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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: a wealth channel, through which higher commodity prices increase domestic demand, and a cost channel, through which they induce wage increases. 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, two-region model with heterogeneous firms and workers to further quantify the mechanisms and evaluate welfare. A counterfactual economy in which commodity booms are purely endowment shocks experiences only 45% of the intersectoral labor reallocation between tradables and nontradables, and 40% of the within-tradables labor reallocation between domestic and exported production. Labor market frictions lead to persistent unemployment as the boom fades, and as a result the welfare gains obtained from a commodity super-cycle are 50% lower relative to those which would be obtained under a fully-flexible labor market.

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1 Introduction

Global commodity prices are a fundamental source of volatility for emerging markets. Commodity price super-cycles evolve at lower frequencies than regular business cycles with booms often lasting more than a decade. These super-cycles explain a third of the variance in output [Fernández et al., 2017b] and often end in deep recessions and slow recoveries [Reinhart et al., 2016]. The literature has typically abstained from micro-founding their transmission channels to the economy. In this paper, we fill this gap by empirically identifying two key transmission channels of commodity super-cycles and studying their effects on labor reallocation and aggregate outcomes.

Firm and sector heterogeneity play a central role in our strategy to identify these two channels. First, during a commodity price boom, the increase in wealth leads to higher spending, and the response to this *wealth* channel is heterogeneous as it benefits more firms that sell their output locally (nonexporters and firms in low-tradability industries). Second, a commodity price boom induces a *cost* channel, operating through an increase in wages in response to an expansion in the labor demand of the commodity sector. Because the commodity sector in Brazil is relatively unskilled-intensive, a commodity price boom lowers the skill premium, increasing the relative cost of less skill-intensive industries. While these two channels can be traced back to the characterization of the Dutch disease by Corden and Neary [1982], ours is the first study to introduce this heterogeneity and to exploit it to identify the existence of these channels using granular data for all sectors in the economy.[1,2]

Our empirical results are drawn from the experience of Brazil during 1999-2013, which is an ideal setting for understanding the mechanisms behind the transmission of commodity price cycles. During this period, the country faced large commodity price fluctuations. This economy has been historically characterized by substantial 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. The price of the local commodity basket is therefore 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 show that firms operating in less skill-intensive industries decrease employment during a commodity boom relative to firms in more skill-intensive industries. To identify the wealth channel, we focus

[1] Our *cost channel* is equivalent to Corden and Neary [1982]'s *resource movement effect*. In line with Alberola and Benigno [2017], we extend the original spending channel to allow for consumption smoothing with an endogenous current account and denote it *wealth channel*.

[2] The term 'Dutch disease' refers to the adverse effect of a boom in a resource sector on other sectors of the economy.

on the manufacturing sector and show that firms selling their output locally expand relative to those exporting or selling to other regions. We consider several alternative mechanisms as well as confounding shocks that may have affected manufacturing or service firms during this period. These include regional trends of trade liberalization, regional variation on import penetration from China, exchange rates, interest rates and financial conditions, and intersectoral productions linkages, among several others. The strength of our main channels is robust to these other forces.

This empirical identification of the transmission channels motivates our quantitative framework. We introduce a three-sector (commodity, manufacturing, and services) small open economy model, which extends the quantitative international finance literature that studies commodity cycles (e.g., Alberola and Benigno [2017]) in at least four dimensions. First, we deviate from the representative firm paradigm by including heterogeneous firms. Within the manufacturing sector, an export productivity cutoff divides firms into exporters and nonexporters, which allows us to capture the differential exposure to the wealth channel. Second, because the cost channel operates through differences in skill intensity across sectors, our model allows for heterogeneous workers (skilled and unskilled labor). Third, to account for regional variation in exposure to commodity prices, we model a two-region small open economy producing region-specific commodities, with both migration and interregional trade responding to commodity price fluctuations. Finally, because of the central role of labor markets and the pervasive labor market frictions in emerging economies, we include downward nominal wage rigidity in the model. Coupled with a managed float exchange rate regime -as Brazil has had during the period we study- this nominal rigidity can translate into real wage rigidity and unemployment. 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 account properly for the wealth channel.[3] Its different elements provide a tight link to the empirical setting described earlier.

We calibrate our model to the Brazilian economy. We assume the two regions are initially symmetric but face very different commodity price cycles, which are calibrated to the prices experienced by Brazil's two largest states: Sao Paulo and Minas Gerais. These two states are contiguous and account for about half of Brazil's employment. To discipline the model, we explicitly target the heterogeneous skill intensities across sectors and the fraction of exporters in manufacturing, interregional trade and migration flows, and several other firm-level and macroeconomic moments.

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

We test the validity of the model contrasting it to nontargeted outcomes. The model is able to replicate the dynamics of the regional skill premium, the reallocation of labor between sectors, and the differential evolution of employment in exporting versus nonexporting firms in response to a commodity price super-cycle. With the calibrated model, we perform a general equilibrium counterfactual to asses the importance of the labor market as a transmission mechanism. A counterfactual economy without transmission through the labor market (in which commodity booms are purely endowment shocks) sees 45% of the intersectoral labor reallocation between tradables and nontradables found in the baseline economy, and 40% of the within-tradables labor reallocation between domestic and exported production. Therefore, while the literature has frequently understood commodity price cycles as pure endowment shocks, our results show that incorporating contagion through the labor market is paramount.

Finally, from an aggregate perspective, we show how the bust in a commodity price cycle leads to unemployment and a recession. 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. The spike in unemployment caused by labor market rigidity reduces by half the welfare gains obtained from the commodity super cycle in comparison to a fully flexible labor market. Consequently, the cross-country variation in the severity of commodity busts could be attributed in part to heterogeneity in labor market rigidity.

Related Literature Our paper builds 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 super-cycles [Reinhart et al., 2016, Shousha, 2016, Fernández et al., 2017a, Drechsel and Tenreyro, 2017, Alberola and Benigno, 2017, Fernández et al., 2020, Kohn et al., 2020]. We contribute on the empirical and the modeling sides to this literature.

On the empirical side, we identify the classic cost and wealth transmission channels proposed by Corden and Neary [1982]. To do so, we combine a novel empirical strategy, a quasi-natural experiment, and rich administrative microdata. Our empirical strategy extends previous studies that have focused on cross-country evidence [Sachs and Warner, 1995, Harding and Venables, 2016, Fernández et al., 2017b] and relies instead on variation in exposure to commodity price fluctuations across regions within a country. In addition, our identification strategy is based on the new insight that commodity price fluctuations have *heterogeneous* impacts across sectors and across firms. It is this heterogeneity, which we incorporate to the Dutch disease framework, that is key to the identification of the transmission mechanisms. A second useful element of our empirical work is the context. We study the large boom of the 2000s, during which Brazilian regions experienced different commodity prices due to differences in their economic structure. Finally, the microdata we use have the novelty of covering not only the manufacturing sector, but also the service and commodity sectors, left out in previous work on this topic but where most individuals are employed. Our use of regional rather than cross-country variation and our microeconomic approach connects our work to the literature examining the consequences of local economic shocks [Autor et al., 2013, Dix-Carneiro and Kovak, 2017, Costa et al., 2016].[4] Closer to our study, Allcott and Keniston [2018] find a positive impact of local oil and gas booms in the U.S. on the manufacturing sector. In their paper, the positive effect on the manufacturing sector is driven by locally-traded subsectors and those with upstream linkages to oil and gas. We find a similar pattern in the manufacturing sector in our data and show that our main results are robust to controlling for these mechanisms. Also related to our work, Faber and Gaubert [2019] study the impact of the expansion of tourism in Mexico on local manufacturing.

Our model features the same heterogeneity that enables our empirical identification. The international finance elements of our model are mostly related to Alberola and Benigno [2017]. They extend the framework of Corden and Neary [1982] to a dynamic multisector model with representative firms featuring endogenous growth to study structural long-run changes driven by temporary commodity booms. We abstract from endogenous growth and extend their framework to include heterogeneous firms and selection into exporting in the spirit of Ghironi and Melitz [2005] and Alessandria and Choi [2007].[5] Because our empirical analysis uses regional variation, and general equilibrium effects may act through interregional trade and migration, we consider a multiregion framework. Our two-region model allows for domestic migration and trade between regions. In this regard, we include features from dynamic models of economic geography and trade such as Caliendo et al. [2019] while maintaining a fully endogenous current account.[6] Because of the central role of local labor markets in the transmission of commodity super-cycles and the frictional nature of labor markets in emerging economies, we include downward nominal wage rigidity as in

[4] Adão [2015] also exploits regional exposure to commodity prices in Brazil, with the different goal of quantifying the distributional effects of the sorting of workers across sectors

[5] We add to this literature allowing for entry and exit not only into export markets but also into the domestic market, which is a margin of adjustment we observe in the data.

[6] More broadly, 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 the consequences of financial integration [Gopinath et al., 2017, Varela, 2015], the response of trade flows to devaluations [Alessandria et al., 2013], sudden stops [Ates and Saffie, 2020], and to measure news shock arising from commodity discoveries [Arezki et al., 2017].

Schmitt-Grohé and Uribe [2016]. Similar to Ottonello [2013] and Bianchi and Mondragon [2018], a managed nominal exchange rate regime potentially translates nominal into real downward wage rigidity, triggering unemployment. Through this mechanism, our model shows that labor market frictions can play a central role to understand the painful landing of commodity super-cycles [Reinhart et al., 2016] even after correcting for price effects as in Kehoe and Ruhl [2008].[7]

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.[8] 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.[9] 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.

[7] 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 [Céspedes and Velasco, 2012].

[8] Differently than recent papers that have used worker-level records from these 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.

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

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.[10] Instead, we choose microregions as 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.[11] They are large enough such that commuting across them 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.[12] The tradable sector includes all manufacturing industries.[13] Nontradables include retail and wholesale trade, hospitality, construction, transportation, finance and real estate, among others.[14]

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.[15] We complement our firm-level panel with additional information on exporting and importing firms. These 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

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

[11]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].

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

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

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

[15]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.

from 3 percent in the *South* to 10 percent in the *North*.[16] 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 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 prices 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. These prices are in nominal U.S. dollars, which we deflate using the U.S. Consumer Price Index. The data is reported at a monthly frequency, and we construct quarterly price indices based on the last month of each quarter.

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,

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

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.[17] We obtain employment data for these weights from Brazil's

[16] 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.

[17] 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

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.[18] 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 cotton or sugarcane. At the national level, our 1999-2013 window captures falling prices up to mid-2002 followed 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.

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across the commodities for which we do have price data found within the same 2-digit industry.

[18] 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.

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, Brazil's input-output table, data on interregional trade flows, and industry-level measures of tradability and income elasticities. All of these are described in Appendix A.1.1

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 identify the cost and wealth channels taking advantage of the fact that each of these has heterogeneous impacts across and within industries.

On conceptual grounds, 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.[19] The tradable sector is relatively unskilled-intensive in comparison to nontradables, so it faces a larger negative cost shock. Further, in both the tradable and nontradable sectors there is heterogeneity in skill intensity across narrow industries. This heterogeneity allows

[19] 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.

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.[20] 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 locally. We identify the wealth channel based on its heterogeneous impact on exporters versus nonexporters within the tradable sector, showing that exporters suffer larger employment losses than nonexporters. Exporter status, however, does not account for trade across regions within a country. For this reason, we provide further evidence in favor of this channel comparing industries with different degrees of tradability within the tradable sector, under the assumption that firms in low-tradability manufacturing industries are more likely to sell their output locally.

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

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

where Emp_{ft} denotes employment of firm f in period t located in region r, 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. Observations are unweighted and standard errors are clustered by region. We estimate equation (2) separately for firms in each sector.The parameter of interest is α_c. The cost channel implies $\alpha_c > 0$.

To identify the wealth channel, we estimate the following linear regression model:

$$\begin{aligned} \log(\text{Emp})_{ft} \quad &= \quad \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_{w1} \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] \\ &+ \quad \beta_{w2} \cdot [\text{Tradability}_i \times \text{Price}_{rt}] + \gamma_f + \delta_t + u_{ft} \;, \qquad (3) \end{aligned}$$

[20]While all nontradable industries rely entirely on domestic demand, heterogenous income elasticities of demand could generate different responses to commodity price shocks. A non-zero correlation between skill intensity and income elasticities of demand would pose a threat to our identification strategy of the wealth channel. In Appendix A.2.10, we show that our results are unchanged when we control for income elasticities.

where Exporter_{ft} is a dummy variable taking a value of one if the firm exports in period t, Tradability_i is an industry-level measure of the extent to which a firm's output is tradable, 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 before, observations are unweighted and standard errors are clustered by region. The parameters of interest are β_{w1} and β_{w2}. The existence of a wealth channel implies $\beta_{w1} < 0$ and $\beta_{w2} < 0$.

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}, 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 Sections 3.3 and 3.4, we discuss how our results are robust to a large set of potentially confounding factors and alternative mechanisms.[21]

3.1 The Cost Channel

The cost channel refers to the increase in wages as a result of commodity booms. This increase in wages raises firms' labor cost, leading to a contraction in 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.

[21] Our approach consists of a shift-share design as we construct regional shocks weighting individual commodity price time series with initial regional employment shares. Adao et al. [2019] propose a correction to standard errors in this type of regression. In Appendix A.2.12, we report standard errors following Adao et al. [2019]. Because these corrected standard errors are smaller, we conservatively leave them to the Appendix and report the standard errors clustered by region in the main text.

We use cross-sectional data in year 2000.[22] 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.

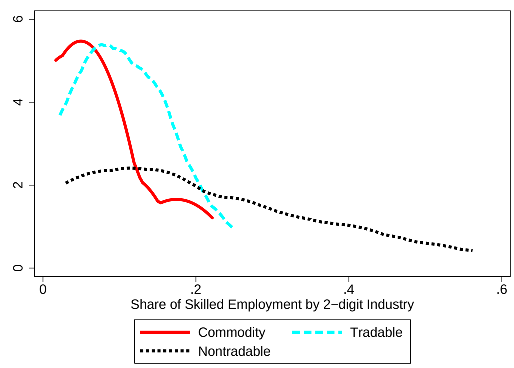


Figure 2: Skill Intensity Across Industries

NOTE: This figure displays kernel density estimates of the distribution of skill intensity (measured as the share of skilled 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:

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

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).[23] 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.[24] The regression includes region fixed effects, as well as macroregion-by-year

[22] We have verified that these statistics are stable over time. While we report these distributions using data from RAIS, data from Brazil's demographic census show a similar pattern.

[23] 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 A15 in Section A.2.4 in the Appendix.

[24] We estimate this regression on the skill premium with annual observations given the nature of how wage data

fixed effects. Observations are unweighted and standard errors are clustered by region.

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). In Appendix A.1.8, we report the impact of commodity prices on the wages of unskilled and skilled workers separately, finding that the response of the skill premium is driven primarily by an increase in unskilled workers' wages.

Table 1: Commodity Prices and the Skill Premium

	(1)	(2)
(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 corresponds to annual earnings. Column 2 corresponds to monthly (December) earnings. 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. To show the existence of a cost channel, we now document that higher commodity prices lead to larger employment losses in relatively unskilled industries. We examine this within the tradable and within the nontradable sector 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 all channels. These results are reported in the first three columns in Table 2 and correspond to excluding the interaction term between skill

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.

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

intensity and the commodity price index in equation (2). The results in the first column indicate that for firms in the commodity sector a one log point increase in the regional commodity price index is associated to a 0.13 log point increase in employment. Column 2 displays the results for the tradable sector, which indicate that commodity prices are negatively correlated with firm employment. A one log point price increase leads to a 0.14 decline in firm-level employment. Finally, in the nontradable sector (column 3) the impact is small and not statistically different from zero.[26]

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 show the existence of both channels.

Columns 4 through 6 in Table 2 display the results after adding the interaction between skill intensity 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. Regarding the interaction term, for the tradable sector (column 5), 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. Within the nontradable sector (column 6), we also 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]

[26] In Appendix A.1.7, we document the impact of regional commodity prices on total regional employment by sector. 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 Appendix Table A6). Further, Appendix Table A8 shows that these results are driven primarily by the response of unskilled labor to commodity prices.

