010**
		(0.003)		(0.005)
Exporter$_{ft}$			0.139***	0.141***
			(0.005)	(0.005)
Exporter$_{ft}$ x (log) Price$_{rt}$			-0.046***	
			(0.012)	
Exporter$_{ft}$ x (log) Price Trend$_{rt}$				-0.058***
				(0.015)
Exporter$_{ft}$ x (log) Price Cycle$_{rt}$				-0.004
				(0.010)
Skill Intensity$_i$ x (log) Price$_{rt}$	0.590***			
	(0.073)			
Skill Intensity$_i$ x (log) Price Trend$_{rt}$		0.846***		
		(0.115)		
Skill Intensity$_i$ x (log) Price Cycle$_{rt}$		-0.011		
		(0.029)		
Observations	30,453,437	30,453,437	8,086,964	8,086,964
R^2	0.849	0.849	0.909	0.903

NOTE: This table reports the results of the estimation of equation (2) (in columns 1 and 2) and (3) (in columns 3 and 4) using the unfiltered regional price index (in columns 1 and 3) or the trend and cyclical component included at the same time (in columns 2 and 4). Each regression includes firm as well as state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by firm. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.5 Interregional Mobility.

We have shown earlier that an increase in the regional commodity price index leads to an increase in total regional employment (see table A7 in appendix A.1.7). We examine in this section to what extent this growth in employment comes from i) workers employed in the same region in the previous period, ii) workers employed in other regions in the previous period, and iii) workers who are not employed in the formal sector in the previous period. For this purpose we use worker identifiers in RAIS that allow us to track workers over time. For each region, we divide employment in period t into the three margins described, computing the share of each margin in total employment.[62] We then estimate the following equation of regional commodity price shocks on each of these margins of regional employment:

$$\text{Emp. Share}_{rt} = \beta \cdot \text{Price}_{rt} + \gamma_r + \delta_t + \epsilon_{rt}\,. \tag{A4}$$

We find that changes in regional commodity prices are associated with very small, not statistically significant changes in each of the three shares in which total employment is decomposed.

Table A14: Shares of Regional Employment

	(1) Same Region	(2) Other Regions	(3) Else
(log) Price_{rt}	0.0165	-0.00387	-0.0126
	(0.0167)	(0.00977)	(0.0110)
Observations	7812	7812	7812
R^2	0.655	0.560	0.678

Note: This table reports the results of the estimation of equation (A4). Column 1 corresponds to the share of workers employed in the same region in the previous period. Column 2 corresponds to the share of workers employed in a different region in the previous period. Column 3 corresponds to the share of workers not employed in the RAIS data in the previous period. Each regression includes region as well as macroregion-by-time fixed effects. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.6 Informality.

A potential concern with the labor market data used in our analysis is that it is restricted to the formal sector. In Brazil, workers must register their employment contracts in their *carteira de trabalho* - a passport-type notebook. The literature widely considers workers that do not register their contract in their *carteira de trabalho* as informal (Paes De Barros and Corseuil [2004]). According to this definition, the share of informal employees within the commodity, tradable and nontradable sector is 35.8% in 2000

[62] On average across all regions and periods, 78.3 percent of workers employed in a region are employed in the same region in the previous period, 8.0 percent are employed in a different region in the previous period, and the remaining 13.6 percent are not observed in RAIS (i.e. are not employed in the formal sector) in the previous period. (This average is weighted by regional employment).

based on Brazil's Demographic Census.[63]

We show that our baseline estimates in the main text are not driven by a spatial correlation between the degree of regional informality and the regional concentration of industries by skill intensity (in the case of the cost channel) or the regional concentration of exporting firms (in the case of the wealth channel). Using the 2000 Demographic Census, we compute state-level shares of informal employment. We augment equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, adding an interaction term between the regional commodity price index and the share of informal employment in each region, as shown in equations (A5) and (A6).[64]

$$\begin{aligned}\log(\text{Emp})_{ft} = \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \\ \alpha_1 \cdot [\text{Price}_{rt} \cdot \text{Informality Share}_r] + \gamma_f + \delta_t + \epsilon_{ft}\,,\end{aligned} \tag{A5}$$

$$\begin{aligned}\log(\text{Emp})_{ft} = \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_w \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] \\ + \beta_2 \cdot [\text{Price}_{rt} \cdot \text{Informality Share}_r] + \gamma_f + \delta_t + u_{ft}\,.\end{aligned} \tag{A6}$$

The results for the cost channel (eq. (2)) are shown in columns 5 and 6 in table A15. While the interaction term between the regional commodity price index and the share of informal employment in each region is statistically significant both for the tradable and nontradable sectors, the difference in the impact of the price index on firm-level employment and its interaction with industries' skill intensity in comparison to the baseline case is very small. The results for the wealth channel (eq. (3)) are shown in column 3 in table A16. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status is also small in comparison to the baseline case.

[63]This number computes the share of informal employees among all employees, excluding employers and self-employed individuals. It is based on males and females aged 20-60.

[64]We estimate equations (A5) and (A6) demeaning the commodity price index and the informality share variables.

A.2.7 Regional Exposure to Chinese Import Competition.

In this section we verify that our baseline estimates in the main text are not driven by a spatial correlation between exposure to the China shock and the regional concentration of industries by skill intensity (in the case of the cost channel) or the regional concentration of exporting firms (in the case of the wealth channel).

We construct measures of regional exposure to the large increase in Chinese import competition observed in Brazil during our sample period. We follow Autor et al. [2013] and define a regional measure of import competition as follows:

$$\Delta \mathrm{IP}_r = \sum_i \frac{L_{ir}}{L_i} \cdot \frac{\Delta \mathrm{Imports}_i}{L_r} \, . \tag{A7}$$

where $\Delta\mathrm{Imports}_i$ is the change in Chinese imports of industry i between 2000 and 2010, L_{ir} is employment in region r and industry i in 2000, L_r is employment in region r in 2000, and L_i is employment in industry i in 2000. To construct this measure, we obtain industry level imports from the UN's Comtrade database. These are originally reported according to the ISIC revision 3 classification, and converted to three-digit level CNAE industries using a cross-walk provided by Brazil's Statistical Institute (IBGE).

We augment equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, adding an interaction term between our regional commodity price index and the change in import competition measure $\Delta\mathrm{IP}_r$, as shown in equations (A8) and (A9).[65]

$$\begin{aligned} \log(\mathrm{Emp})_{ft} = \alpha_0 \cdot \mathrm{Price}_{rt} + \alpha_c \cdot [\mathrm{Price}_{rt} \times \text{Skill Intensity}_i] + \\ \alpha_1 \cdot [\mathrm{Price}_{rt} \cdot \Delta\mathrm{IP}_r] + \gamma_f + \delta_t + \epsilon_{ft} \, , \end{aligned} \tag{A8}$$

$$\begin{aligned} \log(\mathrm{Emp})_{ft} = \beta_0 \cdot \mathrm{Price}_{rt} + \beta_1 \cdot \mathrm{Exporter}_{ft} + \beta_w \cdot \left[\mathrm{Exporter}_{ft} \times \mathrm{Price}_{rt}\right] + \\ \beta_2 \cdot [\mathrm{Price}_{rt} \cdot \Delta\mathrm{IP}_r] + \gamma_f + \delta_t + u_{ft} \, . \end{aligned} \tag{A9}$$

Note that studies of the impact of trade shocks on regional outcomes, such as Autor et al. [2013] instrument $\Delta\mathrm{IP}_r$ with the same weighted average of industry level imports using Chinese exports to a set of "similar" countries. In the case of Brazil, we construct this instrument and find that the correlation across regions with $\Delta\mathrm{IP}_r$ is 0.9725. Given this extremely high correlation, we report OLS results for equations (A8) and (A9). We find very similar results if we use this instrument instead of $\Delta\mathrm{IP}_r$ in

[65] We estimate equations (A8) and (A9) demeaning the commodity price index and standardizing the trade exposure variable to have mean zero and standard deviation one.

equations (A8) and (A9).

The results for the cost channel (eq. (2)) are shown in columns 7 and 8 in table A15. While the interaction term between the regional commodity price index and the regional change in import competition measure $\Delta \mathrm{IP}_r$ is statistically significant both for the tradable and nontradable sectors, the difference in the impact of the price index on firm-level employment and its interaction with industries' skill intensity in comparison to the baseline case is very small. The results for the wealth channel (eq. (3)) are shown in column 4 in table A16. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status is also small in comparison to the baseline case.

A.2.8 Regional Exposure to Trade Liberalization.

In this section we verify that our baseline estimates in the main text are not driven by a spatial correlation between exposure to the Brazil's trade liberalization and the regional concentration of industries by skill intensity (in the case of the cost channel) or the regional concentration of exporting firms (in the case of the wealth channel).

We construct measures of regional exposure to Brazil's trade liberalization carried out in the early 1990's.[66] We define a regional measure of trade liberalization as follows:

$$\Delta\tau_r = \sum_i \frac{L_{ir}}{L_r} \cdot \Delta\tau_i \; , \tag{A10}$$

where $\Delta\tau_i$ is the change in tariffs in industry i between 1990 and 1995, L_{ir} is employment in region r and industry i in 1991, and L_r is employment in region r in 1995. To construct this measure, we obtain industry-level tariffs from Kovak [2013] and follow the timing and industry classification used in that paper. We use the 1991 Demographic Census to construct the weights in (A10).[67]

We augment equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, adding an interaction term between our regional commodity price index and the trade liberalization measure $\Delta\tau_r$, as shown in equations (A11) and (A12).[68].

$$\begin{aligned}\log(\text{Emp})_{ft} = \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \\ \alpha_1 \cdot [\text{Price}_{rt} \cdot \Delta\tau_r] + \gamma_f + \delta_t + \epsilon_{ft} \; ,\end{aligned} \tag{A11}$$

$$\begin{aligned}\log(\text{Emp})_{ft} = \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_w \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] + \\ \beta_2 \cdot [\text{Price}_{rt} \cdot \Delta\tau_r] + \gamma_f + \delta_t + u_{ft} \; .\end{aligned} \tag{A12}$$

The results for the cost channel (eq. (2)) are shown in columns 9 and 10 in table A15. While the interaction term between the regional commodity price index and the regional trade liberalization measure $\Delta\tau_r$ is statistically significant both for the tradable and nontradable sectors, the difference in the impact of the price index on firm-level employment and its interaction with industries' skill intensity in comparison to the baseline case is very small. The results for the wealth channel (eq. (3)) are shown

[66] For evidence on the impact of Brazil's trade liberalization on labor markets see Dix-Carneiro and Kovak [2015], Dix-Carneiro [2014], and Menezes-Filho and Muendler [2011].

[67] As Adão [2015] points out, the definition of microregions by IBGE in the Demographic Census is constant across years between 1991 and 2000, despite the increase in the number of municipalities.

[68] We estimate equations (A11) and (A12) demeaning the commodity price index and the tariff change variable

in column 5 in table A16. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status is also small in comparison to the baseline case.

A.2.9 Use of Commodities as Inputs in Manufacturing Industries.