[27] This result also holds for the commodity sector (see column 4 in Table 2).

[28] In Appendix Table A13 (column 2) we show these results hold when we identify them based on variation across three-digit industries within broader two-digit industries, which reduces concerns about unobserved industry characteristics shaping the response to commodity price shocks.

3.2 The Wealth Channel

As explained above, the impact of commodity price shocks within the tradable sector might also differ depending on the extent to which firms sell their output locally, as opposed to selling to other regions or exporting abroad. We provide evidence on the existence of a wealth channel of transmission by comparing the impact of commodity price shocks on exporting and nonexporting firms. In addition, we compare firms in industries with different degrees of tradability. We use a measure of industry tradability constructed by Holmes and Stevens [2014] and used in a similar context by Allcott and Keniston [2018].[29] Specifically, Holmes and Stevens [2014]'s measure, η, captures the transportation cost of different industries and is constructed based on data on shipment distances. For ease of interpretation, in our estimation of (3) we define $Tradability = -\eta$, such that highly tradable industries have low η values.

Table 3 displays the results for the estimation of equation (3). Column 1 includes only the interaction between the regional price index and the exporter dummy, and excludes the tradability measure. 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.[30] 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). In column 2, we include the interaction term between the regional commodity price index and the industry-level tradability measure, and exclude the interaction of the price index with the exporter dummy. We find that the total elasticity of firm employment to commodity prices is -0.026 for firms at the 75th percentile of tradability and -0.007 at the 25th percentile. Finally, in column 3 we include both interaction terms, finding very similar coefficients to those in the previous two columns. These large and statistically significant differences illustrate the relevance of the wealth channel in the transmission of commodity price shocks.

Next, we verify the robustness of our findings to the existence of alternative transmission mechanisms and to other potentially confounding factors. We also provide further evidence in favor of the cost and wealth channels.

[29] Details on on the tradability measure and summary statistics are provided in Appendix A.1.11.

[30] We include the interaction between the regional commodity price index and the following firm-size dummies: 5 to 50 workers, 50 to 100 workers, 100 to 500 workers, 500 to 1000 workers, and 1000 or more workers.

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

	Total Impact			Cost Channel		
	Commodity (1)	Tradable (2)	Nontradable (3)	Commodity (4)	Tradable (5)	Nontradable (6)
(log) Price$_{rt}$	0.131**	-0.136***	0.010	0.100*	-0.136***	0.014
	(0.065)	(0.030)	(0.021)	(0.056)	(0.030)	(0.021)
Skill Intensity$_i$ x (log) Price$_{rt}$				3.467***	0.795***	0.845***
				(0.476)	(0.205)	(0.114)
Observations	1,007,633	8,086,964	30,453,468	1,007,570	8,007,422	30,453,457
R^2	0.907	0.873	0.849	0.908	0.873	0.849

Note: This table reports the results of the estimation of equation (2) by sector. The first three columns exclude the interaction between the regional commodity price index and industries' skill intensity. Columns 4 through 6 include the interaction term, which allows the identification of the cost channel. Columns 1 and 4 correspond to the commodity sector. Columns 2 and 5 correspond to the tradable sector. Columns 3 and 6 correspond to the nontradable sector. Each regression includes firm and state-by-time (quarter) fixed effects. 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

	(1)	(2)	(3)
(log) Price$_{rt}$	-0.042*	-0.046**	-0.044**
	(0.022)	(0.022)	(0.022)
Exporter$_{ft}$	0.135***	0.135***	0.134***
	(0.005)	(0.005)	(0.005)
Exporter$_{ft}$ x (log) Price$_{rt}$	-0.058***		-0.055***
	(0.015)		(0.015)
Tradability$_i$ x (log) Price$_{rt}$		-0.042**	-0.039**
		(0.017)	(0.017)
Observations	8,086,964	8,005,174	8,005,174
R^2	0.909	0.909	0.909

Note: This table reports the results of the estimation of equation (3). Each regression includes firm and state-by-time (quarter) fixed effects. 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): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

3.3 Alternative Transmission Mechanisms

Upstream and Downstream Linkages. A complementary transmission mechanism consists of upstream and downstream linkages between the commodity sector and other industries. This mechanism has been explored by Allcott and Keniston [2018] in the context of oil and gas booms in the U.S. We explore this mechanism in Appendix A.2.8. Based on Brazil's 2005 input-output table, we construct measures of these vertical linkages, categorizing manufacturing industries as upstream, downstream, or unlinked to the commodity sector. We show that upstream and downstream linkages are relevant; an increase in commodity prices leads to an increase in employment in upstream industries, and a decline in employment in downstream industries. We also find that the coefficients estimated in equations (2) and (3) providing evidence in favor of the cost and wealth channels are robust to including interaction terms between the commodity price index and upstream and downstream dummy variables.

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. While we control for economy-wide shocks using state-time fixed effects, the pass-through of interest rates to firm-level employment could have a different impact on different firms. Although our data do not include financial information, the literature on financial frictions has documented that borrowing constraints are strongly tied to firm size [Gopinath et al., 2017]; small firms are more likely to be constrained and therefore less likely to benefit from the boom. Appendix Table A13 and Table 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.

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 goods 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 these 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 than the national-level minimum).[31] Our firm-level regressions include state-by-time fixed effects, which would absorb changes in state-level

[31] Engbom and Moser [2017], for instance, argue that minimum wages vary little across states.

minimum wages, alongside any other policies determined at this level of regional aggregation.[32].

3.4 Robustness Checks

Trade Shocks. Brazil faced a large increase in imports from China in the period under study [Costa et al., 2016]. In Appendix A.2.6, we construct a measure of regional exposure to the increase in Chinese competition and show that our estimates are not confounded by this shock. 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. In Appendix A.2.7, we construct a measure of regional exposure to trade liberalization and show our estimates are robust to controlling for the effect of tariff liberalization.

Informality. While Brazil has a large share of informal labor, our firm-level data is limited to the formal sector of the economy. Because informality is more common among unskilled workers, a transition of informal workers toward 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, in Appendix A.2.5 we augment equations (2) and (3) including an interaction term between the commodity price index and the regional informality share, finding that our identification of the cost and wealth channels is not driven by regional variation in informality.

Geographic Spillovers. 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 [2018], 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 commodity price index that takes 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. Moreover, we include interregional trade and migration in our model to fully take into account these general equilibrium effects.

[32]In addition, our results are robust to including region-by-time fixed effects as explained in Section 3.4

Exchange Rates. Exchange rate fluctuations could impact employment of exporting and non-exporting 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). While our regressions include time fixed effects that capture aggregate shocks, a spatial correlation between the share of exporters and the local composition of commodity baskets, however, could confound our results.[33] We show in Appendix A.2.3 that this is not the case.

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 A15 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.

Unobservable Regional Shocks. Finally, we can modify equations (2) and (3) to include region-time (quarter) fixed effects. These control for any unobserved regional shock. In this case, the first term in each equation (the regional commodity price index by itself) is absorbed by these fixed effects. The results, in Appendix sections A.2.2 (for the cost channel) and A.2.1 (for the wealth channel) show our results remain robust.

3.5 Further Evidence in Favor of the Cost and Wealth Channels

Identification of the Wealth Channel based on Variation in Income Elasticities. An alternative approach to identifying the wealth channel is based on variation across nontradable industries exploiting differences in income elasticities. If a commodity price increase leads to an increase in wealth and consequently an increase in the local demand for nontradables, this should lead to a relative expansion in industries with a higher income elasticity. In Appendix A.2.10, we show that this is indeed the case. Note that we also show that the identification of both the cost and wealth channels in equations (2) and (3) earlier are robust to the inclusion of these income elasticities.

Importing Firms. Commodity prices could have a differential impact not only on exporters but also on importing firms. One would expect a positive impact of commodity prices on importers

[33] Note that this spatial correlation would have to occur within states, as we include state-by-time fixed effects.

relative to nonimporters because importers purchase inputs instead of producing them, and are thus less exposed to the increase in labor costs induced by the cost channel. In Appendix A.2.3, we show that this is the case. We also report that the negative coefficient on the interaction between the regional commodity price index and the exporter dummy variable is even larger in magnitude after the inclusion of an importer dummy variable. Finally, we also show that the response of importers to exchange rate movements does not confound our results

4 Model

We now develop a quantitative multisector and multiregion small open economy model to complement the reduced-form empirical analysis. The goal is twofold. First, the model allows us to quantify the mechanisms involved in the transmission of commodity price super-cycles, and especially, the role of the labor market in this transmission process. Second, we use the model to evaluate the effect of commodity cycles on aggregate outcomes, including welfare.

The economy consists of two regions $l = \{A, B\}$. Each region has a commodity, nontradable (services), and tradable (manufacturing) sectors. In the commodity sector, a representative firm produces a region-specific commodity good using a scarce natural resource in fixed supply. The commodity prices are exogenously determined in the world market. The two commodities are traded across regions and also exported abroad. In the tradable and nontradable sectors, heterogeneous firms produce differentiated product varieties in a monopolistic competition setting.[34] Nontradable goods are consumed only in the region in which they are produced. Firms in the tradable sector can sell their varieties to their own region, they can export to the other region subject to a fixed cost of interregional exporting, and they can also export internationally subject to a larger fixed cost of international exporting. [35] As a consequence of these fixed export costs, the most productive firms sell their varieties in both regions as well as internationally, less productive firms supply only to the two regions in this country, whereas the least productive firms sell only to consumers in their own region. Firms in all sectors use both skilled and unskilled labor.

There is a household consisting of a continuum of workers and a household head. First, the

[34] Because our results concern employment reallocation between the nontradable and tradable sectors, we impose the same market structure used in the tradable sector to the nontradable sector. In this way, the only differences between these two sectors are tradability and skill intensity in production. Note also that the two key differences between the commodity sector and the tradable (manufacturing) sector are the constant returns to scale (with a representative firm) in the commodity sector and that the commodity good is traded costlessly. An earlier working paper includes heterogeneous firms in the commodity sector.

[35] In Appendix A.1.9 we document that fluctuations in regional commodity prices have an impact on firm entry and exit in the commodity, tradable and nontradable sectors, as well as on entry and exit in and out of exporting in the tradable sector. This motivates the inclusion of the entry and exit margins in the model.

household head collects rents from the natural resource ($\bar{R}^l$) and firms in the economy. She can save and borrow freely from the rest of the world through an external bond B at an exogenous interest rate r^*. The household head solves the aggregate consumption/saving decision of the household and chooses skill-specific transfers to the workers.[36] Second, individual workers receive transfers from the household head and labor income and spend all these resources to consume goods produced by the three sectors of the economy as well as an imported good. A fixed fraction κ of household workers are skilled and the rest are unskilled. The workers are heterogeneous in their time-invariant preferences toward living in either region. Individual workers choose where to work and how to allocate their disposable income upon observing prices, wages, and transfers. Workers of a given skill in a given region pool their unemployment risk.

Finally, because rigid labor markets are a key feature of emerging economies, we include in our framework downward nominal wage rigidity modeled as in Schmitt-Grohé and Uribe [2016]. This friction generates important implications for the model's dynamics. In particular, it leads to unemployment and therefore to a loss in output during the bust.

Notation and Numeraire. We use the symbol $\sim$ to denote variables in nominal terms. We use the imported good as the numeraire, and assume the law of one price holds for this good, such that

$$\tilde{P}^A_{Mt} = \tilde{P}^B_{Mt} = \tilde{P}^\star_{Mt}\mathcal{E}_t = \mathcal{E}_t \,,$$

where $\tilde{P}^\star_{Mt}$ is the world price of the imported good denoted in foreign currency, $\mathcal{E}_t$ the nominal exchange rate (domestic currency price of one unit of foreign currency), and the last equality follows from normalizing $\tilde{P}^\star_{Mt} = 1$. Real prices and wages can thus be obtained by dividing nominal prices and wages by the nominal exchange rate.[37]

We index regions by $l \in \{A, B\}$, sectors by $k \in \{C, N, T\}$ (for commodity, nontradable, and tradable), skill types by $d \in \{U, S\}$ (for unskilled and skilled), and firms by i.

4.1 Household Head and Workers

To focus our attention on the interaction of commodity fluctuations and labor markets, we consider a simple model of a household head's consumption-saving decision, in a similar way to Kehoe et al. [2019] and Kehoe et al. [2020].

[36] Note that if transfers were both region-specific and skill-specific there would be no migration.
[37] The bond B is expressed in real terms and in units of the imported good.

Workers. A type-d worker living in region l at time t has a utility:

$$U\left(C_t^{dl}\right) = \frac{\left(C_t^{dl}\right)^{1-\nu}}{1-\nu} + \xi_d \cdot \epsilon_j^l\,, \tag{5}$$

where ϵ_j^l is a time-invariant location preference term that varies across workers (j) and is drawn from a mean-zero type-I extreme value distribution.[38] For notational simplicity, we omit the worker subscript j whenever possible.[39] C_t^{dl} is the final consumption bundle that is a nested-CES aggregate of an imported good (m_t^{dl}), a tradable bundle (t_t^{dl}), a nontradable bundle (n_t^{dl}), and region-specific commodity goods (c_t^{dlA}, c_t^{dlB}):

$$C_t^{dl} = \left\{\left[\left[\left(m_t^{dl}\right)^{\theta_1} + \alpha_T\left(t_t^{dl}\right)^{\theta_1}\right]^{\frac{\theta_2}{\theta_1}} + \alpha_N\left(n_t^{dl}\right)^{\theta_2}\right]^{\frac{\theta_4}{\theta_2}} + \alpha_C\left[\left(c_t^{dlA}\right)^{\theta_3} + \left(c^{dlB}\right)^{\theta_3}\right]^{\frac{\theta_4}{\theta_3}}\right\}^{\frac{1}{\theta_4}}. \tag{6}$$

The tradable bundle t_t^{dl} and nontradable bundle n_t^{dl} are both CES aggregators of individual varieties according to:

$$t_t^{dl} = \left[\int_{\zeta\in\mathfrak{Z}_t^l} t_t^{dl}(\zeta)^\rho d\zeta\right]^{\frac{1}{\rho}} \qquad \text{and} \qquad n_t^{dl} = \left[\int_{\varphi\in\mathfrak{P}_t^l} n_t^{dl}(\varphi)^\rho d\varphi\right]^{\frac{1}{\rho}},$$

where ζ and φ are indices for individual varieties and $\mathfrak{Z}_t^l$ and $\mathfrak{P}_t^l$ denote sets of individual varieties sold in region l at time t.

In a given location, all workers of a given type pool their total labor income which they then redistribute among themselves, so that there is complete risk-sharing within each region for each skill type. Given the nominal wage $\tilde{w}_t^{dl}$, all workers regardless of their employment status earn an income $\tilde{w}_t^{dl} \cdot \frac{h_t^{dl}}{H_t^{dl}}$. In this expression, h_t^{dl} and H_t^{dl} denote the total measure of employed type-d workers in l at time t and the total measure of type-d workers residing in l at t, respectively; and the ratio h_t^{dl}/H_t^{dl} represents the employment rate. In addition, all workers receive a lump-sum transfer $\tilde{\tau}_t^d$ (that can be positive or negative) from the household head, which is taken as exogenous by individual workers. This transfer is the result of the household head's intertemporal consumption-saving decision.

In each period, workers make two decisions given their location preference, disposable income, and prices. First, they chose where to locate themselves. Second, they choose how to allocate their

[38]This is a tractable way of modeling migration. An alternative is assuming a migration cost.