A concern with our empirical strategy is that some manufacturing industries might use commodities as inputs in the production process. An increase in commodity prices might imply a direct increase costs for these industries, as an additional mechanism to that described by our model. To address this concern, we estimate equations (2) and (3), that measure the impact of commodity prices on firm employment to identify the cost and demand channels, using this alternative sample excluding tradable industries that use commodities as inputs intensively. The results for the cost channel (eq. (2)) are shown in column 7 in table 2. The results for the wealth channel (equation (3)) are shown in column 2 in table 3. In both cases the results are similar to those using the full sample.

To construct a measure of commodity usage in manufacturing industries, we use Brazil's input-output table for year 2005, which reports the value of inputs used by two-digit manufacturing industries. This table is obtained from IBGE. For each two-digit manufacturing industry we aggregate the value of commodity and total inputs used. We compute the share of value represented by commodity inputs. We identify three industries that use commodities intensively: *Food and Beverages Manufacturing*, *Tobacco Manufacturing*, and *Coke, Refined Petroleum and Other Fuels Manufacturing.* These industries have a ratio of commodity inputs over total inputs between 43 and 51 percent. All other two-digit manufacturing industries have ratios below 17 percent, and most often below 10 percent.

A.2.10 Robustness Results.

Table A15: Commodity Prices and Firm-Level Employment: The *Cost* Channel

	Excl. Oil and Gas		Nearby Regions		Informality		China Shock		Trade Liberalization	
	Tradable	Nontradable	Tradable	Nontradable	Tradable	Nontradable	Tradable	Nontradable	Tradable	Nontradable
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(log) Price_{rt}	-0.086***	0.063***	-0.165***	0.088***	-0.148***	0.002	-0.124***	0.016	-0.138***	0.001
	(0.028)	(0.020)	(0.043)	(0.029)	(0.030)	(0.020)	(0.030)	(0.020)	(0.032)	(0.021)
Skill Intensity_i x (log) Price_{rt}	0.983***	0.987***	0.976***	0.981***	0.818***	0.851***	0.776***	0.845***	0.796***	0.849***
	(0.149)	(0.084)	(0.167)	(0.079)	(0.207)	(0.115)	(0.203)	(0.114)	(0.205)	(0.115)
Informality Share_r x (log) Price_{rt}					0.246**	0.403***				
					(0.104)	(0.054)				
ΔIP_r x (log) Price_{rt}							0.036***	0.007		
							(0.014)	(0.007)		
$\Delta\tau_r$ x (log) Price_{rt}									0.002*	0.015***
									(0.008)	(0.006)
Observations	8,007,422	30,453,437	8,007,422	30,453,437	8,007,422	30,453,437	8,007,422	30,453,437	8,007,422	8,007,422
R^2	0.873	0.849	0.873	0.849	0.873	0.849	0.873	0.849	0.873	0.849

NOTE: This table reports the results of the estimation of equation (2) by sector. Columns 1 (tradable sector) and 2 (nontradable sector) use the regional price index excluding oil and gas. Columns 3 (tradable sector) and 4 (nontradable sector) use the regional price index that accounts for the price indices of neighboring regions. Columns 5 (tradable sector) and 6 (nontradable sector) add an interaction term between regions' informality share and the regional price index. Columns 7 (tradable sector) and 8 (nontradable sector) add an interaction term between regional exposure to the change in Chinese imports the regional price index. Columns 9 (tradable sector) and 10 (nontradable sector) add an interaction term between the regional exposure to the change in tariffs during Brazil's trade liberalization and the regional price index. Each regression includes firm as well as state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Table A16: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	Excl. Oil and Gas	Nearby Regions	Informality	China Shock	Trade Liberalization
	(1)	(2)	(3)	(4)	(5)
(log) Price_{rt}	-0.012	-0.065*	-0.052**	-0.036*	-0.048**
	(0.022)	(0.034)	(0.022)	(0.022)	(0.012)
Exporter_{ft}	0.140***	0.139***	0.135***	0.135***	0.135***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Exporter_{ft} x (log) Price_{rt}	-0.054***	-0.055***	-0.056***	-0.060***	-0.057***
	(0.016)	(0.016)	(0.015)	(0.015)	(0.015)
Informality Share_r x (log) Price_{rt}			0.199***		
			(0.068)		
ΔIP_r x (log) Price_{rt}				0.016	
				(0.010)	
$\Delta\tau_r$ x (log) Price_{rt}					0.005
					(0.005)
Observations	8,086,964	8,086,964	8,086,964	8,086,964	8,086,964
R^2	0.909	0.909	0.909	0.909	0.909

NOTE: This table reports the results of the estimation of equation (3). Column 1 uses the regional price index excluding oil and gas. Column 2 uses the regional price index that accounts for the price indices of neighboring regions. Column 3 adds an interaction term between regions' informality share and the regional price index. Column 4 adds an interaction term between regional exposure to the change in Chinese imports the regional price index. Column 5 adds an interaction term between the regional exposure to the change in tariffs during Brazil's trade liberalization and the regional price index. Each regression includes firm as well as state-by-time (quarter) fixed effects. In addition we include dummies for each of the four quarters of the year. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

B Theory Appendix

B.1 Diagram of the Model Economy

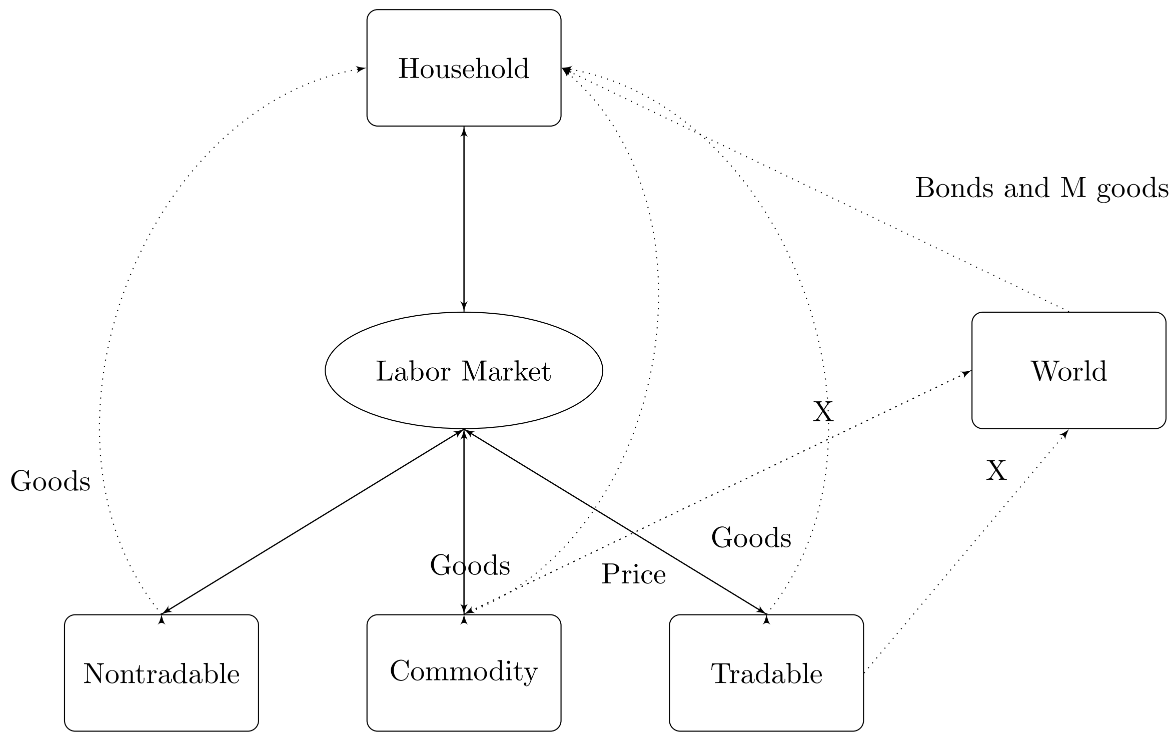


Figure A7: Model Economy

B.2 System of Dynamic Equations

$$
\begin{aligned}
Exogenous(1) &= \{P_t^C\} \\
Endogenous(39) &= \{N_t, M_t, T_t^d, X_t^T, C_t, C_t^d, P_t^N, P_t^T, P_t^R, B_{t+1}, TB_t, \lambda_t, w_t^u, w_t^s, ...\} = 14 \\
&= \{\hat{w}_t^C, L_t^{s,C}, L_t^{u,C}, W_t^C, \mu_t^C, \mathcal{M}_t^C, \tilde{\mathcal{M}}_t^C, \underline{z}_t^C, ...\} = 8 \\
&= \{\hat{w}_t^N, L_t^{s,N}, L_t^{u,N}, W_t^N, \mu_t^N, \mathcal{M}_t^N, \tilde{\mathcal{M}}_t^N, \underline{z}_t^N, ...\} = 8 \\
&= \{\hat{w}_t^T, L_t^{s,T}, L_t^{u,T}, W_t^T, \mu_t^T, \mathcal{M}_t^T, \tilde{\mathcal{M}}_t^T, \underline{z}_t^T, \underline{z}_{x,t}^T, ...\} = 9\,.
\end{aligned}
$$

B.2.1 Households

$$\frac{1}{1+r^*} = \beta \frac{\lambda_{t+1}}{\lambda_t} \equiv \Lambda_{t,t+1} \tag{A13}$$

$$\lambda_t = \left[M_t^{\theta} + \alpha^N N_t^{\theta} + \alpha^T \left(T_t^d \right)^{\theta} + \alpha^C \left(C_t^d \right)^{\theta} \right]^{\frac{1-\theta-\gamma^r}{\theta}} M_t^{\theta-1} \tag{A14}$$

$$N_t = \left(\frac{\alpha^N}{P_t^N} \right)^{\frac{1}{1-\theta}} M_t \tag{A15}$$

$$T_t^d = \left(\frac{\alpha^T}{P_t^T} \right)^{\frac{1}{1-\theta}} M_t \tag{A16}$$

$$C_t^d = \left(\frac{\alpha^C}{P_t^C} \right)^{\frac{1}{1-\theta}} M_t \tag{A17}$$

$$T_t^d = \left[\int_{\zeta \in \mathfrak{Z}} q_{d,t}(\zeta)^{\rho} d\zeta \right]^{\frac{1}{\rho}}$$

$$P_t^T = \left[\int_{\zeta \in \mathfrak{Z}} p_t(\zeta)^{1-\sigma} d\zeta \right]^{\frac{1}{1-\sigma}}$$

$$0 = (L_t^{s,C} + L_t^{s,N} + L_t^{s,T} - (1-\kappa)\overline{L})(w_t^s - \chi w_{t-1}^s) \ , \tag{A18}$$

$$(1-\kappa)\overline{L} \geq L_t^{s,C} + L_t^{s,N} + L_t^{s,T} \ , \quad w_t^s \geq \chi w_{t-1}^s$$

$$0 = (L_t^{u,C} + L_t^{u,N} + L_t^{u,T} - \kappa\overline{L})(w_t^u - \chi w_{t-1}^u) \ , \tag{A19}$$

$$\kappa\overline{L} \geq L_t^{u,C} + L_t^{u,N} + L_t^{u,T} \ , \quad w_t^u \geq \chi w_{t-1}^u$$