[39]Omitting the worker subscript j is not problematic given that in equilibrium, all workers of a given skill d in a given location l have the same consumption.

disposable income. Formally, given their disposable income in a given location, workers choose m_t^l, $t_t^l(\zeta)_{\zeta\in\mathfrak{Z}_t^l}$, $n_t^l(\varphi)_{\varphi\in\mathfrak{P}_t^l}$, c_t^{lA}, and c_t^{lB} to maximize their utility (in equation (5)) subject to their budget constraint:

$$\tilde{P}_{Mt}^l m_t^{dl} + \tilde{P}_{Nt}^l n_t^{dl} + \tilde{P}_{Tt}^l t_t^{dl} + \tilde{P}_{Ct}^A c_t^{dlA} + \tilde{P}_{Ct}^B c_t^{dlB} = \tilde{w}_t^{dl} \cdot \frac{h_t^{dl}}{H_t^{dl}} + \tilde{\tau}_t^d .$$

In this expression, $\tilde{P}_{Tt}$ and $\tilde{P}_{Nt}$ are the price indices in the tradable and nontradable sectors respectively. In real terms, given the normalization described earlier, this budget constraint becomes:

$$m_t^{dl} + P_{Nt}^l n_t^{dl} + P_{Tt}^l t_t^{dl} + P_{Ct}^A c_t^{dlA} + P_{Ct}^B c_t^{dlB} = w_t^{dl} \cdot \frac{h_t^{dl}}{H_t^{dl}} + \tau_t^d .$$

Because the nominal versus real distinction is only relevant in the downward wage rigidity constraint discussed below, we write the model in real terms until that point.

Workers make a discrete decision regarding where to locate themselves in the current period based on the their disposable income $w_t^{dl} \cdot \frac{h_t^{dl}}{H_t^{dl}} + \tau_t^d$ and prices P_t^l in each regions $l = \{A, B\}$, where P_t^l is the price index associated to the final consumption bundle in equation (6) and is defined in the Appendix (equation (A23)).

The Household Head's Problem. The household head collects firm profits and returns from natural resources and then chooses how much to save and the amount of transfers to maximize the lifetime discounted utility of all workers of the household. Let $\bar{U}\left(E_t^{dl}(\tau_t^d), \vec{P}_t^l\right)$ denote a household worker's indirect utility given expenditure and prices. Formally, the household head takes as given the sequence $\{\vec{P}_t^l, w_t^{dl}, H_t^{dl}, h_t^{dl}\}_{\forall d,l,t}$ and chooses $\{\tau_t^d, B_{t+1}\}_{\forall d,t}$ to maximize the sum of utility of unskilled and skilled workers across both regions:

$$\max_{\{\tau_t^d, B_{t+1}\}} \sum_t \beta^t \left(H_t^{uA}\bar{U}_t^{uA}(\tau_t^u) + H_t^{uB}\bar{U}_t^{uB}(\tau_t^u) + H_t^{sA}\bar{U}_t^{sA}(\tau_t^s) + H_t^{sB}\bar{U}_t^{sB}(\tau_t^s)\right),$$

subject to the sequence of budget constraints:

$$B_{t+1} + \left(H_t^{uA} + H_t^{uB}\right)\tau_t^u + \left(H_t^{sA} + H_t^{sB}\right)\tau_t^s \leq \Pi_t + P_{R,t}\bar{R}_t + (1+r)\,B_t \quad \forall\, t.$$

4.2 Production

Labor Input. Firm i in each sector $k \in \{C, N, T\}$ uses a composite labor input that combines skilled and unskilled labor according to the following CES function:

$$l_i^k\left(l_{i,t}^{u,k}, l_{i,t}^{s,k}\right) \equiv \left[(\phi^k)^{\frac{1}{\gamma}}(l_{i,t}^{u,k})^{\frac{\gamma-1}{\gamma}} + (1-\phi^k)^{\frac{1}{\gamma}}(l_{i,t}^{s,k})^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}, \tag{7}$$

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^k), while the elasticity of substitution between skill types is constant across them.

Commodity Sector. In each region, a representative firm produces a region-specific commodity that can be sold in both regions of this country and also exported internationally. To produce the commodity good, the representative firm combines the composite labor input L_{Ct}^l and a resource input R_t according to the following production function:

$$Y_{Ct}^l = \left(L_{Ct}^l\right)^{\eta} \cdot \left(R_t^l\right)^{1-\eta}.$$

The prices of each commodity good, P_{Ct}^l, are determined exogenously in the international market. After the demand from both regions for each commodity is met, the remaining output is exported internationally. During the price boom, the commodity sector expands by hiring more labor. The resulting increase in wages gives rise to the cost channel of transmission of commodity price cycles.

Nontradable Sector. The nontradable sector in each region is composed of a continuum of firms heterogeneous in productivity z each producing a differentiated variety φ under monopolistic competition. Each firm's permanent productivity type z is drawn upon entry from a log-normal distribution with mean μ_N and standard deviation σ_N. A type-z firm in region l produce its variety using the composite labor as the only input according to the following production function:

$$q_{Nt}^l(z) = z \cdot \left(l_{Nt}(z) - f_N^l\right),$$

where f_N^l is a fixed per-period production cost in terms of the labor input. In every period, all continuing firms are subject to an i.i.d. exit shock with probability δ_N. Potential entrants can enter the market by paying an entry cost consisting of a fixed and a convex component in terms of the composite labor input:

$$f_{Net}^{l} = f_{Ne}^{l} + \xi_{Ne}\left[\exp\left(\frac{\mathcal{M}_{Net}^{l} - \overline{\mathcal{M}}_{Ne}^{l}}{\overline{\mathcal{M}}_{Ne}^{l}}\right) - 1\right] .$$

The convex component of the entry cost captures congestion externalities or competition for a fixed resource at entry.[40] After paying the entry cost, the productivity type of the firm is revealed.

Tradable Sector. The production technology of the tradable sector is identical to that of the nontradable sector. In each region, there is a continuum of firms heterogeneous in productivity z each producing a differentiated variety ζ using the following production function:

$$q_t^l(z) = z \cdot \left(l_t^l(z) - f_d^l\right) ,$$

where f_d^l is a fixed per-period production cost in terms of the composite labor input. Akin to the nontradable sector, each firm's productivity type z is permanent and is drawn from a log-normal distribution with mean μ_T and standard deviation Σ_T upon entry.

Unlike the nontradable sector, firms in the tradable sector located in region l can sell their varieties in the other region by paying a fixed per-period interregional export cost f_c^l. Furthermore, they can also export internationally subject to a (larger) per-period fixed cost f_x^l. Both fixed costs are expressed in terms of the composite labor input. The foreign demand for exports is:

$$q_x^l(z) = \Gamma\left[p_t^l(z)\right]^{-\sigma} ,$$

where Γ is exogenous and fixed throughout the commodity super-cycle. In contrast, the size of each domestic region's demand for tradable goods responds endogenously to changes in prices and wealth over the cycle. This feature is key to generating the wealth channel.

In each period all continuing firms face an exogenous exit risk that occurs with probability δ_T that is i.i.d. across firms and time. Meanwhile, potential entrants can enter the market subject to a fixed entry cost:

$$f_{Tet}^{l} = f_{Te}^{l} + \xi_{Te}\left[\exp\left(\frac{\mathcal{M}_{Tet}^{l} - \overline{\mathcal{M}}_{Te}^{l}}{\overline{\mathcal{M}}_{Te}^{l}}\right) - 1\right] .$$

[40] This is used to avoid corner solutions in the transition and the size of the convex component of the cost is set to be small relative to the fixed component so its effects on dynamics are minimal.

4.3 Labor Market Frictions and Exchange Rate Policy

Labor-market rigidity is a key feature of many emerging economies. Because of the central role that labor markets play in our analysis, we allow for a downward wage rigidity constraint on nominal wages in the spirit of Schmitt-Grohé and Uribe [2016] as follows:

$$\tilde{w}_t^{dl} \geq \tilde{\chi}\tilde{w}_{t-1}^{dl}\,, \tag{8}$$

where $0 < \tilde{\chi} < 1$. This constraint can also be expressed in terms of real wages as:

$$\mathcal{E}_t w_t^{dl} \geq \tilde{\chi}\mathcal{E}_{t-1} w_{t-1}^{dl} \quad \text{or} \quad w_t^{dl} \geq \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}\,, \tag{9}$$

where $\epsilon_t \equiv \mathcal{E}_t/\mathcal{E}_{t-1}$ is the nominal depreciation rate of the domestic currency. Under a managed floating exchange rate regime such as the one prevalent in Brazil during the period under study, this nominal rigidity translates into a real rigidity, which can potentially lead to unemployment during the bust of a commodity price cycle.[41]

We assume that the authority aims for a stable nominal exchange rate ($\epsilon_t = 1$) but is also willing to reduce unemployment by depreciating the nominal exchange rate in case it is needed. Define $\left(w_t^{dl}\right)^*$ as the real wage that achieves full employment. Under $\epsilon_t = 1$, there will be full employment if and only if, in every labor market, $\left(w_t^{dl}\right)^* > \tilde{\chi} w_{t-1}^{dl}$. We propose the following simple rule to capture the trade-off between unemployment and exchange rate stability: i) if $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} \geq \tilde{\chi}$ then $\epsilon_t = 1$, ii) otherwise:

$$\left(\min_{\{d,l\}}\left\{\frac{\tilde{w}_{t+1}^{dl}}{\tilde{w}_t^{dl}}\right\}\right)^{\phi}\left(\frac{E_{t+1}}{E_t}\right)^{1-\phi} = 1 \quad \Rightarrow \quad \epsilon_t = \left(\min_{\{d,l\}}\left\{\frac{w_t^{dl}}{w_{t-1}^{dl}}\right\}\right)^{-\phi}. \tag{10}$$

Note that when $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} \geq \tilde{\chi}$ holds, then every labor market is under full employment. When this inequality does not hold, then at least one labor market exhibits unemployment. By focusing on the labor market in which the constraint is most binding, the authority's rule also mitigates unemployment in all the other labor markets.

The parameter ϕ introduced in equation (10) represents the weight the authority gives to full

[41] Ilzetzki et al. [2019] classify Brazil's exchange rate regime as a managed floating regime during most of the 1999-2013 period under study. The exchange rate regime is classified as a managed floating regime during 1999-2002 and 2009 onwards, and as a free floating regime during 2003-2008. Note that the bust in commodity prices, post 2011 (which is when our model predicts a binding rigidity constraint and unemployment) falls under the managed floating regime.

employment relative to exchange rate stability. In the extreme case when $\phi = 0$, the authority sets $\epsilon_t = 1$ to maintain a fixed exchange rate regardless of other economic conditions. At the other extreme, when $\phi = 1$, the authority's unique goal is to avoid unemployment under any circumstance by stabilizing nominal wages. Appendix B.1 derives the joint determination of the nominal exchange rate and unemployment. In particular, we show in the Appendix that under this nominal exchange rate policy, when the authority depreciates the exchange rate, the following real downward wage rigidity constraint arises:

$$w_t^{d,l} \geq \tilde{\chi}^{\frac{1}{1-\phi}} w_{t-1}^{d,l} \equiv \chi w_{t-1}^{d,l} . \tag{11}$$

Therefore, χ combines the degree of nominal downward wage rigidity $\tilde{\chi}$ and the unemployment aversion parameter $\phi \in [0, 1]$. The following set of complementary slackness conditions summarize the state of each labor market:

$$0 = \left(L_t^{dl} - h_t^{dl}\right)\left(w_t^{dl} - \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}\right) .$$

In each labor market, either there is full employment and equation (11) is not binding, or there is unemployment and this constraint binds.

4.4 Equilibrium

We now describe some key aspects of the equilibrium. The full system of equations and the definition of the equilibrium are deferred to Appendix B.2 and the steady state is shown in Appendix B.3.

Location Choices. Given the distributional assumptions on workers' idiosyncratic location preferences, the fraction of type-d workers living in region l at time t is given by:

$$\sigma_t^{d,l} = \frac{\exp\left(U\left(\frac{E_t^{d,l}}{P_t^l}\right)\right)^{1/\xi_d}}{\exp\left(U\left(\frac{E_t^{d,l}}{P_t^l}\right)\right)^{1/\xi_d} + \exp\left(U\left(\frac{E_t^{d,\neg l}}{P_t^{\neg l}}\right)\right)^{1/\xi_d}} ,$$

where $E_t^{d,l} \equiv w_t^{dl} \cdot \frac{h_t^{dl}}{H_t^{dl}} + \tau_t^d$ is a worker's disposable income and P_t^l is the ideal price index of the final consumption bundle. Note that migration flows are determined by regional differences in wages, prices, and employment levels. All else equal, an increase in wages leads to population inflows, whereas an increase in price levels or unemployment rates lead to population outflows.

This is consistent with dynamic economic geography models such as Caliendo et al. [2019].

Entry and Exit in the Nontradable Sector. Firms are subject to an exogenous exit probability δ_N in every period. In addition, firms exit endogenously when the discounted present value of profits is negative. Letting optimal profits of a nontradable firm i be denoted by $\pi^l_{i,t}$, the value function of a firm with productivity z is:

$$W^l_{i,t}(z) = \max\left\{0, \pi^l_{i,t}(z) + \beta(1-\delta_N)W^l_{i,t+1}(z)\right\} .$$

The domestic productivity cutoff $\bar{z}^l_t$ is implicitly defined by the productivity level that solves $W^l_{i,t}(\bar{z}^l_t) = 0$.

In each period, potential entrants may pay the fixed entry cost to draw their permanent productivity levels z. If the realized draw is higher than the domestic cutoff, the firm will enter the market and produce. Potential entrants will pay to get their productivity draws until the present discounted value of entry is equal to the fixed entry cost:

$$\hat{w}^l_{Nt} \cdot f^l_{Net} = \int_{\bar{z}^l_t}^{\infty} W^l_t(z)g(z)dz\,,$$

where $\hat{w}^l_{Nt}$ is the wage associated to the composite labor input defined in (7).

Entry, Exit, and Exporting in the Tradable Sector. Entry and exit decisions in the tradable sector are identical to those in the nontradable sector. However, in the tradable sector, firms make the additional decisions of whether or not to sell to the other region in the economy and to the foreign market.

Let $\pi^l_{m,t}$ denote the static profits associated with each sales mode $m \in \{d, c, x\}$ (selling in the own region, exporting to the other region, and exporting internationally, respectively). The value functions corresponding to each of these modes are:

$$\begin{aligned}
W^l_{d,t}(z) &= \max\left\{0, \pi^l_{d,t}(z) + \beta(1-\delta_N)W^l_{t+1}(z)\right\} ,\\
W^l_{c,t}(z) &= \max\left\{0, \pi^l_{d,t}(z) + \pi^l_{c,t}(z) + \beta(1-\delta_N)W^l_{t+1}(z)\right\} ,\\
\text{and}\quad W^l_{x,t}(z) &= \max\left\{0, \pi^l_{d,t}(z) + \pi^l_{c,t}(z) + \pi^l_{x,t}(z) + \beta(1-\delta_N)W^l_{t+1}(z)\right\} .
\end{aligned}$$

The continuation value is given by: $W_{t+1}(z) = \max\{W^l_{d,t}(z), W^l_{c,t}(z), W^l_{x,t}(z)\}$. The domestic ($\bar{z}^l_{d,t}$), interregional export ($\bar{z}^l_{c,t}$), and international export cutoffs ($\bar{z}^l_{x,t}$) are implicitly defined by

$W^l_{d,t}(\bar{z}^l_{d,t}) = 0$, $\pi^l_{c,t}(\bar{z}^l_{c,t}) = 0$, and $\pi^l_{x,t}(\bar{z}^l_{x,t}) = 0$. Finally, the free entry condition is:

$$\hat{w}^l_{Tt} \cdot f^l_{Tet} = \int_{\bar{z}^l_t}^{\infty} W^l_t(z) g(z) dz \,.$$

5 Quantitative Analysis

We calibrate the model with two main objectives. Our first goal is to quantify the mechanisms that propagate commodity price super-cycles throughout the economy. In particular, we use counterfactual simulations to determine the extent to which the labor market is a relevant channel of transmission of commodity price cycles to other sectors of the economy. This is relevant given that the role of the labor market as a transmission mechanism has often been ignored in the literature by assuming that commodity booms are purely endowment shocks.[42] Our second goal is to evaluate the welfare implications of commodity price fluctuations under flexible and downwardly rigid wages. We proceed as follows. 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 regressions results in Section 3 for outcomes which were not targeted in the calibration. Finally, we use the calibrated model to quantify transmission mechanisms and evaluate welfare.

5.1 Calibration

In our quantitative analysis, we analyze two regions that are symmetric in the steady state but face different commodity price sequences. We assign to these two regions the prices faced by the states of Sao Paulo and Minas Gerais, based on the following criteria. These states are the largest in Brazil and are representative of the country as a whole in terms of their economic structure.[43] In addition, they experience very different commodity prices, with Minas Gerais among the top 10% and Sao Paulo in the bottom 10% in terms of the magnitude of the commodity boom between the trough in 2002 and the peak in 2011. Finally, these two states share a large border between them, which leads to a larger amount of migration than between more distant states. We calibrate the model to target the observed migration and trade between the two states.

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

[42] Fernández et al. [2017a], Shousha [2016], and Fernández et al. [2017b] model commodity booms as endowment shocks. Exceptions are Alberola and Benigno [2017] and Arezki et al. [2017] who model commodity production with representative firms.

[43] The share of employment in Sao Paulo and Minas Gerais combined is 42% of the national employment in 2001.

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 the year 2001.[44]

Externally Calibrated Parameters. Table 4 shows a first set of parameters that are either normalized or externally calibrated to values in the literature and to 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 sectoral goods (θ's), substitution between tradable varieties (σ), and substitution between skilled and unskilled labor (γ) are taken from the international trade and international finance literatures.[45] The exogenous sectoral exit rates (δ^N and δ^T) are computed directly from RAIS.

Because we study 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.[46] We normalize the total population of the economy to be 100. In addition, we set $\alpha_T = \alpha_M = 1$ and $P_T^l = P_M^l = 1$ such that importables and domestic tradables are symmetric in the initial steady state.

The degree of downward nominal wage rigidity ($\tilde{\chi}$) is calibrated based on the macroeconomic evidence described in Appendix C.13. Following Schmitt-Grohé and Uribe [2016] we obtain this parameter by analyzing the dynamics of wages in an episode of low inflation, an exchange rate regime characterized as managed floating and rising unemployment. Between 2012 and 2014, during the commodity bust, unemployment in Brazil was rising while nominal wages, after adjusting by long-run foreign inflation and economic growth, only decreased at an annual rate of 0.3%. We therefore calibrate $\tilde{\chi}$ to 0.997. This value is consistent with Schmitt-Grohé and Uribe [2016]'s calculation for Argentina. In addition, using the change in real wages during this episode, we also calibrate the degree of downward real wage rigidity. We then infer the value of parameter ϕ which captures the importance given by the authority to unemployment relative to exchange rate stability, from the two measures of nominal and real downward wage rigidity ($\tilde{\chi}$ and χ). We find $\chi = 0.99$ and $\phi = 0.76$.[47] Sections 5.3 and 5.4 illustrate the impact of downward wage rigidity in

[44] We choose 2001 because it is the year right before the start of the boom. The model is calibrated to the exact same sample used in the empirical analysis.

[45] 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].

[46] We show in Appendix C.4 that the quantitative results of the model are robust to alternative initial conditions. The model is solved using a shooting algorithm, in the spirit of Alberola and Benigno [2017], extended to our multi-region setting with heterogeneous firms.

[47] Appendix A.1.10 provides both microeconomic and macroeconomic evidence of wage rigidity in Brazil. 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 regime and inflation stabilization during the 1990s. The highly unionized Brazilian labor market, the automatic correction of the minimum wage by inflation, and a

the economy.

Table 4: Externally Calibrated Parameters

Parameter	Description	Value	Source
r^*	Interest rate	0.04	Macroeconomic data
ν	Discount factor	1.5	Literature
σ	Elast. of substitution between varieties in T and N	4	Literature
ρ	Inverse of markup in T and N	0.75	$\sigma = \frac{1}{1-\rho}$
γ	Elast. of subs. between skilled and unskilled labor	1.41	Katz and Murphy [1992]
η	Labor share in C	0.5	Gollin et al. [2014]
δ_T	Exogenous exit probability in T	0.14	Firm-level data (RAIS)
δ_N	Exogenous exit probability in N	0.18	Firm-level data (RAIS)
θ_1	Elast. of Subs. between importables and domestic tradables	$\frac{1}{1-0.85}$	Corsetti et al. [2008]
θ_2	Elast. of subs. between tradables and nontradables	$\frac{1}{1-0.74}$	Mendoza [1995]
θ_3	Elast. of subs. between regional commodities	$\frac{1}{1-0.85}$	See table note
θ_4	Elast. of subs. between commodities and non-commodities	$\frac{1}{1-0.50}$	Buera and Kaboski [2009]
μ_T	Mean of productivity distribution in T	0	Normalization
$\bar{B}$	Steady state debt	0	Normalization
$\bar{H}$	Total inelastic labor supply	100	Normalization
α_T	Weight on T good in utility function	1	Normalization
P_T	Steady state price of T good	1	Normalization
$\tilde{\chi}$	Downward nominal wage rigidity parameter	0.997	Macroeconomic data
ϕ	Authority preference	0.76	Macroeconomic data

NOTE: This table shows the values and sources of the externally-calibrated parameters. The abbreviations C, T and N stand for the commodity, tradable and nontradable sectors. Note that the elasticity of substitution between regional commodity goods is assumed to be the same than that between importables and domestic tradables.

Internally Calibrated Parameters. Table 5 displays the set of 18 parameters that are internally calibrated. Twelve of these parameters are calibrated in the steady state. The initial price level of the commodity good (P_C) is used to match the commodity output share, while the weight on the nontradable good in the utility function (α_N) is used to target the nontradable output share. Because all commodity output in excess of domestic demand is exported internationally, the weight on commodity good (α_C) can be identified by the share of commodities in total exports. The fixed costs of interregional sales and international exports in the tradable sector (f_c,f_x) are calibrated to match the interstate trade to GDP ratio, and the fraction of exporting firms.[48] The firm size distributions in the tradable and nontradable sectors are used to discipline the fixed operating costs (f_d,f_N) and the variance of the productivity distributions (Σ_T,Σ_N). Having normalized μ_T (the mean of the productivity distribution in the tradable sector) to 0, the mean of the productivity

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).

[48]Because the commodity price series used in the quantitative exercise correspond to that of Minas Gerais and Sao Paulo, we use the interstate trade to GDP ratio between these two states.

distribution in the nontradable sector (μ_N) captures the relative differences in average size between the tradable and nontradable sectors. As such, we calibrate this paramter to the relative mass of firms between the two sectors. The size of foreign demand for exports (Γ) targets the export to GDP ratio. The endowment of natural resources ($\bar{R}$) is used to match the commodity sector's share of total employment. We observe a close match between the model's moments and the target moments.[49]

The next set of parameters is calibrated to match perfectly macroeconomic ratios of the Brazilian economy. The share of unskilled labor in the model economy (κ) is set to generate the skill premium observed in Brazil. The skill intensities in each sector (ϕ_C, ϕ_T, ϕ_N) are chosen to replicate the ratio of unskilled to skilled labor employed in each sector.

The remaining two parameters are calibrated to the transition over the commodity super-cycle. The entry congestion elasticity (ξ_e) is chosen such that at the peak of the boom, the convex component of the entry cost is 25% of the fixed component. The location preference parameter (ξ_d) is calibrated to mimic the net migration rate between Minas Gerais and Sao Paulo during the commodity boom.[50]

As Table 5 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.

Simulation. 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. The size of the cycle is different for the two regions in the economy, with region A being subject to a larger boom in commodity prices. As Figure 3 shows, the price of the commodity good produced in region A increases steadily for ten years (period which is marked by the darker gray area in each graph) and reaches a cumulative increase close to 90%. Region B experiences a smaller boom-bust cycle, with the peak cumulative increase being around 50%. These trough-to-peak amplitudes are obtained from the increase in commodity prices observed in the State of Minas

[49] The only exception is the share of nontradable employment by the largest firms which can be attributed to the fact that the log normal productivity distribution used does not have fat tails.

[50] Using a regression of state-level employment on commodity price, we find that a one log point increase in the regional commodity price index is associated to an increase of 0.32 log point in total regional employment. Between 2002q2 and 2011q4, Sao Paulo had a 39 log point increase in the commodity price index (12.5 log point increase in employment) while Minas Gerais had a 53 log point increase in the commodity price index (17 log point increase in employment). Holding the total population in the model economy fixed, and assuming both regions start with a population equal to 50 in the initial steady state, these results imply that Minas Gerais (region A in the model) has a population of 51 at the peak of the boom while Sao Paulo (region B in the model) has a population of 49.

Table 5: Internally-Calibrated Parameters

Parameter	Description	Moment Targeted	Moment (Data)	Moment (Model)	Param. Value
P_C	Commodity price	C share in GDP	0.14	0.14	5.37
α_N	Weight on N good in utility	N share in GDP	0.55	0.59	14.76
α_C	Weight on C good in utility	Share of C in exports	0.32	0.31	0.11
f_d	Production fixed cost in T	Share of T emp. in 20% smallest firms	0.02	0.02	0.21
f_c	Fixed cost of interregional sales in T	Interstate trade to GDP ratio	0.12	0.12	0.39
f_x	Fixed cost of international exports in T	Fraction of exporting firms in T	0.09	0.08	6.99
Σ_T	St. dev. of productivity distribution in T	Share of T emp. in 10% largest firms	0.68	0.64	0.82
Γ	Foreign demand	Export to GDP ratio	0.15	0.16	196.62
$\bar{R}$	Resource endowment	C share in employment	0.08	0.09	18.15
f_N	Production fixed cost in N	Share of N emp. in 20% smallest Firms	0.04	0.04	0.14
μ_N	Mean of productivity distribution in N	Relative mass of firms: M_T/M_N	0.27	0.27	0.08
Σ_N	St. dev. of productivity distribution in N	Share of N emp. in 10% largest firms	0.66	0.54	1.08
κ	Aggregate share of unskilled labor	Skill premium (w^s/w^u)	3.16	3.16	0.83
ϕ^C	Skill intensity in C	Unskilled to skilled labor in C $(L^{u,C}/L^{s,C})$	0.92	0.92	0.69
ϕ^N	Skill intensity in N	Unskilled to skilled labor in N $(L^{u,N}/L^{s,N})$	0.79	0.79	0.42
ϕ^T	Skill intensity in T	Unskilled to skilled labor in T $(L^{u,T}/L^{s,T})$	0.88	0.88	0.58
ξ_e	Entry congestion elasticity	Fraction of entry cost: $\max\{\frac{\text{cong. term}}{f_e}\}$	0.25	0.25	1
ξ_d	Location preference	Minas Gerais Share of national employment at peak of boom	0.51	0.51	10

Note: This table shows the values of internally-calibrated parameters. The abbreviations C, T and N stand for the commodity, tradable and nontradable sectors.

Gerais (corresponding to region A) and Sao Paulo (corresponding to region B) in Brazil between 2002 and 2011, as measured with employment-weighted prices at the state level. In both regions, commodity prices decrease steadily after the peak of the boom, reverting to their initial levels after ten years. The price dynamic during the bust is extrapolated from the data in a symmetric fashion.

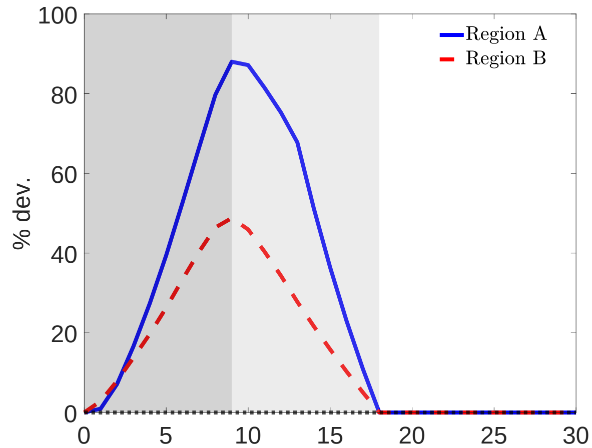


Figure 3: Commodity Price Super-Cycle

NOTE: This figure shows the path of the prices of the commodity goods used in the quantitative analysis.

5.2 Model Validation

Prior to quantifying the mechanisms of the model, we perform a validation exercise focusing on key nontargeted moments. 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. We estimate the skill premium regression in equation (4) in Section 3 using simulated data from the model. Recall that in the model there are two regions, corresponding to Brazilian states. Consequently, we contrast this result with the same regression estimated with the original data at the state level.[51,52] The results are displayed in columns 1 and 2 in Table 6. 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 (Emp. Share_{rst}) on an interaction between

[51] As shown in Table 1 in Section 3 we found similar results when observations correspond to microregions.

[52] The simulated price series fed into the model (shown in Figure 3) are based on an increase like the bust to boom commodity price increase in each state from 2002 to 2013, with 2002 corresponding to the initial steady state in the model. In this subsection we contrast data and model using in both cases the "transition years" 2003-2013, although we find similar results with different timing assumptions.

Table 6: Model Validation: Skill Premium and Regional Employment

	(1)	(2)	(3)	(4)
	Skill Premium		Regional Employment	
	Model	Data	Model	Data
(log) Price_{rt}	-0.099***	-0.221***		
	(0.005)	(0.087)		
(log) $\text{Price}_{rt} \cdot T_s$			-0.100***	-0.199***
			(0.033)	(0.026)
Observations	22	267	44	594

Note: The first two columns report the results of the estimation of equation (4). Each regression includes state and year fixed effects. The last two columns report the results of the estimation of equation (12). Each regression includes state-year and sector fixed effects. Columns 1 and 3 use simulated data. Columns 2 and 4 use actual data. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

the price and a tradable sector dummy (T_S), and region-time and sector fixed effects:[53]

$$\text{Emp. Share}_{rst} = \beta_1 \cdot \text{Price}_{rt} \cdot T_s + \nu_{rt} + \gamma_s + \epsilon_{rst}\,. \tag{12}$$

The coefficient β_1 measures the differential employment response in the tradable sector relative to the nontradable sector. As before, to match the model closely, we use data at an annual frequency with each observation corresponding to a state, although we find similar patterns using data at the microregion level. We compare the estimated parameters obtained using the simulated data with those obtained based on the actual data. The results are reported in columns 3 and 4 in Table 6. We observe a close match between model and data in the reallocation of employment across sectors.

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

$$\log(\text{Emp})_{ft} = \beta_1 \cdot \text{Exporter}_{ft} + \beta_2 \cdot \text{Exporter}_{ft} \cdot \text{Price}_{rt} + \gamma_f + \delta_{rt} + \epsilon_{ft}\,. \tag{13}$$

This equation is analogous to equation (3) estimated in the empirical section, but we include region by time (quarter) fixed effects which absorb the uninteracted regional price index.[54] Once again,

[53] 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.

[54] As in equation (3) we also include interaction terms between firm-size-bin dummies and the price index.

we use actual data with prices defined at the state level at an annual frequency to be consistent with the model calibration. The results are displayed in Table 7, and again show a close parallel between the behavior of the model and the empirical results.