$$B_{t+1} = (1+r^*)B_t + TB_t \tag{A20}$$

$$TB_t = P_t^C \left(C_t - C_t^d \right) + X_t^T - M_t \tag{A21}$$

B.2.2 Commodity Sector

Optimal Decisions

$$\hat{w}_t^C = \left[\phi^C (w_t^u)^{1-\gamma} + (1-\phi^C)(w_t^s)^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \tag{A22}$$

$$
\begin{aligned}
C_{i,t} &= \left(\xi^{\xi}\eta^{\eta}\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}_t^C)^{-\eta}\left(P_t^R\right)^{-\xi}(P_t^C)^{\xi+\eta}\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} \\
R_{i,t} &= \left(\xi^{1-\eta}\eta^{\eta}\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}_t^C)^{-\eta}\left(P_t^R\right)^{-(1-\eta)}P_t^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} \\
l_{i,t}^C &= \left(\xi^{\xi}\eta^{1-\xi}\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}_t^C)^{-(1-\xi)}\left(P_t^R\right)^{-\xi}P_t^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} + f^C \\
l_{i,t}^{s,C} &= (1-\phi^C)\left(\frac{\hat{w}_t^C}{w_t^s}\right)^{\gamma} l_{i,t}^C \\
l_{i,t}^{u,C} &= \phi^C\left(\frac{\hat{w}_t^C}{w_t^u}\right)^{\gamma} l_{i,t}^C \\
\pi_{i,t} &= (1-\xi-\eta)\left(\xi^{\xi}\eta^{\eta}\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}_t^C)^{-\eta}\left(P_t^R\right)^{-\xi}P_t^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} - \hat{w}_t^C f^C
\end{aligned}
$$

Value Function

$$W_t^C(z^C) = \max\left\{0,\ \pi_t(z^C) + (1-\delta^C)\beta\max\left\{0, W_{t+1}^C(z^C)\right\}\right\}. \tag{A23}$$

Cutoff

$$0 = W_t^C(\underline{z}_t^C)\,. \tag{A24}$$

Free entry condition

$$\hat{w}_t^C \hat{f}_e^C\left(\tilde{\mathcal{M}}_t^C\right) = \int_{\underline{z}_t^N}^{\infty} W_t^C(z^C)g(z_j^C)dz^C. \tag{A25}$$

Distribution of producers law of motion

$$\mathcal{M}_{t+1}^C\mu_{t+1}^C(z^C) = \left(1-\delta^C\right)\mathcal{M}_t^C\mu_t^C(z^C)1(z^C \geq \underline{z}_{t+1}^C) + \tilde{\mathcal{M}}_{t+1}^C g(z^C)1(z^C \geq \underline{z}_{t+1}^C)\,. \tag{A26}$$

Mass of producers law of motion

$$\mathcal{M}_{t+1}^C = \left(1-\delta^C\right)\mathcal{M}_t^C\int_{\underline{z}_{t+1}^C}^{\infty}\mu_t^C(z^C)dz^C + \tilde{\mathcal{M}}_{t+1}^C\int_{\underline{z}_{t+1}^C}^{\infty} g(z^C)dz^C\,. \tag{A27}$$

Aggregate variables

- Total natural resource constraint (Fixed Supply)

$$\bar{R} = \mathcal{M}_t^C\int_{\underline{z}_t^C}^{\infty} R_t(z^C)\mu_t^C(z^C)dz^C\,. \tag{A28}$$

- Total skilled and unskilled labor for production (including operational cost)

$$L_{p,t}^{s,C} = \mathcal{M}_t^C \int_{\underline{z}_t^C}^{\infty} l_t^{s,C}(z^C)\mu_t^C(z^C)dz^C \; ,$$
$$L_{p,t}^{u,C} = \mathcal{M}_t^C \int_{\underline{z}_t^C}^{\infty} l_t^{u,C}(z^C)\mu_t^C(z^C)dz^C \; .$$

- Total skilled and unskilled labor for fixed entry cost

$$L_{e,t}^{s,C} = \tilde{\mathcal{M}}_t^C(1-\phi^C)\left(\frac{\hat{w}_t^C}{w_t^s}\right)^{\gamma} \hat{f}_e^C\left(\tilde{\mathcal{M}}_t^C\right) ,$$
$$L_{e,t}^{u,C} = \tilde{\mathcal{M}}_t^C\phi^C\left(\frac{\hat{w}_t^C}{w_t^u}\right)^{\gamma} \hat{f}_e^C\left(\tilde{\mathcal{M}}_t^C\right) .$$

- Total skilled and unskilled labor demand

$$L_t^{s,C} = L_{p,t}^{s,C} + L_{e,t}^{s,C} \; , \tag{A29}$$
$$L_t^{u,C} = L_{p,t}^{u,C} + L_{e,t}^{u,C} \; . \tag{A30}$$

- Total Commodity Output (net of operational cost)

$$C_t = \mathcal{M}_t^C \int_{\underline{z}_t^C}^{\infty} C_t(z^C)\mu_t^C(z^C)dz^C \; . \tag{A31}$$

B.2.3 Nontradable Sector

Optimal decisions

$$\hat{w}_t^N = \left[\phi^N(w_t^u)^{1-\gamma} + (1-\phi^N)(w_t^s)^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A32}$$

$$l_{i,t}^N = \left(\alpha\, z_i^N\, \frac{P_t^N}{\hat{w}_t^N}\right)^{\frac{1}{1-\alpha}} + f^N$$
$$l_{i,t}^{s,N} = (1-\phi^N)\left(\frac{\hat{w}_t^N}{w_t^s}\right)^{\gamma} l_{i,t}^N$$
$$l_{i,t}^{u,N} = \phi^N\left(\frac{\hat{w}_t^N}{w_t^u}\right)^{\gamma} l_{i,t}^N$$
$$N_{i,t} = \left(\alpha\,(z_i^N)^{\frac{1}{\alpha}}\,\frac{P_t^N}{\hat{w}_t^N}\right)^{\frac{\alpha}{1-\alpha}}$$
$$\pi_{i,t} = \alpha^{\frac{\alpha}{1-\alpha}}\,(1-\alpha)\,(\hat{w}_t^N)^{-\frac{\alpha}{1-\alpha}}\,(P_t^N)^{\frac{1}{1-\alpha}}\,(z_i^N)^{\frac{1}{1-\alpha}} - \hat{w}_t^N f^N$$

Value Function

$$W_t^N\left(z^N\right) = \max\left\{0, \pi_t\left(z^N\right) + (1-\delta^N)\beta \max\left\{0, W_{t+1}^N\left(z^N\right)\right\}\right\}. \tag{A33}$$

Cutoff

$$0 = W_t^N\left(\underline{z}_t^N\right)\ . \tag{A34}$$

Free entry condition

$$\hat{w}_t^N \hat{f}_e^N\left(\tilde{\mathcal{M}}_t^N\right) = \int_{\underline{z}_t^N}^{\infty} W_t^N(z^N)g(z^N)dz^N. \tag{A35}$$

Distribution of producers law of motion

$$\mathcal{M}_{t+1}^N \mu_{t+1}^N(z^N) = \left(1-\delta^N\right)\mathcal{M}_t^N \mu_t^N(z^N)1(z^N \geq \underline{z}_{t+1}^N) + \tilde{\mathcal{M}}_{t+1}^N g(z^N)1(z^N \geq \underline{z}_{t+1}^N) \tag{A36}$$

Mass of producers law of motion

$$\mathcal{M}_{t+1}^N = \left(1-\delta^N\right)\mathcal{M}_t^N \int_{\underline{z}_{t+1}^N}^{\infty} \mu_t^N(z^N)dz^N + \tilde{\mathcal{M}}_{t+1}^N \int_{\underline{z}_{t+1}^N}^{\infty} g(z^N)dz^N\ . \tag{A37}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$\begin{aligned} L_{p,t}^{s,N} &= \mathcal{M}_t^N \int_{\underline{z}_t^N}^{\infty} l_t^{s,N}(z^N)\mu_t^N(z^N)dz^N\ , \\ L_{p,t}^{u,N} &= \mathcal{M}_t^N \int_{\underline{z}_t^N}^{\infty} l_t^{u,N}(z^N)\mu_t^N(z^N)dz^N\ . \end{aligned}$$

- Total skilled and unskilled labor for fixed entry cost

$$\begin{aligned} L_{e,t}^{s,N} &= \tilde{\mathcal{M}}_t^N(1-\phi^N)\left(\frac{\hat{w}_t^N}{w_t^s}\right)^{\gamma} \hat{f}_e^N\left(\tilde{\mathcal{M}}_t^N\right), \\ L_{e,t}^{u,N} &= \tilde{\mathcal{M}}_t^N \phi^N\left(\frac{\hat{w}_t^N}{w_t^u}\right)^{\gamma} \hat{f}_e^N\left(\tilde{\mathcal{M}}_t^N\right). \end{aligned}$$

- Total skilled and unskilled labor demand

$$L_t^{s,N} = L_{p,t}^{s,N} + L_{e,t}^{s,N}\ , \tag{A38}$$

$$L_t^{u,N} = L_{p,t}^{u,N} + L_{e,t}^{u,N}\ . \tag{A39}$$

- Total output (net of operational cost)

$$N_t = \mathcal{M}_t^N \int_{\underline{z}_t^N}^{\infty} N_t(z^N)\mu_t^N(z^N)dz^N \,. \tag{A40}$$

B.2.4 Tradable Sector

$$\hat{w}_t^T = \left[\phi^T (w_t^u)^{1-\gamma} + (1-\phi^T)(w_t^s)^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A41}$$

$$p_t(z^T) = \frac{\hat{w}_t^T}{\rho z^T}$$

$$q_{d,t}\left(z^T\right) = T_t^d \left(\frac{P_t^T \rho z^T}{\hat{w}_t^T}\right)^{\sigma}$$

$$q_{x,t}\left(z^T\right) = \gamma_0 \left(\frac{\rho z^T}{\hat{w}_t^T}\right)^{\sigma}$$

$$l_{d,t}^{s,T}\left(z^T\right) = (1-\phi^T)\left(\frac{\hat{w}_t^T}{w_t^s}\right)^{\gamma}\left[f_d^T + T_t^d (P_t^T)^{\sigma}\left(\frac{\rho}{\hat{w}_t^T}\right)^{\sigma}(z^T)^{\sigma-1}\right]$$

$$l_{d,t}^{u,T}\left(z^T\right) = \phi^T\left(\frac{\hat{w}_t^T}{w_t^u}\right)^{\gamma}\left[f_d^T + T_t^d (P_t^T)^{\sigma}\left(\frac{\rho}{\hat{w}_t^T}\right)^{\sigma}(z^T)^{\sigma-1}\right]$$

$$l_{x,t}^{s,T}\left(z^T\right) = (1-\phi^T)\left(\frac{\hat{w}_t^T}{w_t^s}\right)^{\gamma}\left[f_x^T + \gamma_0\left(\frac{\rho}{\hat{w}_t^T}\right)^{\sigma}(z^T)^{\sigma-1}\right]$$

$$l_{x,t}^{u,T}\left(z^T\right) = \phi^T\left(\frac{\hat{w}_t^T}{w_t^u}\right)^{\gamma}\left[f_x^T + \gamma_0\left(\frac{\rho}{\hat{w}_t^T}\right)^{\sigma}(z^T)^{\sigma-1}\right]$$

$$r_{d,t}\left(z^T\right) = P_t^T T_t^d \left[\frac{P_t^T \rho z^T}{\hat{w}_t^T}\right]^{\sigma-1}$$

$$\pi_{d,t}\left(z^T\right) = \frac{r_{d,t}\left(z^T\right)}{\sigma} - \hat{w}_t^T f_d^T$$

$$r_{x,t}\left(z^T\right) = \gamma_0\left(\frac{\rho z^T}{\hat{w}_t^T}\right)^{\sigma-1}$$

$$\pi_{x,t}\left(z^T\right) = \frac{r_{x,t}\left(z^T\right)}{\sigma} - \hat{w}_t^T f_x^T$$

q_d and q_x: optimal output sold in domestic, and foreign market, resp..