Table 7: Model Validation: Firm-Level Employment

	(1)	(2)
	Tradable	
	Model	Data
Exporter$_{ft}$ x (log) Price$_{rt}$	-0.153***	-0.094***
	(0.002)	(0.024)
Observations	1,222,042	1,538,219

NOTE: Columns 1 and 2 in this table reports the results of the estimation of equation (13) using the simulated and actual data respectively. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

5.3 Transmission Mechanisms

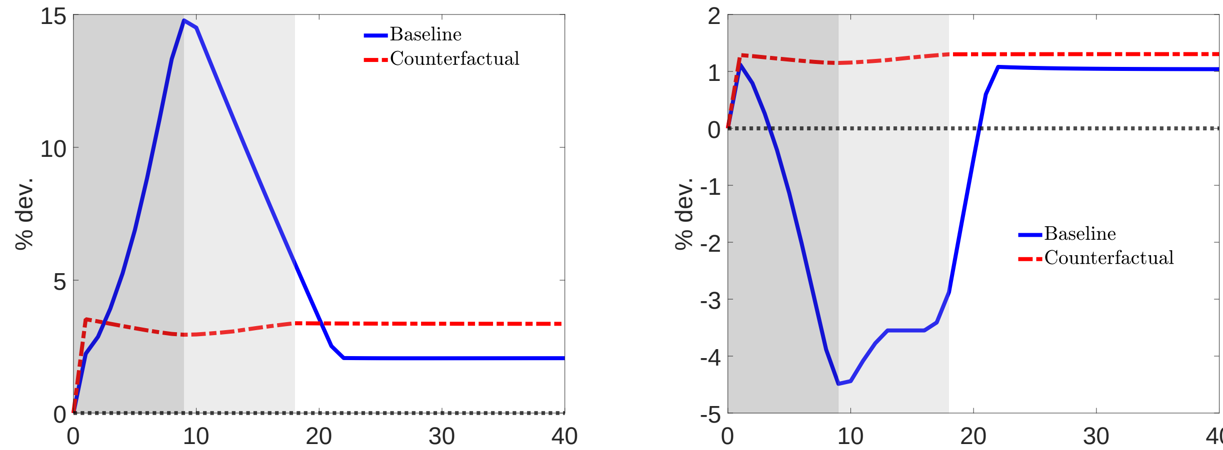
We first use the calibrated model to analyze the extent to which changes in wages determine labor reallocation. We focus both on intersectoral reallocation between tradables and nontradables as well as on reallocation within the tradable sector. Having a calibrated model allows us to document general equilibrium effects, furthering our understanding of the role of labor markets in the transmission of a commodity boom throughout the economy beyond the empirical results in Section 3.

For this purpose, we compare the baseline economy to a counterfactual economy in which the commodity sector's labor demand does not change in response to commodity price fluctuations, thus shutting down transmission through the labor market. Therefore, in the counterfactual economy, a commodity boom becomes purely an endowment shock. To construct this counterfactual economy, we fix the commodity sector's employment at the initial steady-state level. We calculate and feed to the counterfactual economy a path for the natural resource stock such that commodity output follows the same trajectory in the counterfactual and baseline economies. Thus, commodity prices, output, and revenue are identical in the baseline and counterfactual economies. In the counterfactual economy, by construction, the commodity super-cycle has no direct impact on wages. Second order wage movements in the counterfactual economy are the result of general equilibrium effects due to increases in wealth.

Consider first the reallocation of labor between the tradable and nontradable sectors. In the baseline economy, the commodity boom raises the demand for labor in the commodity sector, leading to an increase in wages during the boom (see Figure 4a), which implies a cost increase in both the tradable and nontradable sectors. Given that the tradable sector is unskilled intensive relative to the nontradable sector, the cost increase in the baseline economy is larger in the tradable sector. In addition, the increase in wages during the boom raises the prices of all goods, lowering the domestic demand for output, which has a negative impact on sales for the nontradable sector and on domestic sales for the tradable sector. Overlapping these mechanisms, the commodity price boom leads to a decline in employment in tradables relative to nontradables, as shown in Figure 5a. In contrast, in the counterfactual economy, the expansion of the commodity sector leads to changes in wages only through general equilibrium effects, so the reallocation of labor is driven primarily by changes in spending.[55]

By comparing the baseline and counterfactual economies, we find that about 55% (measured at the peak of the boom) of the intersectoral reallocation in labor between tradables and nontradables is due to changes in wages. The remaining reallocation can thus be attributed to the overall wealth increase in the economy due to the commodity boom, which causes a disproportionate increase in the demand for nontradables. It is worth noting that in the first periods, both the baseline and counterfactual economies behave similarly, and the difference appears gradually over time. The reason is that both economies immediately adjust to the increase in permanent wealth resulting from the forthcoming boom, while only the baseline economy faces a gradual reallocation of labor as a result of the transmission occuring through the labor market as the boom develops.

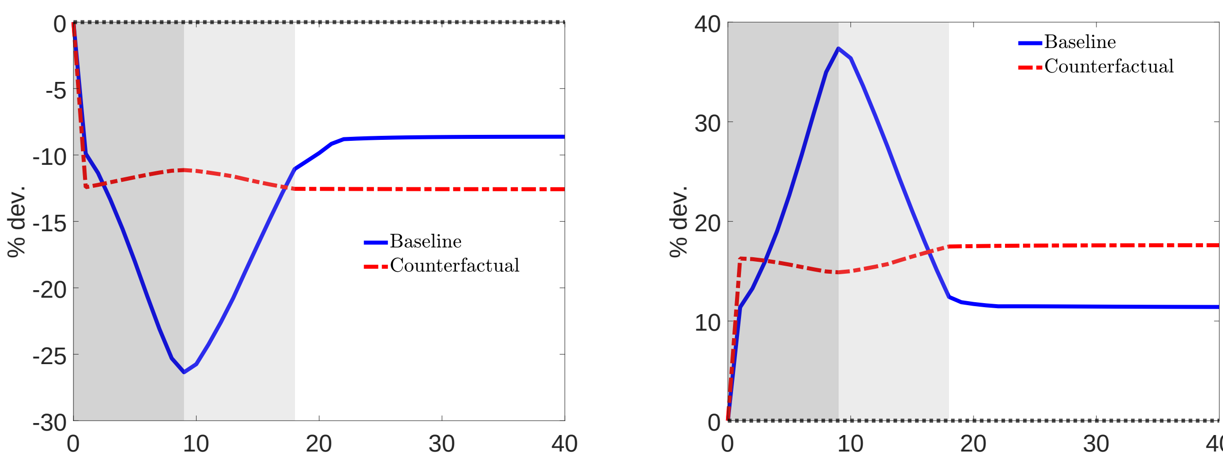
[55] Appendix Figure A29 contains additional plots of the path of wages in the baseline and counterfactual economies by skill type and region.



a) Unskilled Wage (Region A) b) Skill Premium (region A)

Figure 4: Wage Dynamics in the Baseline and Counterfactual Economies

Note: This figure shows the response of the unskilled wages and the skill premium in region A to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.



a) Relative T to N Employment (L^T/L^N) b) Relative Employment in Domestic to Exported Production for Marginal Exporter in T (L_d^T/L_x^T)

Figure 5: Employment Reallocation in the Baseline and Counterfactual Economies

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 in the marginal exporter defined in the text (right) to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.

The second outcome on which we focus is the intrasectoral reallocation of labor within the tradable sector, distinguishing between workers producing output for domestic sales versus exports.

In the baseline economy, the commodity boom raises local spending, which benefits goods sold locally relative to goods sold to other regions or exported abroad. In the tradable sector, this leads to an increase in employment oriented toward domestic relative to export sales during the boom.

We focus on a single firm that both sells domestically and exports in every period and compute the ratio between employment oriented to domestic versus export sales.[56] In Figure 5b, we plot this outcome in the baseline and counterfactual economies. Comparing both economies, we find that about 60% (measured at the peak of the boom) of the reallocation of labor within this marginal exporter in the tradable sector is due to changes in wages. Note that wages impact changes in the proportion of employment producing output for domestic versus export sales through general equilibrium effects. Higher wages in the domestic economy lead to an increase in prices, which, aggregated in the price index, lead to changes in demand for domestic relative to exported output. The remaining reallocation is caused by the wealth increase in the economy due to the commodity boom, which causes a disproportionate increase in the demand for local sales. As in the case of intersectoral reallocation, we see a similar behavior of the baseline and counterfactual economies in the initial period and a subsequent divergence for the same reason discussed earlier.

Next, we assess the role of wage movements on interregional migration. Figure 6a plots the population in region A in both economies.[57] In the counterfactual economy there is no migration.[58] In the baseline economy, in contrast, region A (i.e., the region facing the larger boom) receives an inflow of workers during the boom. The reason is that the boom leads to higher wages, therefore attracting workers. This is shown in Figure 6b, which plots the unskilled wage in region A relative to region B.[59] During the bust, a decline in wages (slowed by downward wage rigidity) and unemployment result in an outflow of workers from region A.

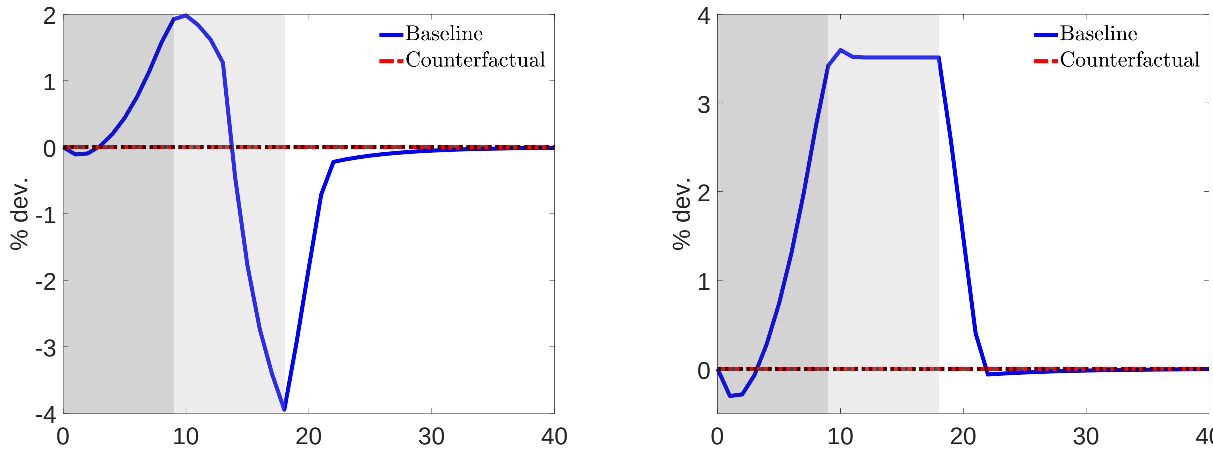
Overall, the findings on labor reallocation highlight the first order role played by the labor market in propagating commodity price cycles throughout the economy. In light of this, in the next section we study the role of labor market frictions in shaping the welfare impact of commodity price super-cycles.

[56] We choose a "marginal exporter" that is the least productive exporter at the peak of the boom (i.e. the least productive firm that exports in every period). In the counterfactual economy, we focus on a firm with the same productivity than this marginal exporter in the baseline economy.

[57] Appendix Figure A28 plots the population in region A by skill.

[58] There is no migration in the counterfactual economy because prices and wages move symetrically in both regions. This is because the household head receives profits from the commodity sector and allocates them equally to both regions.

[59] This pattern is similar for wages of skilled workers. Appendix C.8 plots the unskilled and skilled workers' wages by region.



a) Population in Region A

b) Relative Unskilled Wage between Regions A and B

Figure 6: Migration in the Baseline and Counterfactual Economies

NOTE: This figure shows the response of the population in region A (left) and the relative unskilled wage between regions A and B (right) to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.

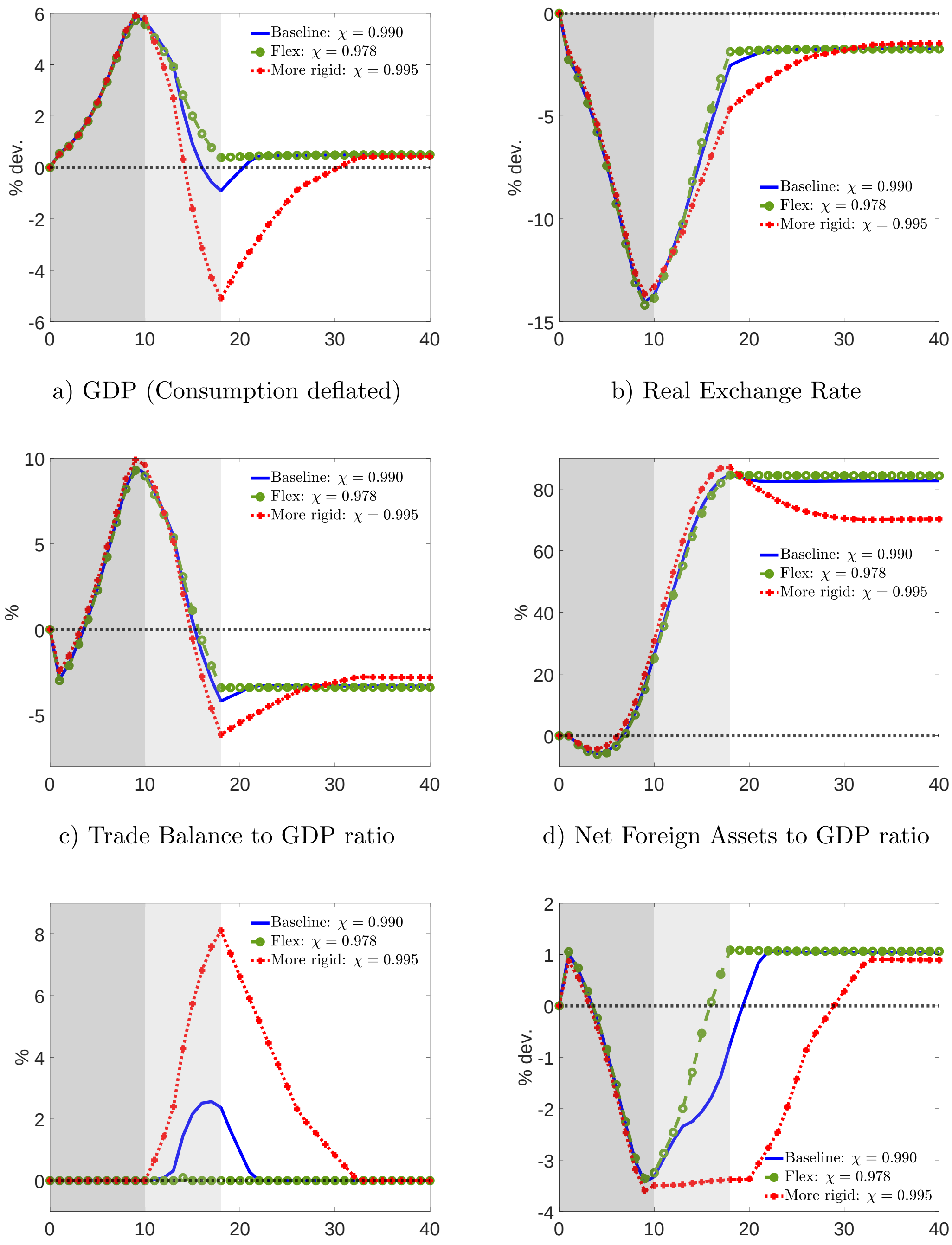
5.4 Aggregate Impacts and Welfare

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 real wage rigidity: a flexible economy ($\chi = 0.978$), 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 ($\chi = 0.995$). Recall that the degree of downward real wage rigidity (χ), which we vary here, is a result of both downward nominal wage rigidity ($\tilde{\chi}$) and the parameter capturing the importance given by the authority to unemployment relative to exchange rate stability (ϕ).

Figure 7e 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.[60,61] Figure 7f 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

[60] In Appendix A.2.11 we show that states which face a larger decline in commodity prices during the bust (2011-2015) also see a larger increase in the unemployment rate, which is consistent with the predictions of the model.

[61] Appendix Figure A25 shows the evolution of the unemployment rate under different degrees of rigidity by skill type and by region.



a) GDP (Consumption deflated) b) Real Exchange Rate

c) Trade Balance to GDP ratio d) Net Foreign Assets to GDP ratio

e) Unemployment f) Skill Premium

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 (center left), the net foreign assets to GDP ratio (center right), the unemployment rate (bottom left) and the skill premium (bottom right) 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 dotted line).

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. The reason is that, if wages were flexible, the downward adjustment of unskilled wages would be larger than that of skilled 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. This leads to a lasting difference in the allocation of employment between the flexible and more rigid economies, as shown in Appendix C.9.[62]

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 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 7% and real (consumption-deflated) GDP falling by up to 4%. Appendix C.11 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. Consistent with the empirical cross-country literature, the real exchange rate appreciates persistently (domestic prices increase as the economy is permanently wealthier).[63] 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, the household adjusts its permanent consumption level on impact and chooses 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 10 percentage points more foreign assets than the most rigid economy.[64,65] Note that less rigid economies accumulate more foreign assets and can therefore afford a larger trade balance deficit

[62] Further, Appendix C.7 describes the evolution of productivity cutoffs that pin down the extensive margin under different degrees of wage rigidity.

[63] The real exchange rate is defined as the inverse of the ideal price index.

[64] 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).

[65] These long-run effects of commodity price super-cycles are consistent with Alberola and Benigno [2017].

following the end of the commodity price super-cycle.

Next, 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.[66] We choose a range for the rigidity parameter that spans from the fully flexible economy to the highly rigid economy. Our $\chi = 0.990$ estimate 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 very large. Moving from a completely flexible labor market to the most rigid labor market reduces the consumption–equivalent welfare gain from the cycle from 1.8% to 0.5%.[67] Summing up, downward wage rigidity amplifies the impact of a commodity price super-cycle, generating deep and persistent recessions and unemployment at the end of the cycle.

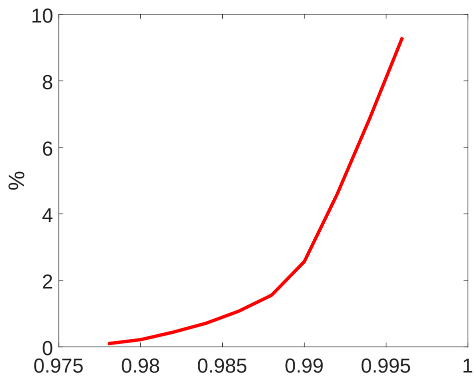
We motivated this section arguing that standard models in the literature view commodity booms as endowment shocks, abstracting from the transmission through the labor market. We showed earlier that labor markets are quantitatively important when studying the impact of a commodity price cycle on the reallocation of labor across and within sectors. We conclude by asking what are the aggregate impacts of acknowledging labor markets as a transmission mechanism. In Figure 9, we plot real GDP and the unemployment rate. In the counterfactual economy, the increase in GDP is more than twice as large, given that the lack of movement in wages implies that the commodity sector does not absorb labor from the other sectors. In addition, the counterfactual economy does not generate unemployment, given that as wages do not increase during the boom, the downward wage rigidity constraint does not become binding during the bust.[68] Thus, our model allows us to conclude that the omission of labor markets as a transmission mechanism of commodity booms leads to large differences in aggregate outcomes.

Finally, we evaluate the robustness of our quantitative results to modifications in key pa-

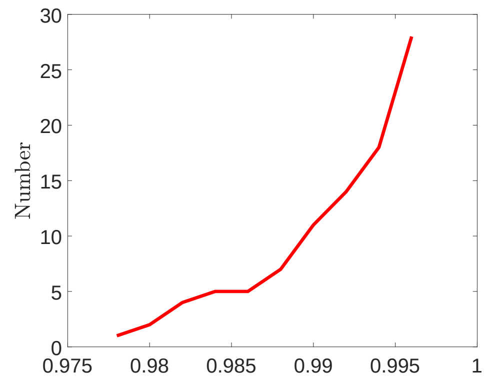
[66] To assess the impact of the commodity price super-cycle on welfare we calculate the consumption-equivalent welfare gain from the episode. This is the difference between the welfare gain of an economy exposed to the cycle W_{cycle} versus that of one not exposed W_0, measured as the amount of consumption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

$$\text{Consumption-Equivalent Welfare Gain} = \left(\frac{W_{cycle}}{W_0}\right)^{\frac{1}{1-\upsilon}} - 1\,. \tag{14}$$

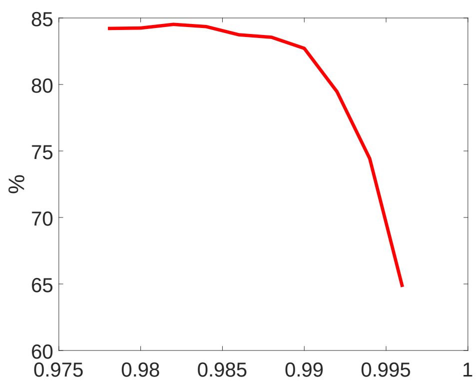
[67] Galí and Monacelli [2016] study the relationship between welfare and wage flexibility under different types of exchange rate regimes. They find that wage rigidities diminish welfare in an economy facing an export shock



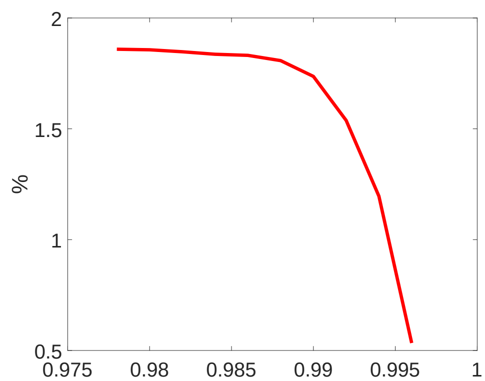
a) Peak Unemployment Rate (%)



b) Number of Periods with Positive Unemployment



c) Long-Run Net Foreign Assets to GDP ratio



d) Consumption-Equivalent Welfare (%)

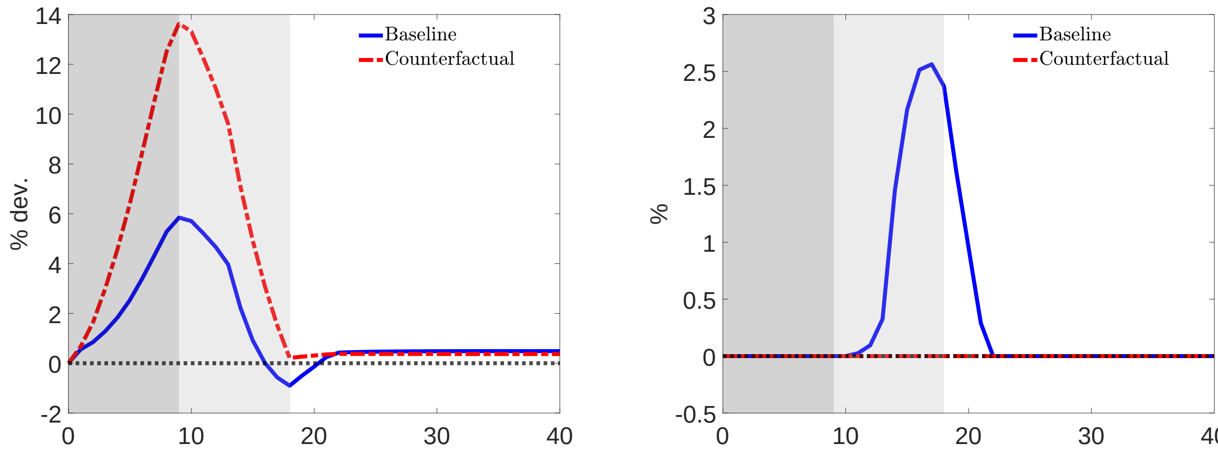
Figure 8: Aggregate Consequences of Downward Wage Rigidity

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.

rameters, including the location preferences (Appendix C.1), the fixed cost of interregional sales (Appendix C.2), and the fixed cost of international exports (Appendix C.3). We also show our results are robust to different assumptions regarding the initial bond holdings (Appendix C.4), and to allowing for a bond-holding cost that eliminates the long-run effects of commodity super-cycles (Appendix C.5). In Appendix Section C.6, we report the peak unemployment and consumption equivalent welfare of all these alternative simulations, showing that our quantitative results are robust to variations in key model parameters.

(irrespective of the exchange rate regime), which is consistent with our results.

[68]In Appendix C.10 we compare other aggregate outcomes in the baseline versus counterfactual economies.



a) Real GDP

b) Unemployment Rate

Figure 9: GDP and Unemployment Rate in the Baseline and Counterfactual Economies

Note: This figure shows the response of real GDP (left) and the unemployment rate (right) to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.

6 Conclusions

In this paper, we study the transmission of commodity price super-cycles throughout the economy. We combine rich administrative microdata, a novel empirical strategy, and a quantitative multi-sector model of firm dynamics to identify and quantify key transmission channels in the context of a large commodity boom in Brazil.

We focus on two key transmission channels that were originally proposed by Corden and Neary [1982]'s analysis of the Dutch disease. In response to a commodity boom, an increase in wealth boosts local demand. In addition, an increase in the commodity sector's labor demand generates a cost increase for all sectors of the economy. We extend this framework by studying the heterogeneous impact of each of these mechanisms across firms and sectors, depending on their exposure to local demand (in the case of the wealth channel) and on their skill intensity (in the case of the cost channel). This heterogeneity is the key to the empirical strategy we design to identify the existence of these channels in the data. Our empirical work exploits variation across Brazilian regions in terms of their exposure to the large commodity boom in the 2000s. Using unique microdata on the universe of formal-sector firms across the commodity, manufacturing, and services sectors, we provide clear evidence of the existence of these two transmission channels. We then build and calibrate a multisector and multiregion model that fits the empirical setting tightly to quantify the transmission mechanisms, study counterfactuals, and assess welfare. We find that transmission through the labor market is crucial. A counterfactual economy which abstracts from it experiences only 45% of the intersectoral labor reallocation between tradables and nontradables, and 40% of the labor reallocation between domestic and exported production within the tradable sector. Finally, we find that downward wage rigidity, prominent in an emerging-market context, reduces the welfare gains obtained from the super-cycle by more than 50% in comparison to a fully-flexible labor market.

Future work could examine optimal fiscal policy in the setting studied in this paper. First, our results suggest that a countercyclical tax on commodity production might reduce output cyclicality and thus the welfare costs emanating from labor market frictions. Second, in many emerging economies that are commodity exporters, fiscal spending tends to be procyclical, further increasing aggregate demand during the boom. Our findings, on the contrary, suggest the desirability of a countercyclical fiscal policy, which would not raise wages during the boom, and would help avoid a recession during the bust. Finally, our results promote policies that increase flexibility in the labor market and the exchange rate regime.

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A Empirical Appendix

A.1 Data and Additional Results

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.2.5; 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.2.6; 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.2.7. 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.1.10. 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.2.6 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 and Importer Status. We obtain a list of the universe of exporting and importing firms from Brazil's Secretariat of Foreign Trade (SECEX), which we match to RAIS. This is available at a 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.2.7.

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.2.8. This input-output table is produced by Brazil's Statistical Institute (IBGE).

Interregional Trade Patterns. We use data on interstate trade flows for 1999 compiled by Vasconcelos [2001] and recorded as a result of Brazil's state tax on the movement of goods and services (Imposto sobre Circulacao de Mercadorias e Servicos - ICMS). These data has also been used by Morten and Oliveira [2016].

Tradability Measure. We use a measure of industries' tradability constructed by Holmes and Stevens [2014] for the U.S. based on the Commodity Flow Survey. We map this to the Brazilian CNAE classification. Appendix A.1.11 provides more details and descriptive statistics.

Income Elasticities. We obtain industry-level measures of income elasticities from Borusyak and Jaravel [2018], estimated using the US consumer expenditure survey (CEX).

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.

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

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.

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*.

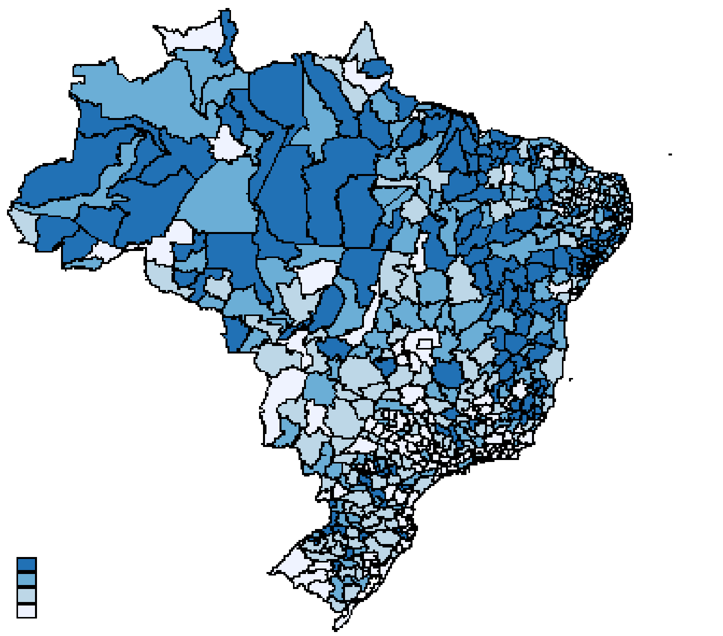


Figure A1: Regional Specialization in Commodities

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.

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.

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 (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.

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.

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..

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.[69] As in the skill-premium regression from the main text, we include region fixed effects as well as macroregion-by-time (quarter) fixed effects. 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 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.

To measure the impact on employment levels, we re-estimate equation (A1) but using total

[69] We show below that in fact commodity prices are positively correlated with total regional employment.

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. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

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. 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 mechanisms described 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. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.1.8 Regional Commodity Prices and Skilled and Unskilled Wages

In this section we report results regarding the impact of commodity prices on wages of unskilled and skilled workers. In the main text, equation (4) captures the relationship between the regional skill premium and the regional price index. Here, we replace the dependent variable by the log of the average skilled or unskilled wage. As in column 2 in Table 1, wages correspond to monthly (December) earnings. The results are shown in Table A9. They indicate that an increase in commodity prices leads to a large increase in unskilled wages. A one log point increase in the regional commodity price index is associated to a 0.163 log point in unskilled wages.[70] The coefficient for skilled wages is also positive but smaller in magnitude and not statistically significant.

Table A9: Commodity Prices and Regional Wages

	(1) Unskilled Wage	(2) Skilled Wage
(log) Price_{rt}	0.163^{***}	0.032
	(0.039)	(0.071)
Observations	7919	7912
R^2	0.925	0.841

NOTE: This table reports the results of the estimation of equation (4) with (log) unskilled wages (column 1) or (log) skilled wages (column 2) as the dependent variable. Wages correspond to monthly (December) earnings. 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.

[70] Note that this elasticity implies that 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 an 8.97 log point increase in unskilled wages.

A.1.9 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:[71] 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 at the firm level. We estimate this equation using annual data.[72]

Table A10 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.

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 spirit of (A2) but with a dummy variable taking a value of one if the firm's exports in period t, and zero otherwise.

Table A10 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.[73] These results are consistent

[71] 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.

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

[73] 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.

with the combined effect of the cost and wealth channels.

Table A10: 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.1.10 Downward Wage Rigidity in Brazil

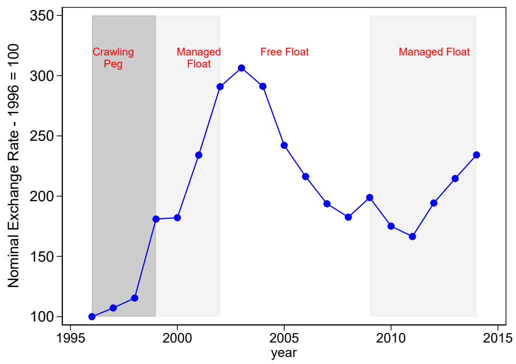
In what follows we provide evidence on the nature of wage adjustments in Brazil.[74] We first provide macroeconomic evidence of downward real wage rigidity. Next we document the distribution of individual wage changes, showing that wage cuts are significantly more infrequent in Brazil than in the US.

Macroeconomic Evidence of Downward Real Wage Rigidiy. In this section we discuss macroeconomic evidence of downward wage rigidity.

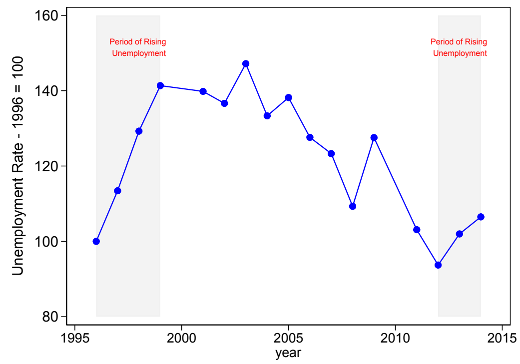
Following the analysis in Schmitt-Grohé and Uribe [2016], during 2012-2014, under rising unemployment, and a managed floating exchange rate regime, one would expect real wages to fall in the absence of rigidities. We show here that this was not he case, which is suggestive of downwardly rigid wages. During 2012-2014, real wages in fact actually grew at a rate of 1.7% annually. Note that this period coincides with the bust in commodity prices in Brazil, which is when our model predicts a binding rigidity constraint and unemployment.