$l_j^{s,T}$ and $l_j^{u,T}$: optimal skilled and unskilled labor demand to produce $(j = d, x)$ tradable goods.

r_d and r_x: revenue from domestic and foreign market, resp..

π_d and π_x: profits from domestic and foreign market, resp..

Revenue and Profits

$$r_t\left(z^T\right) = \begin{cases} r_{d,t}\left(z^T\right) & \text{, if nonexporter} \\ r_{d,t}\left(z^T\right) + r_{x,t}\left(z^T\right) & \text{, if exporter,} \end{cases}$$

$$\pi_t\left(z^T\right) = \begin{cases} \pi_{d,t}\left(z^T\right) & \text{, if nonexporter} \\ \pi_{ex,t} = \pi_{d,t}\left(z^T\right) + \pi_{x,t}\left(z^T\right) & \text{, if exporter} \end{cases}$$

Value functions

$$W_t^T\left(z^T\right) = \max\left\{W_{d,t}^T, W_{ex,t}^T\right\} \tag{A42}$$

$$W_{d,t}^T\left(z^T\right) = \max\left\{0, \pi_{d,t}\left(z^T\right) + \left(1-\delta^T\right)\beta W_{t+1}^T\left(z^T\right)\right\}$$

$$W_{ex,t}^T\left(z^T\right) = \max\left\{0, \pi_{ex,t}\left(z^T\right) + \left(1-\delta^T\right)\beta W_{t+1}^T\left(z^T\right)\right\}$$

$$W_{t+1}^T\left(z^T\right) = \begin{cases} W_{d,t+1}^T & \text{, if } \underline{z}_{t+1}^T \leq z^T < \underline{z}_{x,t+1}^T \\ W_{ex,t+1}^T & \text{, if } z^T \geq \underline{z}_{x,t+1}^T \\ 0 & \text{, otherwise} \end{cases}$$

Cut-offs

$$0 = W_{d,t}^T\left(\underline{z}_t^T\right) \tag{A43}$$

$$0 = \pi_{x,t}\left(\underline{z}_{x,t}^T\right) \tag{A44}$$

Free entry condition

$$\hat{w}_t^T \hat{f}_e^T\left(\tilde{\mathcal{M}}_t^T\right) = \int_{\underline{z}_t^T}^{\infty} W_t^T\left(z^T\right) g\left(z^T\right) dz^T \tag{A45}$$

Laws of Motion: Distribution and Mass of producers

$$\mathcal{M}_{t+1}^T \mu_{t+1}^T(z^T) = \left(1-\delta^T\right) \mathcal{M}_t^T \mu_t^T(z^T) 1(z^T \geq \underline{z}_{t+1}^T) + \tilde{\mathcal{M}}_{t+1}^T g(z^T) 1(z^T \geq z_{t+1}^T) \tag{A46}$$

$$\mathcal{M}_{t+1}^T = \left(1-\delta^T\right) \mathcal{M}_t^T \int_{\underline{z}_{t+1}^T}^{\infty} \mu_t^T(z^T) dz^T + \tilde{\mathcal{M}}_{t+1}^T \int_{\underline{z}_{t+1}^T}^{\infty} g(z^T) dz^T \tag{A47}$$

Aggregate variables

- Total skilled and unskilled labor demand to produce tradable goods sold in domestic market

$$L_{d,p,t}^{s,T} = \mathcal{M}_t^T \int_{\underline{z}_t^T}^{\infty} l_{d,t}^{s,T}(z^T) \mu_t^T(z^T) dz^T$$
$$L_{d,p,t}^{u,T} = \mathcal{M}_t^T \int_{\underline{z}_t^T}^{\infty} l_{d,t}^{u,T}(z^T) \mu_t^T(z^T) dz^T$$

- Total skilled and unskilled labor demand to produce tradable goods exported

$$L_{x,p,t}^{s,T} = \mathcal{M}_t^T \int_{\overline{z}_{x,t}^T}^{\infty} l_{x,t}^{s,T}(z^T) \mu_t^T(z^T) dz^T$$
$$L_{x,p,t}^{u,T} = \mathcal{M}_t^T \int_{\overline{z}_{x,t}^T}^{\infty} l_{x,t}^{u,T}(z^T) \mu_t^T(z^T) dz^T$$

- Total skilled and unskilled labor for fixed entry cost

$$L_{e,t}^{s,T} = \tilde{\mathcal{M}}_t^T (1-\phi^T) \left(\frac{\hat{w}_t^T}{w_t^s}\right)^{\gamma} \hat{f}_e^T(\tilde{\mathcal{M}}_t^T)$$
$$L_{e,t}^{u,T} = \tilde{\mathcal{M}}_t^T \phi^T \left(\frac{\hat{w}_t^T}{w_t^u}\right)^{\gamma} \hat{f}_e^T(\tilde{\mathcal{M}}_t^T)$$

- Total skilled and unskilled labor demands

$$L_t^{s,T} = L_{d,p,t}^{s,T} + L_{x,p,t}^{s,T} + L_{e,t}^{s,T} \tag{A48}$$
$$L_t^{u,T} = L_{d,p,t}^{u,T} + L_{x,p,t}^{u,T} + L_{e,t}^{u,T} \tag{A49}$$

- Total tradable good outputs sold in domestic market

$$T_t^d = \left[\mathcal{M}_t^T \int_{\underline{z}_t^T}^{\infty} \left[q_{d,t}(z^T)\right]^{\rho} \mu_t^T(z^T) dz^T\right]^{\frac{1}{\rho}} \tag{A50}$$

- Value of tradable good outputs sold in foreign market

$$X_t^T = \mathcal{M}_t^T \int_{\underline{z}_{x,t}^T}^{\infty} p_t(z^T) q_{x,t}(z^T) \mu_t^T(z^T) dz^T \tag{A51}$$

B.2.5 Transition Equilibrium Definition

Given an exogenous sequence of commodity prices $\{P_t^C\}_{t=0}^T$, initial and final conditions for bond holdings $(B_0, \overline{B})$, and sectoral distributions $\left(\mathcal{M}_0^j, \mu_0(z^j)\right)_{j\in\{C,N,T\}}$, a competitive equilibrium consists of sequences of (i) value functions $\{\left(W_t^j(z^j)\right)_{j\in\{C,N,T\}}\}_{t=0}^T$, (ii) masses of producers and entrants $\{\left(\mathcal{M}_t^j, \tilde{\mathcal{M}}_t^j\right)_{j\in\{C,N,T\}}\}_{t=0}^T$, (iii) operation and exporting cut-off rules $\{\left(\underline{z}_t^j\right)_{j\in\{C,N,T\}}, \underline{z}_{x,t}^T\}_{t=0}^T$, (iv) measures $\{\left(\mu_t(z^j)\right)_{j\in\{C,N,T\}}\}_{t=0}^T$, (v) decision rules for firms $\{\left(l_t^{j,u}(z^j), l_t^{j,s}(z^j)\right)_{j\in\{C,N,T\}}\}_{t=0}^T$ and $\{R_t(z^C), C_t(z^C), N_t(z^N), T_t^d(z^T)\}_{t=0}^T$, (vi) decision rules for households $\{M_t, N_t, T_t^d, C_t^d\}_{t=0}^T$, and (vii) sequences of prices $\{w_t^u, w_t^s, P_t^R, P_t^N, P_t^T\}_{t=0}^T$, such that, for all $t = 1, ..., T$:

1. Given prices in (vii), the value functions (i), cut-off rules (iv), and decision rules (v) solve the firms' problem in each sector.

2. Given prices in (vii) and value functions (i), the sectoral masses of entrants satisfy the free-entry conditions (equations (A25), (A35), (A45)):

$$\hat{w}_t^j \hat{f}_e^j(\tilde{\mathcal{M}}_t^j) = \int_{\underline{z}_t^j}^{\infty} W_t^j\left(z^j\right) g\left(z^j\right) dz^j, \quad j \in \{C, N, T\}, \quad \forall t$$

3. Given prices in (vii), the sequences of distributions $\{\left(\mu_t(z^j)\right)_{j\in\{C,N,T\}}\}_{t=0}^T$ are consistent with the decision rules (v).

4. The sequences of wages satisfy the complementary slackness conditions (equations (A18)-(A19)) induced by the downward wage rigidity in both skilled and unskilled labor markets:

$$0 = \left(L_t^{k,C} + L_t^{k,N} + L_t^{k,T} - \overline{L}^k\right)\left(w_t^k - \chi w_{t-1}^k\right), \quad k \in \{u, s\}, \quad \forall t$$

5. The fixed resource market (equations (A28)) clears:

$$\bar{R} = \mathcal{M}_t^C \int_{\underline{z}_t^C}^{\infty} R_t(z^C) \mu_t^C(z^C) dz^C, \quad \forall t$$

6. The nontradable and domestic tradable goods markets (equations (A40) and (A50)) clear:

$$T_t^d = \left[\mathcal{M}_t^T \int_{\underline{z}_t^T}^{\infty} \left[q_{d,t}(z^T)\right]^{\rho} \mu_t^T(z^T) dz^T\right]^{\frac{1}{\rho}}, \quad \forall t$$
$$N_t = \mathcal{M}_t^N \int_{\underline{z}_t^N}^{\infty} N_t(z^N)\mu_t^N(z^N)dz^N, \quad \forall t$$

7. The aggregate resource constraint induce a law of motion for the net foreign asset position of the economy (balance of payments) that can be written as follows:

$$B_{t+1} = (1+r^*)B_t + TB_t$$
$$TB_t = P_t^C\left(\mathcal{M}_t^C \int_{\underline{z}_t^C}^{\infty} C_t(z^C)\mu_t^C(z^C)dz^C - C_t^d\right) + \mathcal{M}_t^T \int_{\underline{z}_{x,t}^T}^{\infty} p_t(z^T)q_{x,t}(z^T)\mu_t^T(z^T)dz^T - M_t$$

8. In period $t = T$ the economy has settled in the new steady state with a finite and stable net foreign asset position ($B_\tau = \overline{B} \quad \forall \tau \geq T$).