Figure A3 plots the path of nominal wages, nominal wages in dollar terms, and real wages in each of these episodes. These are computed using the household survey PNAD. In the model, the numeraire is the price of imports. Consequently, real wages are defined as nominal wages (in dollars) divided by the price of a foreign basket, captured by the price index of Brazilian imports. Figure A2 plots the path of the nominal exchange rate and unemployment. 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.

[74] 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.



a) Nominal Exchange Rate

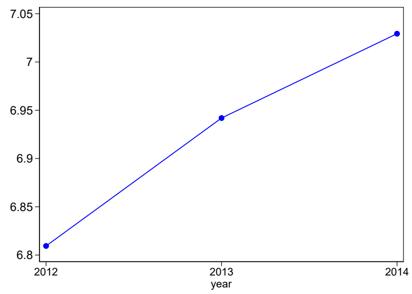


b) Unemployment Rate

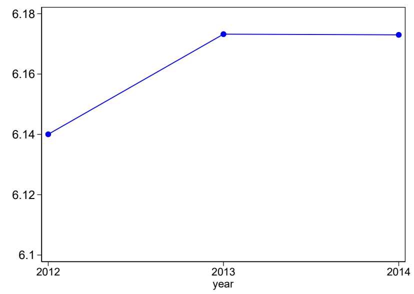
c) Commodity Price Index

Figure A2: Nominal Exchange Rate, Unemployment Rate and Commodity Price Index: 1996-2014

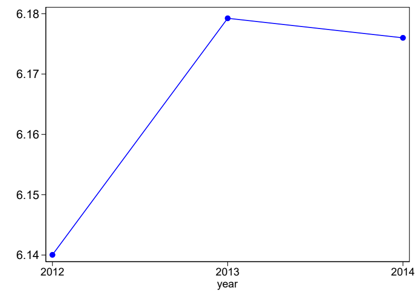
NOTE: This figure shows the path of the nominal exchange rate (in panel (a)), the unemployment rate (in panel (b)), and the commodity price index (in panel (c)). Unemployment is computed from the household survey PNAD. The nominal exchange rate and unemployment rate are indexed to 100 in 1996.



a) Nominal Wage (log)



b) Nominal Wage (in Dollar Terms) (log)



c) Real Wage (in Units of Imported Goods) (log)

Figure A3: Nominal and Real Wages in Brazil: 2012-2014

NOTE: This figure shows the path of nominal wages (in panel (a)), nominal wages in dollar terms (in panel (b)), and real wages (in panel (c)). Real wages are computed as nominal wages in dollar terms deflated by Brazil's import price index. All series are in logs and are computed from the household survey PNAD.

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 A4 shows the kernel density of the pooled distribution of wage changes.[75] 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.[76] 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 A5a and A5b show that the distribution of wage changes is similar for skilled and

[75] The path over time of the percentiles of this distribution are shown in Figure A5e.

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

unskilled individuals, as well as across sectors.[77] 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 A5c shows. We also classify region-year pairs into quartiles according to the intensity of regional commodity price shocks. As Figure A5d 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 A5e.

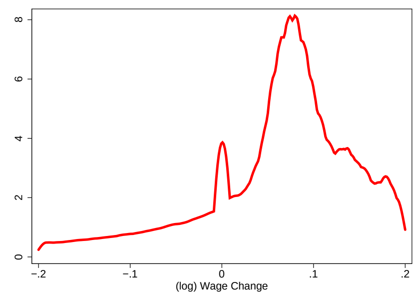


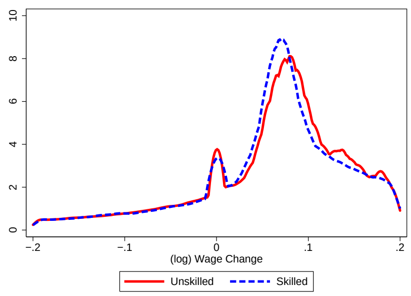
Figure A4: Distribution of Nominal Wage Changes

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

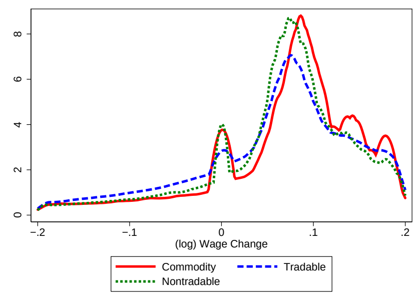
We also compute three measures used in the literature that capture asymmetries in the wage change distribution. Following Kurmann and McEntarfer [2017] we define the mass at zero as $M_0 = F(0.005) - F(-0.005)$, the excess zero spike as $ES_0 = [F(0.005) - F(-0.005)] + [F(2 \times median + 0.005)] -$

$[F(2 \cdot median - 0.005)]$, 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 A5f. All of these are indicative of downward wage rigidity.

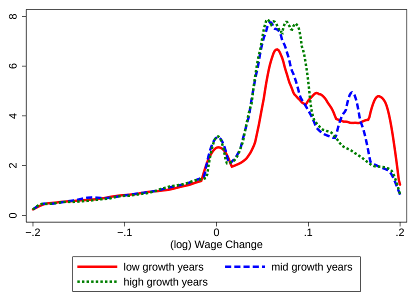
[77] This justifies why in the model we impose the same downward wage rigidity restriction to skilled and unskilled labor. This similar behavior of wage changes for skilled and unskilled workers is also consistent with a labor code that treats these two types of workers similarly.



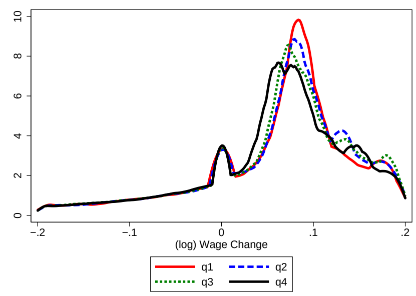
a) By skill



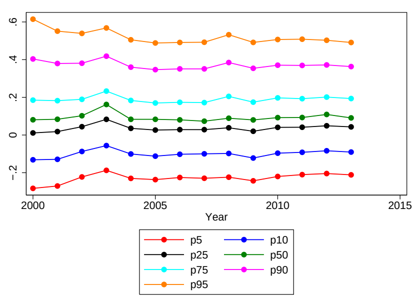
b) By sector



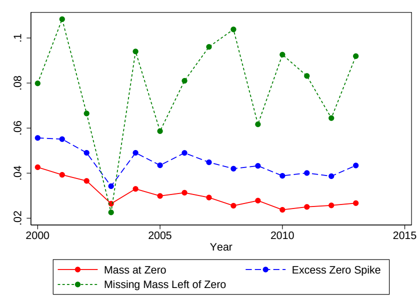
c) By year



d) By quartiles of regional commodity price shock



e) Percentiles



f) Statistics

Figure A5: 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.1.11 Tradability Measure

In Section 3 we use an industry measure of transportation costs to capture differences in tradability constructed by Holmes and Stevens [2014]. This measure is defined for the manufacturing sector. Holmes and Stevens [2014] construct this measure based on shipment distances of U.S. plants using the U.S. Commodity Flow Survey. We map the measure originally reported by four-digit SIC codes to the Brazilian CNAE classification.[78] Our tradability measure is defined for 99 3-digit industries. Table A11 reports summary statistics of Holmes and Stevens [2014]'s transport cost measure, η, across industries. Figure A6 plots the kernel density across industries. Note that in the main text we define Tradability $= -\eta$ for ease of interpretation. This means highly tradable industries are those with low transportation costs.

Table A11: Summary Statistics of Holmes and Stevens [2014]'s Transportation Cost Measure η

Mean	Std. deviation	25th Pct.	50th Pct.	75th Pct.
0.65	0.33	0.41	0.58	0.86

Note: This table reports summary statistics of Holmes and Stevens [2014]'s measure of industry transportation costs across CNAE 3-digit industries.

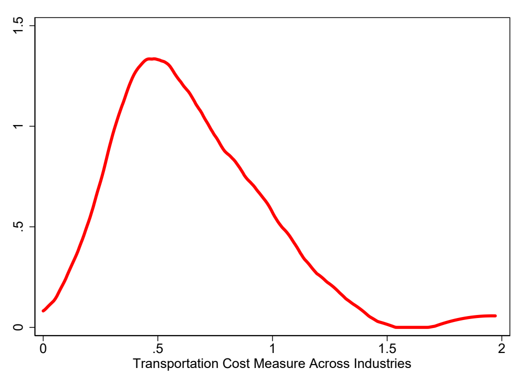


Figure A6: Kernel Density Estimate of Holmes and Stevens [2014]'s Transportation Cost Measure η

Note: This figure displays kernel density estimate of the distribution of Holmes and Stevens [2014]'s measure of industry transportation costs across CNAE 3-digit industries.

[78]For this purpose we use concordances from SIC to ISIC and from ISIC to CNAE.

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 of each tradable industry. The results, shown in in column 1 in Table (A12) below, are very similar to the baseline results in the main text.

Controlling for Region-Time Fixed Effects We also verify the robustness of equation (3) to including region by time fixed effects. These region-time fixed effects control for any region-specific shock and provide the strongest possible evidence of the robustness of our results. In this case, the first term in equation (3), the regional commodity price by itself, is absorbed by the fixed effects. The results, shown in column 2 in Table (A12) below, are consistent with those in the baseline case.

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

	Tradable (1)	Tradable (2)
(log) Price_{rt}	-0.042*	
	(0.022)	
Exporter_{ft}	0.134***	0.134***
	(0.004)	(0.005)
Exporter_{ft} x (log) Price_{rt}	-0.060***	-0.046***
	(0.014)	(0.015)
Skill Intensity_i x (log) Price_{rt}	0.278***	
	(0.108)	
Tradability_i x (log) Price_{rt}	-0.043**	-0.057***
	(0.016)	(0.017)
Observations	8,005,174	8,005,174
R^2	0.909	0.910

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. It includes firm as well as state-by-time (quarter) fixed effects. Column 2 includes firm and region by time (quarter) fixed effects so the first term (the regional commodity price on its own) is absorbed by the fixed effects. 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 A13 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 A13 below, are again similar to the baseline results discussed in the main text.

Controlling for Region-Time Fixed Effects We also verify the robustness of equation (2) to including region by time fixed effects. These region-time fixed effects control for any region-specific shock and provide the strongest possible evidence of the robustness of our results. In this case, the first term in equation (2), the regional commodity price by itself, is absorbed by the fixed effects.

The results, shown in column 3 in Table (A13) below, show even stronger evidence in favor of the cost channel than those in the baseline case.

Table A13: Commodity Prices and Firm-Level Employment: The *Cost* Channel

	Nontradable	Nontradable	Nontradable
	(1)	(2)	(3)
(log) Price_{rt}	0.033^{*}	0.056	
	(0.018)	(0.056)	
Skill Intensity_i x (log) Price_{rt}	0.485^{***}	0.430^{***}	0.844^{***}
	(0.069)	(0.094)	(0.117)
Observations	30,453,457	30,453,457	30,453,457
R^2	0.891	0.850	0.850

NOTE: This table reports the results of the estimation of equation (2) for the nontradable sector. Column 1 includes (but does not display) the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50 workers, 50 to 100 workers, 100 to 500 workers, 500 to 1000 workers, and 1000 and more workers. Column 2 includes the interaction between the regional commodity price index and two-digit industry dummy variables. Columns 1 and 2 include firm and state-by-time (quarter) fixed effects. Column 3 includes firm and region by time (quarter) fixed effects so the first term (the regional commodity price on its own) is absorbed by the fixed effects. 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.

A.2.3 Exporters, Importers and the Exchange Rate.

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

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 (A14) below, confirm the robustness of our main findings.

Table A14: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	(1)	(2)	(3)
(log) Price_{rt}	-0.043**	-0.045**	-0.043**
	(0.022)	(0.022)	(0.022)
Exporter_{ft}	0.135***	0.124***	0.124***
	(0.004)	(0.004)	(0.004)
Exporter_{ft} x (log) Price_{rt}	-0.065***	-0.132***	-0.133***
	(0.015)	(0.013)	(0.013)
Tradability_i x (log) Price_{rt}	-0.039**	-0.052***	-0.052***
	(0.017)	(0.017)	(0.017)
Exporter_{ft} x Exchange Rate_t	-0.017**		0.000
	(0.007)		(0.007)
Importer_{ft}		0.099***	0.099***
		(0.006)	(0.006)
Importer_{ft} x (log) Price_{rt}		0.200***	0.192***
		(0.018)	(0.018)
Importer_{ft} x Exchange Rate_t			-0.017***
			(0.006)
Observations	8,005,174	8,005,174	8,005,174
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. Standard errors are clustered by firm. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

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 A17. The results for the wealth channel (eq. (3)) are shown in column 1 in Table A18. 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. These linkages could lead to geographic spillovers. Following Allcott and Keniston [2018] 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 takes 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.[79] 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 A17. The results for the wealth channel (eq. (3)) are shown in column 2 in Table A18. The fact that the coefficients are very similar to those in the baseline case in the main text indicate that geographic spillovers are small in magnitude. These results are also robust to i) assigning lower weight to more distant regions and ii) modifying the 100 km. radius.

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

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 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 (A15) below, indicate that it is the trend component (which we use in our empirical analysis in the main text) that drives the results. These result also indicate that using the unfiltered price index leads to very similar results than using the trend.

Table A15: Firm-Level Employment: *Cost* and *Wealth* Channels

	Cost Channel		Wealth Channel	
	Nontradable (1)	Nontradable (2)	Tradable (3)	Tradable (4)
(log) Price$_{rt}$	0.010		-0.005	
	(0.008)		(0.009)	
(log) Price Trend$_{rt}$		0.013		-0.046**
		(0.021)		(0.022)
(log) Price Cycle$_{rt}$		0.005		0.010**
		(0.003)		(0.005)
Exporter$_{ft}$			0.135***	0.135***
			(0.005)	(0.005)
Exporter$_{ft}$ x (log) Price$_{rt}$			-0.043***	
			(0.012)	
Exporter$_{ft}$ x (log) Price Trend$_{rt}$				-0.054***
				(0.015)
Exporter$_{ft}$ x (log) Price Cycle$_{rt}$				-0.005
				(0.010)
Tradability$_i$ x (log) Price$_{rt}$			-0.019*	
			(0.011)	
Tradability$_i$ x (log) Price Trend$_{rt}$				-0.041**
				(0.017)
Tradability$_i$ x (log) Price Cycle$_{rt}$				0.021***
				(0.006)
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	8,005,174	8,005,174
R^2	0.849	0.849	0.909	0.909

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). Columns 3 and 4 include the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers. Each regression includes firm as well as state-by-time (quarter) fixed effects. Standard errors are clustered by firm. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.5 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 based on Brazil's Demographic Census.[80]

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 (A3) and (A4).[81]

$$\log(\text{Emp})_{ft} = \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \alpha_1 \cdot [\text{Price}_{rt} \times \text{Informality Share}_r] + \gamma_f + \delta_t + \epsilon_{ft}\ , \quad \text{(A3)}$$

$$\log(\text{Emp})_{ft} = \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_{w1} \cdot [\text{Exporter}_{ft} \times \text{Price}_{rt}] + \beta_{w2} \cdot [\text{Tradability}_i \times \text{Price}_{rt}] + \beta_2 \cdot [\text{Price}_{rt} \times \text{Informality Share}_r] + \gamma_f + \delta_t + u_{ft}\ . \quad \text{(A4)}$$

The results for the cost channel (eq. (A3)) are shown in columns 5 and 6 in Table A17. 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

[80]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.

[81]We estimate equations (A3) and (A4) demeaning the commodity price index and the informality share variables.

wealth channel (eq. (A4)) are shown in column 3 in Table A18. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status and with industry tradability is also small in comparison to the baseline case.