B.2.6 Transition Algorithm

Assumptions

- Economy is in stationary equilibrium at $t = 0$, associated with known P_0^C.
- Economy is in stationary equilibrium at $t = \infty$, associated with known P_∞^C.
- Full sequence $\{P_t^C\}_{t=1}^{\infty}$ is exogenously given. Transition is complete after T periods.

Algorithm

1. Fix T. Compute the initial steady state.
2. **Outer Loop.** Guess the marginal utility λ in the new steady state. Given λ we in fact obtain the full sequence $\{\lambda_t = \lambda\}_{t=1}^{T}$ from (A13) (permanent income).
3. For each level of λ, recover the implied new steady state.
4. **Inner Loop.** Guess sequences $\{w_t^u, w_t^s, P_t^R, P_t^N, P_t^T\}_{t=1}^{T}$.
5. **Backward Iteration Loop**. Use time-T value functions (at the new steady state) and the guessed sequences to find several decision rules. For each $t = T, ..., 1$.
   - Plug (A15), (A16) and (A17) into (A14) to solve analytically for M_t, and then compute the associated N_t, T_t^d and C_t^d.

- Get w_t^C, w_t^N, w_t^T, from (A22), (A32), (A41).
- Evaluate the value functions (A23), (A33), (A42), to get the operation cut-offs $\underline{z}_t^C$, $\underline{z}_t^N$, $\underline{z}_t^T$, using (A24), (A34), (A43), and the exporter cutoff $\underline{z}_{x,t}^T$ using (A44).
- Given value functions and cut-offs, recover the masses of entrants $\tilde{\mathcal{M}}_t^C$, $\tilde{\mathcal{M}}_t^N$ and $\tilde{\mathcal{M}}_t^T$, from the free entry conditions (A25), (A35), and (A45).

6. **Forward Iteration Loop**. Use the initial masses and distributions, the guesses, and the cut-off rules, to iterate the sectoral distributions forward. For each $t = 1, ..., T$.

   - Get the mass $\mathcal{M}_t^C$ and distribution $\mu_t^C(z)$ in the C sector using (A27) and (A26).
   - Get the mass $\mathcal{M}_t^N$ and distribution $\mu_t^N(s)$ in the N sector using (A37) and (A36).
   - Get the mass $\mathcal{M}_t^T$ and distribution $\mu_t^T(s)$ in the T sector using (A47) and (A46).

7. **Update Guessed Wages and Prices**

   - Get implied sequence $\{P_t^R\}_{t=1}^T$ from resource market clear (A28).
   - Get implied sequence $\{P_t^N\}_{t=1}^T$ from nontradable market clear (A40).
   - Get implied sequence $\{P_t^T\}_{t=1}^T$ from domestic tradable market clear (A50).
   - Get labor aggregates from (A29), (A30), (A38), (A39), (A48), (A49).
   - Get implied sequences $\{w_t^s, w_t^u\}_{t=1}^T$ jointly from both labor market clearings (A18) and (A19), assuming that downward wage rigidity is not binding (full employment).
   - Check and impose DWR on both wage sequences, if necessary.
   - Update guesses for wages and prices using a weighted average of the initial guess and the model-implied values.
   - Go back to step 4 and repeat until convergence.

8. **Update Guess for λ.**

   - Compute C_t and X_t^T from (A31) and (A51).
   - Compute the trade balance TB_t using (A21).
   - Compute the implied net foreign assets by iterating the balance of payment equation (A20) forward.
   - Check the transversality condition for bond holdings and update the guess for marginal utility λ using a bisection rule:
     - If the economy accumulates too many assets, decrease λ.
     - If the economy accumulates too much debt, increase λ.
   - Go back to step 2 and repeat until convergence.

B.3 Steady State System

$$\begin{aligned}
Exogenous(1) &= \{P^C\} \\
Endogenous(45) &= \{N, M, T^d, X^T, C, C^d, P^N, P^T, P^R, w^u, w^s, SP, ...\} = 12 \\
&= \{\hat{w}^C, L^{s,C}, L^{u,C}, W^C, \mu^C, \mathcal{M}^C, \tilde{\mathcal{M}}^C, \underline{z}^C, ...\} = 8 \\
&= \{\hat{w}^N, L^{s,N}, L^{u,N}, W^N, \mu^N, \mathcal{M}^N, \tilde{\mathcal{M}}^N, \underline{z}^C, ...\} = 8 \\
&= \{\hat{w}^T, L^{s,T}, L^{u,T}, W^T, \mu^T, \mathcal{M}^T, \tilde{\mathcal{M}}^T, \underline{z}^T, \underline{z}_x^T, ...\} = 9 \\
&= \{Y, TB, X, TBY, CY, CDY, XY, NY\} = 8
\end{aligned}$$

$$SP = \frac{w_s}{w_u} \tag{A52}$$

$$N = \left(\frac{\alpha^N}{P^N}\right)^{\frac{1}{1-\theta}} M \tag{A53}$$

$$T^d = \left(\frac{\alpha^T}{P^T}\right)^{\frac{1}{1-\theta}} M \tag{A54}$$

$$C^d = \left(\frac{\alpha^C}{P^C}\right)^{\frac{1}{1-\theta}} M \tag{A55}$$

$$(1-\kappa)\bar{L} = L^{s,C} + L^{s,N} + L^{s,T} \tag{A56}$$

$$\kappa\bar{L} = L^{u,C} + L^{u,N} + L^{u,T} \tag{A57}$$

$$r^*\bar{B} = -TB \tag{A58}$$

$$TB = X - M \tag{A59}$$

$$X = P^C\left(C - C^d\right) + X^T \tag{A60}$$

$$TBY = \frac{TB}{Y} \tag{A61}$$

$$CY = \frac{P^C C}{Y} \tag{A62}$$

$$CDY = \frac{P^C C^d}{Y} \tag{A63}$$

$$XY = \frac{X}{Y} \tag{A64}$$

$$NY = \frac{P^N N}{Y} \tag{A65}$$

$$Y = P^N N + P^T T^d + X^T + P^C C \tag{A66}$$

B.3.1 Commodity Sector

Optimal Decisions

$$\hat{w}^C = \left[\phi^C (w^u)^{1-\gamma} + (1-\phi^C)(w^s)^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A67}$$

$$C_i = \left(\xi^\xi \eta^\eta\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}^C)^{-\eta} \big(P^R\big)^{-\xi} (P^C)^{\xi+\eta}\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}}$$

$$R_i = \left(\xi^{1-\eta} \eta^\eta\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}^C)^{-\eta} \big(P^R\big)^{-(1-\eta)} P^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}}$$

$$l_i^C = \left(\xi^\xi \eta^{1-\xi}\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}^C)^{-(1-\xi)} \big(P^R\big)^{-\xi} P^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} + f^C$$

$$l_i^{s,C} = (1-\phi^C) \left(\frac{\hat{w}^C}{w^s}\right)^\gamma l_i^C$$

$$l_i^{u,C} = \phi^C \left(\frac{\hat{w}^C}{w^u}\right)^\gamma l_i^C$$

$$\pi_i = (1-\xi-\eta) \left(\xi^\xi \eta^\eta\right)^{\frac{1}{1-\xi-\eta}} \left[(\hat{w}^C)^{-\eta} \big(P^R\big)^{-\xi} P^C\right]^{\frac{1}{1-\xi-\eta}} \left[z_i^C\right]^{\frac{1}{1-\xi-\eta}} - \hat{w}^C f^C$$

Value Function and Cutoff

$$W^C(z^C) = \max\left\{0,\ \frac{\pi(z^C)}{1-\beta(1-\delta^C)}\right\} \tag{A68}$$

$$W^C(\underline{z}^C) = 0 \tag{A69}$$

Free entry condition

$$\hat{w}^C f_e^C = \int_{\underline{z}^C}^{\infty} W^C(z^C) g(z^C) dz^C \tag{A70}$$

Stationary Distribution

$$\mu^C(z^C) = \begin{cases} \dfrac{g(z^C)}{1-G(\underline{z}^C)} & \text{, if } z^C \geq \underline{z}^C \\ 0 & \text{, otherwise} \end{cases} \tag{A71}$$

Stationary Mass of Firms

$$\delta^C \mathcal{M}^C = \left[1 - \mathcal{F}\big(\underline{z}^C\big)\right] \tilde{\mathcal{M}}^C. \tag{A72}$$

Aggregate variables

- Total natural resource constraint (Fixed Supply)

$$\bar{R} = \mathcal{M}^C \int_{\underline{z}^C}^{\infty} R(z^C)\mu^C(z^C)dz^C \tag{A73}$$

- Total skilled and unskilled labor for production

$$L_p^{s,C} = \mathcal{M}^C \int_{\underline{z}^C}^{\infty} l^{s,C}(z^C)\mu^C(z^C)dz^C$$
$$L_p^{u,C} = \mathcal{M}^C \int_{\underline{z}^C}^{\infty} l^{u,C}(z^C)\mu^C(z^C)dz^C$$

- Total skilled and unskilled labor for fixed entry cost

$$L_e^{s,C} = \tilde{\mathcal{M}}^C(1-\phi^C)\left(\frac{\hat{w}^C}{w^s}\right)^\gamma f_e^C$$
$$L_e^{u,C} = \tilde{\mathcal{M}}^C\phi^C\left(\frac{\hat{w}^C}{w^u}\right)^\gamma f_e^C$$

- Total skilled and unskilled labor demand

$$L^{s,C} = L_p^{s,C} + L_e^{s,C} \tag{A74}$$
$$L^{u,C} = L_p^{u,C} + L_e^{u,C} \tag{A75}$$

- Total Commodity Output

$$C = \mathcal{M}^C \int_{\underline{z}^C}^{\infty} C(z^C)\mu^C(z^C)dz^C \tag{A76}$$

B.3.2 Nontradable Sector

Optimal decisions

$$\hat{w}^N = \left[\frac{\phi^N}{(w^u)^{\gamma-1}} + \frac{1-\phi^N}{(w^s)^{\gamma-1}}\right]^{-\frac{1}{\gamma-1}} \tag{A77}$$

$$l_i^N = \left(\alpha\, z_i^N\, \frac{P^N}{\hat{w}^N}\right)^{\frac{1}{1-\alpha}} + f^N$$

$$l_i^{s,N} = (1-\phi^N)\left(\frac{\hat{w}^N}{w^s}\right)^{\gamma} l_i^N$$

$$l_i^{u,N} = \phi^N \left(\frac{\hat{w}^N}{w^u}\right)^{\gamma} l_i^N$$

$$N_i = \left(\alpha\ \left[z_i^N\right]^{\frac{1}{\alpha}}\ \frac{P^N}{\hat{w}^N}\right)^{\frac{\alpha}{1-\alpha}}$$

$$\pi_i = \alpha^{\frac{\alpha}{1-\alpha}}\,(1-\alpha)\,(\hat{w}^N)^{-\frac{\alpha}{1-\alpha}}\,(P^N)^{\frac{1}{1-\alpha}}\ \left[z_i^N\right]^{\frac{1}{1-\alpha}} - \hat{w}^N f^N$$

Value Function and Cutoff

$$W^N\left(z^N\right) = \max\left\{0, \frac{\pi(z^N)}{1-\beta(1-\delta^N)}\right\} \tag{A78}$$

$$W^N\left(\underline{z}^N\right) = 0 \tag{A79}$$

Free entry condition

$$\hat{w}^N f_e^N = \int_{\underline{z}^N}^{\infty} W^N(z^N) g(z^N) dz^N \tag{A80}$$

Stationary Distribution

$$\mu^N(z^N) = \begin{cases} \dfrac{g(z^N)}{1-G(\underline{z}^N)} & \text{, if } z^N \geq \underline{z}^N \\ 0 & \text{, otherwise} \end{cases} \tag{A81}$$

Stationary Mass of Firms

$$\delta^N \mathcal{M}^N = \left[1 - G\big(\underline{z}^N\big)\right]\tilde{\mathcal{M}}^N \tag{A82}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$L_p^{s,N} = \mathcal{M}^N \int_{\underline{z}^N}^{\infty} l^{s,N}(z^N)\mu^N(z^N)dz^N$$
$$L_p^{u,N} = \mathcal{M}^N \int_{\underline{z}^N}^{\infty} l^{u,N}(z^N)\mu^N(z^N)dz^N$$

- Total skilled and unskilled labor for fixed entry cost

$$L_e^{s,N} = \tilde{\mathcal{M}}^N(1-\phi^N)\left(\frac{\hat{w}^N}{w^s}\right)^{\gamma} f_e^C$$
$$L_e^{u,N} = \tilde{\mathcal{M}}^N\phi^N\left(\frac{\hat{w}^N}{w^u}\right)^{\gamma} f_e^C$$

- Total skilled and unskilled labor demand

$$L^{s,N} = L_p^{s,N} + L_e^{s,N} \tag{A83}$$
$$L^{u,N} = L_p^{u,N} + L_e^{u,N} \tag{A84}$$

- Total output (net of operational cost)

$$N = \mathcal{M}^N \int_{\underline{z}^N}^{\infty} N(z^N)\mu^N(z^N)dz^N \tag{A85}$$

B.3.3 Tradable Sector

Optimal decisions

$$\begin{aligned}
\hat{w}^T &= \left[\phi^T (w^u)^{1-\gamma} + (1-\phi^T)(w^s)^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \qquad \text{(A86)} \\
p(z^T) &= \frac{\hat{w}^T}{\rho z^T} \\
q_d\left(z^T\right) &= T^d \left(\frac{P^T \rho z^T}{\hat{w}^T}\right)^{\sigma} \\
q_x\left(z^T\right) &= \gamma_0 \left(\frac{\rho z^T}{\hat{w}^T}\right)^{\sigma} \\
l_d^{s,T}\left(z^T\right) &= (1-\phi^T)\left(\frac{\hat{w}^T}{w^s}\right)^{\gamma}\left[f_d^T + T^d (P^T)^{\sigma}\left(\frac{\rho}{\hat{w}^T}\right)^{\sigma}(z^T)^{\sigma-1}\right] \\
l_d^{u,T}\left(z^T\right) &= \phi^T \left(\frac{\hat{w}^T}{w^u}\right)^{\gamma}\left[f_d^T + T^d (P^T)^{\sigma}\left(\frac{\rho}{\hat{w}^T}\right)^{\sigma}(z^T)^{\sigma-1}\right] \\
l_x^{s,T}\left(z^T\right) &= (1-\phi^T)\left(\frac{\hat{w}^T}{w^s}\right)^{\gamma}\left[f_x^T + \gamma_0\left(\frac{\rho}{\hat{w}^T}\right)^{\sigma}(z^T)^{\sigma-1}\right] \\
l_x^{u,T}\left(z^T\right) &= \phi^T \left(\frac{\hat{w}^T}{w^u}\right)^{\gamma}\left[f_x^T + \gamma_0\left(\frac{\rho}{\hat{w}^T}\right)^{\sigma}(z^T)^{\sigma-1}\right] \\
r_d\left(z^T\right) &= P^T T^d \left[\frac{P^T \rho z^T}{\hat{w}^T}\right]^{\sigma-1} \\
\pi_d\left(z^T\right) &= \frac{r_d\left(z^T\right)}{\sigma} - \hat{w}^T f_d^T \\
r_x\left(z^T\right) &= \gamma_0 \left(\frac{\rho z^T}{\hat{w}^T}\right)^{\sigma-1} \\
\pi_x\left(z^T\right) &= \frac{r_x\left(z^T\right)}{\sigma} - \hat{w}^T f_x^T
\end{aligned}$$

q_d and q_x: optimal output sold in domestic, and foreign market, resp..

$l_j^{s,T}$ and $l_j^{u,T}$: optimal skilled and unskilled labor demand to produce ($j = d, x$) tradable goods.

r_d and r_x: revenue from domestic and foreign market, resp..

π_d and π_x: profits from domestic and foreign market, resp..

Revenue of a firm

$$r\left(z^T\right) = \begin{cases} r_d\left(z^T\right) & \text{, if nonexporter} \\ \\ r_d\left(z^T\right) + r_x\left(z^T\right) & \text{, if exporter,} \end{cases}$$

Profits of a firm

$$\pi\left(z^T\right) = \begin{cases} \pi_d\left(z^T\right) & \text{, if nonexporter} \\ \pi_{ex} = \pi_d\left(z^T\right) + \pi_x\left(z^T\right) & \text{, if exporter} \end{cases}$$

Value functions

$$W^T\left(z^T\right) = \max\left\{W_d^T, W_{ex}^T\right\} \tag{A87}$$

$$W_d^T(z^T) = W_d^T\left(z^T\right) = \max\left\{0, \frac{\pi_d\left(z^T\right)}{1-(1-\delta^T)\beta}\right\}$$

$$W_{ex}^T(z^T) = W_{ex}^T\left(z^T\right) = \max\left\{0, \frac{\pi_{ex}\left(z^T\right)}{1-(1-\delta^T)\beta}\right\}$$

Cut-offs

$$0 = W_d^T\left(\underline{z}^T\right) \tag{A88}$$

$$0 = \pi_x\left(\underline{z}_x^T; \hat{w}^T\right) \tag{A89}$$

Free entry condition

$$\hat{w}^T f_e^T = \int_{\underline{z}^T}^{\infty} W^T\left(z^T\right) g\left(z^T\right) dz^T \tag{A90}$$

Stationary Distribution

$$\mu^T\left(z^T\right) = \begin{cases} \dfrac{g(z^T)}{1-G\left(\underline{z}^T\right)} & \text{, if } z^T \geq \underline{z}^T \\ \\ 0 & \text{, otherwise,} \end{cases} \tag{A91}$$

Stationary Mass of Firms

$$\delta^T \mathcal{M}^T = \left[1 - G(\underline{z}^T)\right] \tilde{\mathcal{M}}^T \tag{A92}$$

Aggregate variables

- Total skilled and unskilled labor demand to produce tradable goods sold in domestic market

$$L_{d,p}^{s,T} = \mathcal{M}^T \int_{\underline{z}^T}^{\infty} l_d^{s,T}(z^T)\mu^T(z^T)dz^T$$
$$L_{d,p}^{u,T} = \mathcal{M}^T \int_{\underline{z}^T}^{\infty} l_d^{u,T}(z^T)\mu^T(z^T)dz^T$$

- Total skilled and unskilled labor demand to produce tradable goods exported

$$L_{x,p}^{s,T} = \mathcal{M}^T \int_{\underline{z}_x^T}^{\infty} l_x^{s,T}(z^T)\mu^T(z^T)dz^T$$
$$L_{x,p}^{u,T} = \mathcal{M}^T \int_{\underline{z}_x^T}^{\infty} l_x^{u,T}(z^T)\mu^T(z^T)dz^T$$

- Total skilled and unskilled labor for fixed entry cost

$$L_e^{s,T} = \tilde{\mathcal{M}}^T(1-\phi^T)\left(\frac{\hat{w}^T}{w^s}\right)^{\gamma} f_e^T$$
$$L_e^{u,T} = \tilde{\mathcal{M}}^T\phi^T\left(\frac{\hat{w}^T}{w^u}\right)^{\gamma} f_e^T$$

- Total skilled and unskilled labor demands

$$L^{s,T} = L_{d,p}^{s,T} + L_{x,p}^{s,T} + L_e^{s,T} \tag{A93}$$
$$L^{u,T} = L_{d,p}^{u,T} + L_{x,p}^{u,T} + L_e^{u,T} \tag{A94}$$

- Total tradable good outputs sold in domestic market

$$T^d = \left[\mathcal{M}^T \int_{\underline{z}^T}^{\infty} \left[q_d(z^T)\right]^{\rho} \mu^T(z^T)dz^T\right]^{\frac{1}{\rho}} \tag{A95}$$

- Total tradable good output sold in foreign market (P*Q)

$$X^T = \mathcal{M}^T \int_{\underline{z}_x^T}^{\infty} p(z^T)q_x(z^T)\mu^T(z^T)dz^T \tag{A96}$$

B.3.4 Calibration Algorithm

The steady state of the exogenous commodity price P^C is given and normalized to 1. We target seven steady states variables based on macrodata for Brazil: the trade-balance-to-GDP ratio $(\overline{TBY})$, commodity production-to-GDP ratio $(\overline{CY})$, total exports-to-GDP ratio $(\overline{XY})$, domestic commodity demand-to-

GDP ratio $(\overline{CDY})$, nontradable output-to-GDP ratio $(\overline{NY})$, the domestic tradable price $(\overline{P}^T)$, and a normalized value for total GDP $(\overline{Y})$ by endogenizing the following seven parameters: $\overline{B}$, $\overline{R}$, γ_0, α^C, α^N, α^T, and $\overline{L}$, respectively. We also target four relevant ratios based on the microdata: the economy-wide skill premium $\left(SP = \frac{w_s}{w_u}\right)$ and the ratios between skilled and skilled labor $\left(\frac{l_i^{s,j}}{l_i^{u,j}}\right)$ in each sector $j = C, N, T$, by endogenizing the values of κ and ϕ^j, respectively. Importantly, from the individual labor demands in any sector $j = C, N, T$, note that we can write:

$$\frac{l_i^{s,j}}{l_i^{u,j}} = \frac{(1-\phi^j)}{\phi^j}\left(\frac{w_u}{w_s}\right)^{\gamma} = \frac{(1-\phi^j)}{\phi^j}\left(\frac{1}{SP}\right)^{\gamma}, \tag{A97}$$

so that given targets for the skill premium and relative labor demands, we can back out a unique ϕ_j for each $j = C, N, T$.

Algorithm

1. Set parameters in Table 4 and targeted values in Table 5.
2. Given precalibrated parameters and targets, we back out ϕ^j for $j = C, N, T$, using (A97).
3. **Main Calibration Loop:** Guess values for the parameters in Table 6.
4. **Steady State Loop:** Guess values for (w_u, κ).
   - Get w_s from (A52).
   - Given targets, get directly $TB = \overline{TBY} \cdot \overline{Y}$ from (A61), $C = \frac{\overline{CY} \cdot \overline{Y}}{P^C}$ from (A62), $C^d = \frac{\overline{CDY} \cdot \overline{Y}}{P^C}$ from (A63), $X = \overline{XY} \cdot \overline{Y}$ from (A64).
   - Get imports $M = X - TB$ from (A59), and $X^T = X - P^C(C - C^d)$ from (A60).
   - Recover required $\overline{B}$ consistent with targeted $\overline{TBY}$ using (A58): $\bar{B} = -\frac{TB}{r^*}$.
   - Given C^d and M recover α^C consistent with $\overline{CDY}$ target from (A55).
   - Get sectoral wages $\hat{w}^C$, $\hat{w}^N$, $\hat{w}^T$ from (A67), (A77), (A86).
   - **Inner Loop 1**: Solve for P^R using the FEC for C sector (A70). This requires to evaluate the value function from (A68), get the cutoff from (A69), and use the stationary distribution (A71).
   - Given C, get mass of producers $\mathcal{M}^C$ from commodity market clear (A76).
   - Get the mass of entrants $\tilde{\mathcal{M}}^C$ and sectoral labor aggregates from (A72), (A74) and (A75).
   - Recover required $\overline{R}$ consistent with targeted $\overline{CY}$ from the resource market clearing (A73).

- **Inner Loop 2**: Solve for P^N using the FEC for N sector (A80). This requires to evaluate the value function from (A78), get the cutoff from (A79), and use the stationary distribution (A81).
- Given P^N, get $N = \frac{\overline{NY} \cdot \overline{Y}}{P^N}$ from (A65).
- Given P^N, N, and M recover α^N consistent with targeted $\overline{NY}$ from (A53).
- Given N, get mass of producers from nontradables market clear (A85).
- Get the mass of entrants and sectoral labor aggregates from (A82), (A83) and (A84).
- Get T^d from the GDP definition (A66).
- Given T^d and M recover α^T consistent with targeted $\overline{P}^T$ from (A54).
- Evaluate T sector domestic value function to get the operational cutoff from (A88).
- Get mass of producers from domestic tradables market clear (A95), using the stationary distribution (A91).
- Get the mass of entrants and sectoral labor aggregates from (A92), (A93) and (A94).
- **Inner Loop 3**: Solve for the required γ_0 consistent with $\overline{XY}$ target, using the market clearing condition for exported tradables (A96). To do so, we need to compute the threshold for exporters via (A89).
- Given γ_0, evaluate the T sector value function (A87), which will be used below in the FEC for the T sector as residual.
- Recover the required $\overline{L}$ consistent with the aggregate GDP target $\overline{Y}$ from the skilled labor market clearing condition (A56).

5. **Check Steady State Residuals**

- Use FEC T (A90) and Labor Market Clear Unskilled (A57) as residuals to discipline the guesses for w_u and κ.
- Iterate over steps 4-5 until convergence.

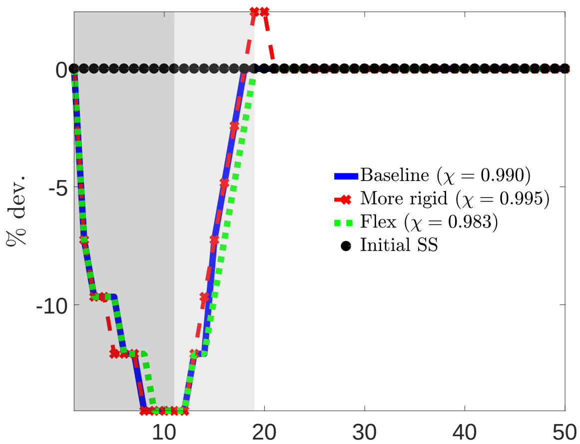
6. **Evaluate Loss Function**

- Get model-implied moments and construct the loss function as the maximum of the absolute percentage distance between model and data targets in Table 6.
- Iterate over steps 3-6 until the maximum absolute distance is less than 10%.

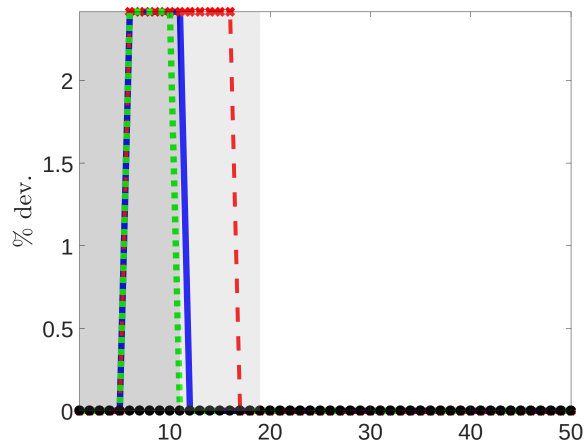
7. Outside the steady state, calibrate the elasticity of the entry cost function (γ_e) to match the observed volatility of entry rates in the commodity sector in the data, during the transition exercise.

B.4 Additional Transition Outcomes

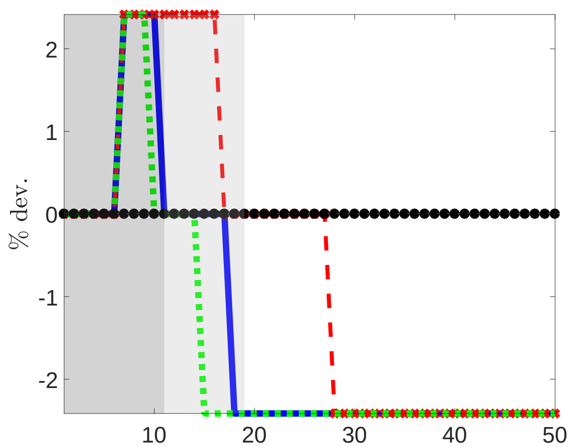
Figure A8 shows the dynamics of the productivity cut-offs in each sector. Note that during the commodity boom there is less selection into entry in the commodity sector but more selection into entry in the other two sectors. As expected from the superposition of the cost and wealth channel, the largest increase in selection is on the exporting margin. Economies with more labor rigidity show more persistent impacts on selection in the tradable and the nontradable sectors.



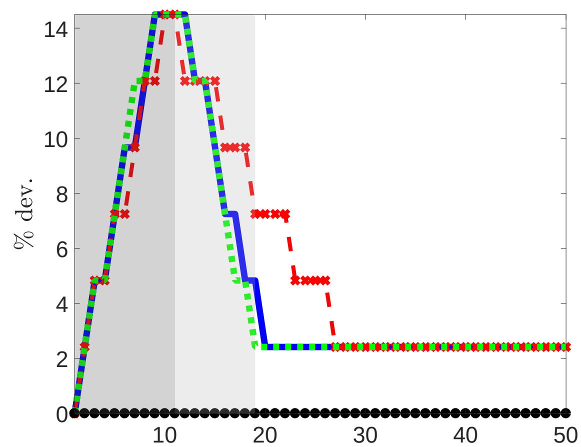
Entry Productivity Cut-Off C



Entry Productivity Cut-Off N



Entry Productivity Cut-Off T



Exporting Productivity Cut-Off T

Figure A8: Productivity Cut-offs

Figure A9 complements the analysis in the main text by showing the path of wages and unemployment by skill group. During the boom, the skill premium decreases as the skilled wage rises by less than the unskilled wage. The larger increase in the unskilled wage during the boom increases the likelihood of binding downward wage rigidity for unskilled workers. In fact, only in the most rigid economy we see skilled unemployent. Even in that case, the unemployment rate among unskilled workers increases by three times more than that for skilled workers.

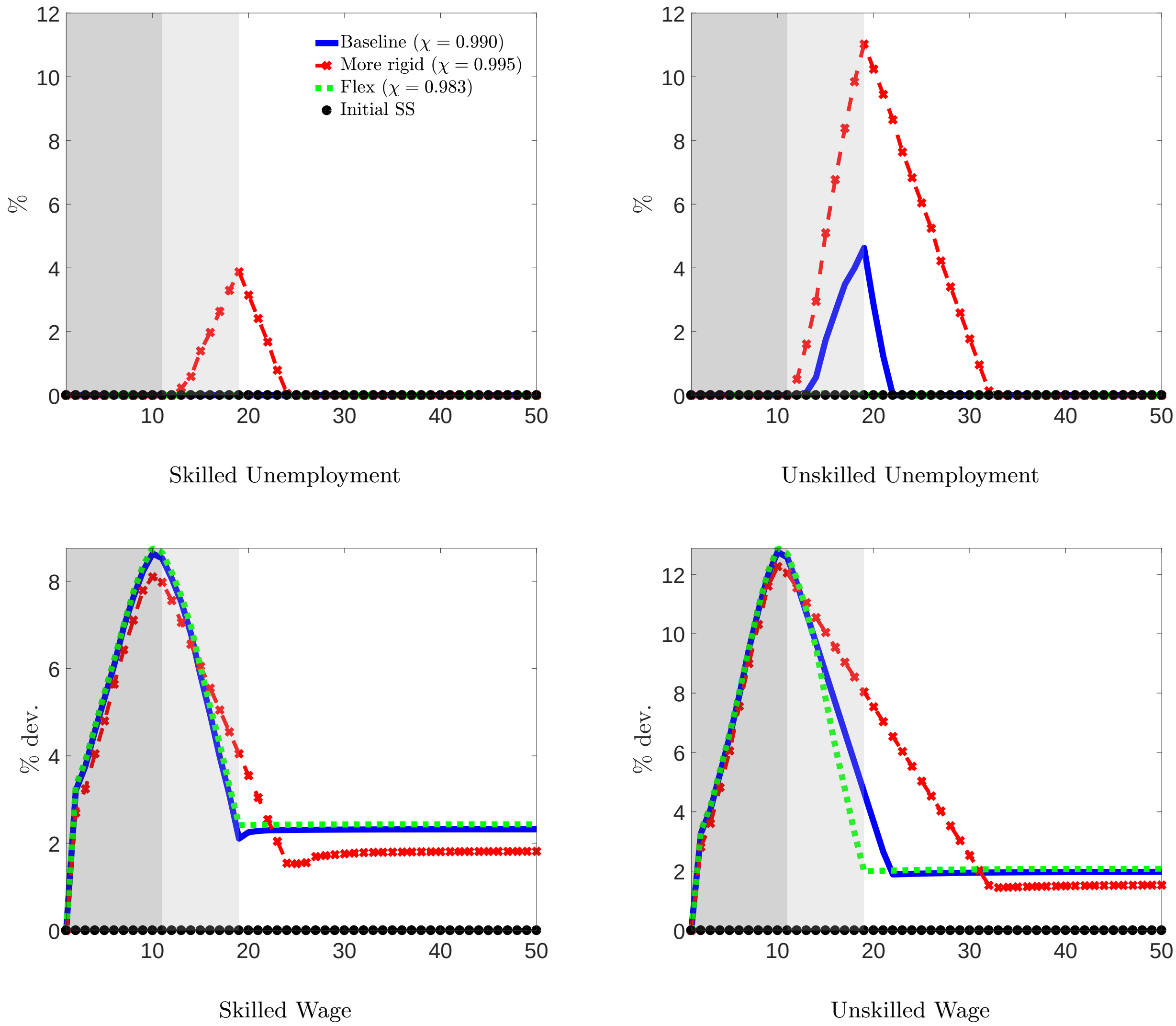


Figure A9: Unemployment and Wages by Skill

Figure A10 illustrates the path of the share of total employment, output, and the mass of entrants in the tradable and nontradable sectors. The increase in employment and output in the nontradable sector relative to the tradable sector shown in the main text is driven by a smaller decrease in this outcomes in the nontradable sector than in the tradable sector. There is a large fall in the mass of entrants in the tradable sector, while in the nontradable sector entry has a non-monotonic behavior during the boom and decreases four times less than the mass of entrants in the tradable sector.

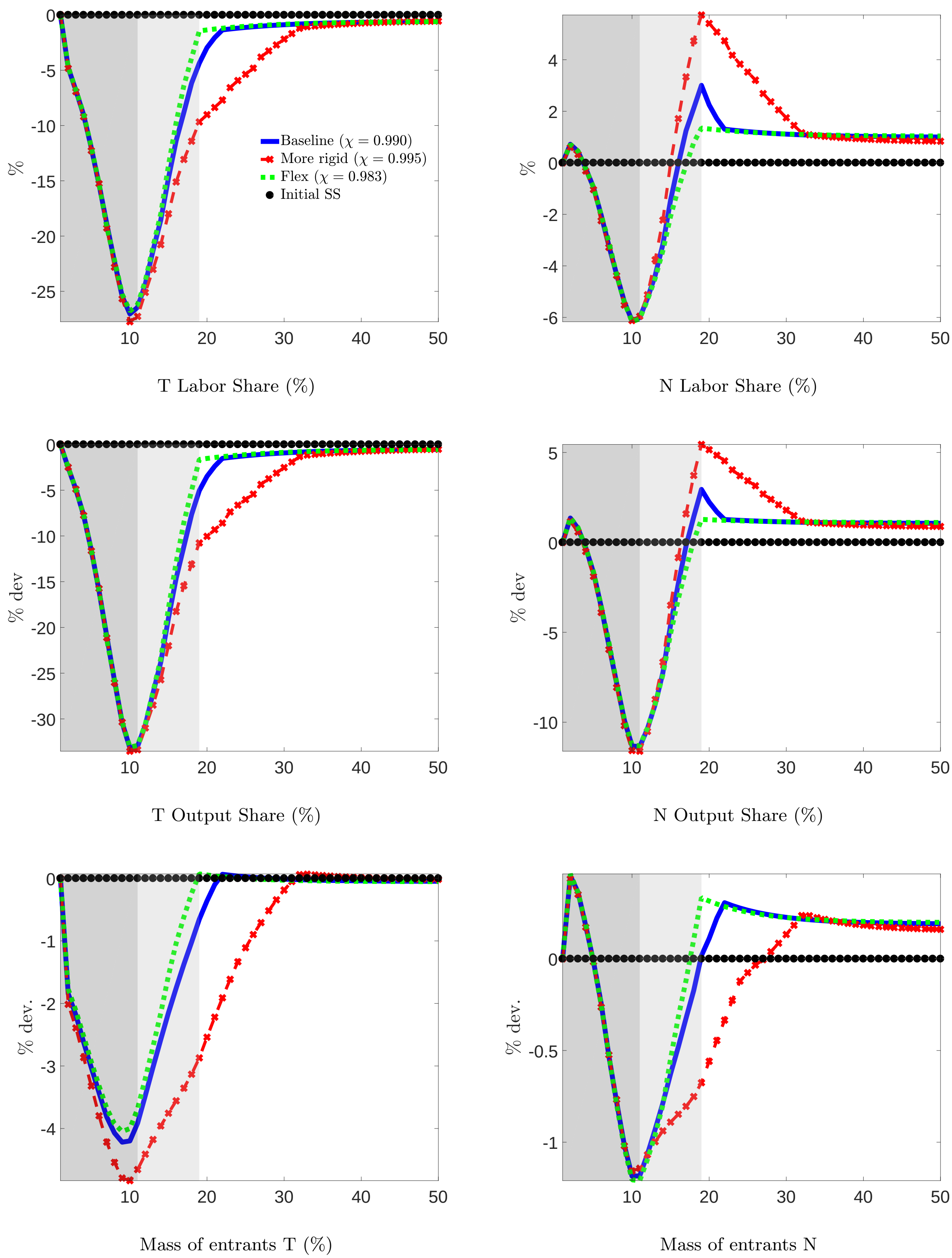


Figure A10: Sectoral Contagion

B.5 Real Outcomes

This section decomposes the real effects of commodity cycles into sectoral responses using an alternative measure of real GDP than that used in the main text. In this appendix we measure real GDP using a chained Fisher index. The relative expansion of the nontradable sector and the deep recession at the end of the cycle described in the main text are robust to this and other measures of real GDP.

Figure A11 shows the evolution of real production in the economy. Panel A11a shows the evolution of commodity production. The dynamics of commodity production follow the dynamic of the exogenous commodity price reaching a 40% increase at the peak of the boom. Commodity production decreases up to 5% in the most rigid economy at the end of the boom. Panel A11b shows a moderate expansion in nontradable production at the start of the cycle that quickly reverts to a 2.5% contraction. The recovery is faster in the most flexible economy. Moreover, as the more flexible economy is wealthier at the end of the cycle, nontradable consumption and production are also higher in the long-run in the most flexible economy. Panel A11c illustrates the response of the production of tradable varieties using the initial steady state prices. The negative cycle of the tradable sector is impressive: tradable production falls by more than 25%. therefore, the relative importance of the nontradable sector increases during the episode. Firm heterogeneity and monopolistic competition play an important role in amplifying the cost and wealth channel that drive this decline. In fact, there is a one to one pass-through between the effective wage wage in the tradable sector and the price of each variety while the pass-trough to quantity is governed by $\sigma > 1$. Therefore, the decrease in nominal production of tradables is mostly driven by a decrease in real production. Because the cost and demand channels are the underlying drivers of this relative decline, it also holds if we allow for differentiated varieties among nontradable goods. Even in the flexible economy and in contrast to Kehoe and Ruhl [2008], every sector has significant real responses to the commodity cycle. Firm heterogeneity (no sector has constant returns to scale in the aggregate) and the sluggish reactions introduced by the entry margin are behind this difference. Moreover, the tradable sector sees a larger response due to its market structure. In the main text we use the consumption deflator to aggregate these responses, given that the main focus of our analysis is on welfare. Panel A11d complements the analysis in the main text using the chained Fisher index, following the suggestion of Kehoe and Ruhl [2008]. In this case, the decrease in the tradable quantity dominates the immediate response due to two factors. First, the commodity sector represents a small share of the economy, implying a moderate pass-through of its expansion. Second, perfect foresight implies an immediate reaction in prices and quantities in the tradable sector due to the news component of the shock (the representative household foresees the increase in income and runs a trade deficit on impact) while the commodity price, and therefore entry and production, increase smoothly. After the initial correction in real output, the economy grows steadily up to 1% until the recession hits. As noted by Kehoe and Ruhl [2008], input frictions can deliver a strong pass-through between terms of trade shocks and real outcomes. In our analysis, the baseline economy exhibits a recession of 3% in real terms at the end of the super-cycle. Therefore, future research can use this framework to study the pass-through of commodity prices to real output and measured TFP. In fact, our framework suggest a moderate TFP expansion during booms accompanied with a potentially large and persistent TFP decline during the bust.

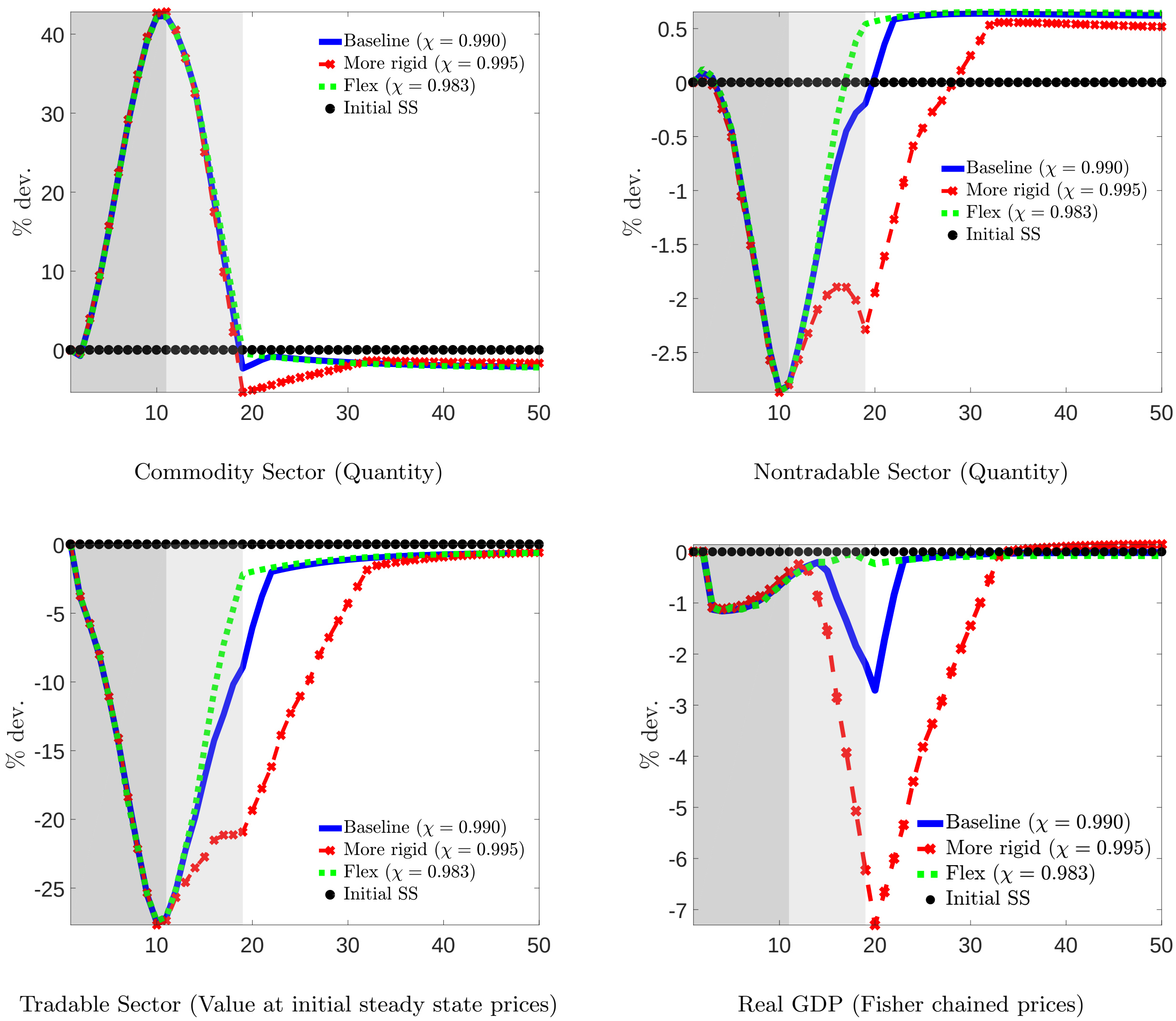


Figure A11: Real Outcomes