A.2.6 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:

$$\Delta \text{IP}_r = \sum_i \frac{L_{ir}}{L_i} \cdot \frac{\Delta \text{Imports}_i}{L_r} \,. \tag{A5}$$

where $\Delta\text{Imports}_i$ 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 ΔIP_r, as shown in equations (A6) and (A7).[82]

$$\log(\text{Emp})_{ft} = \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \alpha_1 \cdot [\text{Price}_{rt} \times \Delta\text{IP}_r] + \gamma_f + \delta_t + \epsilon_{ft} \,, \tag{A6}$$

$$\log(\text{Emp})_{ft} = \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_{w1} \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] + \beta_{w2} \cdot [\text{Tradability}_i \times \text{Price}_{rt}] + \beta_2 \cdot [\text{Price}_{rt} \times \Delta\text{IP}_r] + \gamma_f + \delta_t + u_{ft} \,. \tag{A7}$$

Note that studies of the impact of trade shocks on regional outcomes, such as Autor et al.

[82] We estimate equations (A6) and (A7) demeaning the commodity price index and standardizing the trade exposure variable to have mean zero and standard deviation one.

[2013] instrument ΔIP_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 ΔIP_r is 0.9725. Given this extremely high correlation, we report OLS results for equations (A6) and (A7). We find very similar results if we use this instrument instead of ΔIP_r in equations (A6) and (A7).

The results for the cost channel (eq. (A6)) are shown in columns 7 and 8 in Table A17. While the interaction term between the regional commodity price index and the regional change in import competition measure ΔIP_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. (A7)) are shown in column 4 in Table A18. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status and industry tradability is also small in comparison to the baseline case.

A.2.7 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.[83] We define a regional measure of trade liberalization as follows:

$$\Delta\tau_r = \sum_i \frac{L_{ir}}{L_r} \cdot \Delta\tau_i \, , \tag{A8}$$

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 (A8).[84]

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 (A9) and (A10).[85].

$$\begin{aligned} \log(\text{Emp})_{ft} = {} & \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] \\ & + \alpha_1 \cdot [\text{Price}_{rt} \times \Delta\tau_r] + \gamma_f + \delta_t + \epsilon_{ft} \, , \end{aligned} \tag{A9}$$

$$\begin{aligned} \log(\text{Emp})_{ft} = {} & \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_{w1} \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] + \beta_{w2} \cdot [\text{Tradability}_i \times \text{Price}_{rt}] \\ & + \beta_2 \cdot [\text{Price}_{rt} \times \Delta\tau_r] + \gamma_f + \delta_t + u_{ft} \, . \end{aligned} \tag{A10}$$

The results for the cost channel (eq. (A9)) are shown in columns 9 and 10 in Table A17. While the interaction term between the regional commodity price index and the regional trade

[83] 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].

[84] 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.

[85] We estimate equations (A9) and (A10) demeaning the commodity price index and the tariff change variable

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. (A9)) are shown in column 5 in Table A18. The difference in the impact of the price index on firm-level employment and its interaction with firms' exporting status and industry tradability is also small in comparison to the baseline case.

A.2.8 Upstream and Downstream Linkages.

In this section we explore the role of upstream and downstream linkages in the transmission across industries of commodity price fluctuations. We establish that while this is a complementary transmission channel it does not invalidate the results presented in the main text regarding the identification of the cost and wealth channels.

- First, following Allcott and Keniston [2018], we define industries with upstream and downstream linkages to the commodity sector, based on Brazil's input-output table. Details on this defintion are provided below.

- Next, we show that an increase in the regional commodity price leads to an increase in employment in industries that are defined as upstream from the commodity sector and a decline in employment in downstream industries. The results, discussed in more detail below, are shown in Table A16. We find that the coefficients used to identify the cost and wealth channels (in equations (2) and (3)) remain essentially unchanged when we introduce interaction terms between the regional commodity price index and dummy variables capturing the upstream and downstream status of industries.

Definition and measurement of upstream and downstream industries 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 22 two-digit manufacturing industries. This table is obtained from Brazil's Statistical Agency, IBGE.

To define upstream industries we compute what fraction of output each industry ships to the commodity sector. We mark as upstream five industries that ship more than 5% of their output directly to the commodity sector. These upstream industries are *manufacture of chemicals and chemical products*, *food and beverages manufacturing*, *machinery and equipment manufacturing*, *coke, refined petroleum, and other fuels manufacturing*, and *manufacture of fabricated metal products*.

To define downstream industries, we compute the share of inputs sourced from the commodity sector. We mark as downstream industries that source more than 5% of their inputs from the commodity sector. These downstream industries are *coke, refined petroleum, and other fuels manufacturing*, *tobacco manufacturing*, *food and beverages manufacturing*, *manufacture of wood and wood products (except furniture)*, *manufacture of basic metals*.

Overall, we have five downstream, five upstream, and twelve unlinked two-digit industries.

Note that two industries are classified as both upstream and downstream relative to the commodity sector. This is reasonable. *Food and beverages manufacturing* uses crops as an input, and it produces animal feed. *Coke, refined petroleum, and other fuels manufacturing* uses oil and gas as an input and is used as fuel in farming or mining.

Results 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 dummy variables for upstream and downstream industries.

$$\log(\text{Emp})_{ft} = \alpha_0 \cdot \text{Price}_{rt} + \alpha_c \cdot [\text{Price}_{rt} \times \text{Skill Intensity}_i] + \alpha_1 \cdot [\text{Price}_{rt} \times \text{Upstream}_i] + \alpha_2 \cdot [\text{Price}_{rt} \times \text{Downstream}_i] + \gamma_f + \delta_t + \epsilon_{ft}\ , \quad \text{(A11)}$$

$$\log(\text{Emp})_{ft} = \beta_0 \cdot \text{Price}_{rt} + \beta_1 \cdot \text{Exporter}_{ft} + \beta_{w1} \cdot \left[\text{Exporter}_{ft} \times \text{Price}_{rt}\right] + \beta_{w2} \cdot [\text{Tradability}_i \times \text{Price}_{rt}] + \beta_2 \cdot [\text{Price}_{rt} \times \text{Upstream}_i] + \beta_3 \cdot [\text{Price}_{rt} \times \text{Downstream}_i] + \gamma_f + \delta_t + u_{ft}\ . \quad \text{(A12)}$$

Our results for the cost channel regression (equation (A11)) are shown in column 1 in Table A16. The sample corresponds to the tradable (i.e. manufacturing) sector. These results can be compared to the baseline estimation in column 5 in Table 2. The elasticity of firm employment to commodity prices is -0.17 for unlinked firms, 0.12 for upstream firms and -0.31 for downstream firms. The coefficient on the interaction term between the regional commodity price and industry skill intensity is larger than in the baseline case. Its magnitude is such that the elasticity of firm employment to commodity prices for firms at the 25th and 75th percentiles of skill intensity is -0.19 and -0.16 respectively.

The results for the wealth channel regression (equation (A12)) are shown in column 2 in Table A16, and can be contrasted to the baseline estimation in Table 3. In this case, we find similar coefficients on the upstream and downstream dummy variables in comparison to column 1. The elasticity of firm employment to commodity prices is -0.07 for unlinked firms, 0.13 for upstream firms and -0.17 for downstream firms. The coefficients on the interaction term between the regional commodity price and exporting status and on the interaction term between the regional commodity price and industry tradability are very close to those found in the main text (Table 3).

Table A16: Firm-Level Employment and Input-Output Linkages

	Cost Channel (1)	Wealth Channel (2)
(log) Price_{rt}	-0.173***	-0.068***
	(0.031)	(0.022)
Upstream_i x (log) Price_{rt}	0.291***	0.195***
	(0.019)	(0.014)
Downstream_i x (log) Price_{rt}	-0.146***	-0.099***
	(0.022)	(0.014)
Skill Intensity_i x (log) Price_{rt}	0.413**	
	(0.175)	
Exporter_{ft}		0.133***
		(0.004)
Exporter_{ft} x (log) Price_{rt}		-0.060***
		(0.014)
Tradability_i x (log) Price_{rt}		-0.040**
		(0.016)
Observations	8,007,422	8,005,174
R^2	0.873	0.909

NOTE: This table reports the results of the estimation of equations (2) (in column 1) and (3) (in column 2) for the tradable sector. In each case, we add interaction terms between the regional price index and dummy variables for upstream and downstream industries (see text). Each regression includes firm as well as state-by-time (quarter) fixed effects. Column 2 includes the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers. Note we demean the commodity price index, skill intensity and tradability variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.9 Robustness Results.

Table A17: 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. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Table A18: Firm-Level Employment and Export Status in the Tradable Sector: The *Wealth* Channel

	Excl. Oil and Gas (1)	Nearby Regions (2)	Informality (3)	China Shock (4)	Trade Liberalization (5)
(log) Price_{rt}	-0.013	-0.070**	-0.053**	-0.038**	-0.049**
	(0.022)	(0.034)	(0.022)	(0.022)	(0.022)
Exporter_{ft}	0.135***	0.135***	0.135***	0.135***	0.135***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Exporter_{ft} x (log) Price_{rt}	-0.051***	-0.052***	-0.053***	-0.056***	-0.054***
	(0.017)	(0.016)	(0.015)	(0.015)	(0.015)
Tradability_i x (log) Price_{rt}	-0.038**	-0.037**	-0.034**	-0.043**	-0.037**
	(0.019)	(0.018)	(0.017)	(0.017)	(0.017)
Informality Share_r x (log) Price_{rt}			0.184***		
			(0.067)		
ΔIP_r x (log) Price_{rt}				0.018*	
				(0.010)	
$\Delta \tau_r$ x (log) Price_{rt}					0.004
					(0.005)
Observations	8,005,174	8,005,174	8,005,174	8,005,174	8,005,174
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. All columns include the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers.Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.10 Identification of the Wealth Channel based on Differences in Income Elasticities within the Nontradable Sector and Robustness of Results to Controlling for Income Elasticities.

Identification of the Wealth Channel based on Differences in Income Elasticities An alternative approach to identifying the wealth channel is based on variation across nontradable industries exploiting differences in income elasticities. If a commodity price increase leads to an increase in wealth and consequently an increase in the local demand for nontradables, this should lead to a relative expansion in industries with a higher income elasticity. We estimate the following equation in which we interact the regional commodity price index with a measure of industry-level income elasticities.

$$\log(\text{Emp})_{ft} \quad = \quad \beta_0 \cdot \text{Price}_{rt} + \beta_w \cdot [\text{Price}_{rt} \times \text{Income Elasticity}_i] + \gamma_f + \delta_t + \epsilon_{ft} \,. \qquad \text{(A13)}$$

We obtain income elasticities from Borusyak and Jaravel [2018]. These are constructed based on the U.S. Consumer Expenditure Survey and reported according to BEA I-O codes. We use a concordance to transform them first to the ISIC classification and then to the Brazilian CNAE classification. We are able to obtain measures of income elasticities that vary by two-digit industry.

Note that while not shown in the equation, we control for the interaction of the price index and industry skill intensity. The results are shown in Table A19. They indicate that among nontradable industries with higher income elasticities the positive response of firm employment to an increase in the regional commodity price index is larger, and the coefficient on the interaction term is statistically significant. The magnitude is such that the total elasticity of firm employment to the regional commodity price index is -0.02 for firms in industries at the 25th percentile of income elasticity and 0 for firms in industries at the 75th percentile of income elasticity.

Robustness of Results to Controlling for Income Elasticities Table A20 shows the results of estimation equations (2) and (3) for the tradable sector controlling for the interaction between the regional commodity price index and the income elasticity of each firm's industry.

Table A19: Firm-Level Employment and Income Elasticities in the Nontradable Sector: Alternative Identification of the *Wealth* Channel

	Nontradable
	(1)
(log) Price_{rt}	-0.007
	(0.030)
Skill Intensity_i x (log) Price_{rt}	0.559^{***}
	(0.089)
Income Elasticity_i x (log) Price_{rt}	0.055^{**}
	(0.021)
Observations	22,859,404
R^2	0.842

NOTE: This table reports the results of the estimation of equation (A13). The regression includes firm and state-by-time (quarter) fixed effects. Note we estimate equation (A13) demeaning all variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

Table A20: Commodity Prices and Firm-Level Employment: Controlling for Income Elasticities

	Cost Channel	Wealth Channel
	(1)	(2)
(log) Price_{rt}	-0.123^{***}	-0.135^{***}
	(0.030)	(0.039)
Skill Intensity_i x (log) Price_{rt}	0.604^{***}	
	(0.182)	
Income Elasticity_i x (log) Price_{rt}	0.177^{**}	0.076^{**}
	(0.023)	(0.035)
Exporter_{ft}		0.121^{***}
		(0.004)
Exporter_{ft} x (log) Price_{rt}		-0.127^{***}
		(0.012)
Tradability_i x (log) Price_{rt}		-0.036^{**}
		(0.015)
Observations	8,002,953	6,894,808
R^2	0.873	0.899

NOTE: This table reports the results of the estimation of equations (2) (in column 1) and (3) (in column 2) for the tradable sector. The regression includes firm and state-by-time (quarter) fixed effects. Column 2 includes the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers.. Note we demean all variables. Standard errors are clustered by region. ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

A.2.11 Commodity Prices and Unemployment

In this section we document the effect of commodity prices on unemployment, showing that states experiencing a larger decline in commodity prices during the bust of 2011-2015 also experience larger increases in unemployment. It is important to note that unemployment data with national geographical coverage is quite limited in Brazil. We compute state-level unemployment rates at an annual frequency using the household survey PNAD.[86,87]

The prediction of our model regarding unemployment is that states facing larger declines of commodity prices during the bust (i.e. the period of declining commodity prices) will see larger increases in unemployment. During the period 2002-2011, all regions in Brazil faced an increase in commodity prices, while nearly all faced a decline after 2011. To analyze the bust, we extend the data beyond our baseline sample, now going up to 2015. Figure A7 shows a scatterplot between the 2011-2015 change in unemployment rates (in the vertical axis) and the 2011-2015 (log) change in commodity prices (in the horizontal axis). The 2011-2015 change in regional commodity prices in the horizontal axis is normalized by the change in commodity prices during the boom years (2002-2011). In this way, the horizontal axis captures the extent of the bust *relative* to the magnitude of the boom. There is a clear negative correlation between the change in commodity prices and the unemployment rate across states. A linear fit has a slope -0.022 and is almost statistically significant (with a p-value of 0.135).

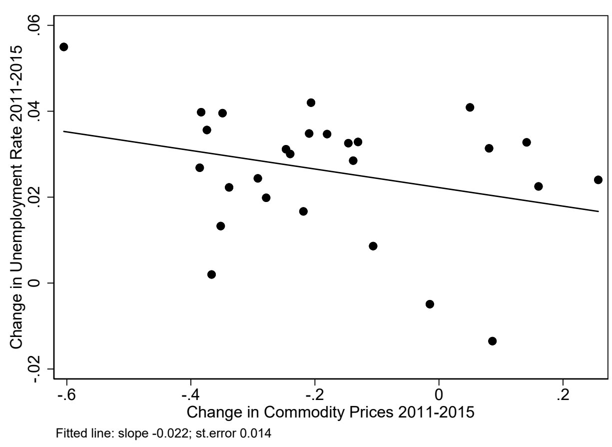


Figure A7: Commodity Prices and Unemployment

NOTE: This figure displays a scatter plot between between state-level changes in unemployment rates (in the vertical axis) and (log) changes in commodity prices (in the horizontal axis).

[86] The alternative source of unemployment data in Brazil is the Pesquisa Mensual de Emprego (PME), only available for 12 large urban centers.

[87] The PNAD survey does not report more disaggregate regional data beyond the state level, and does not report quarterly or monthly data.

A.2.12 Standard Errors

Our regional price index defined in equation (1) is a weighted average of commodity prices, with weights given by initial regional employment shares in each commodity industry. Adao et al. [2019] develop a method to compute standard errors in cross-regional regressions with these type of regressors. In this section we apply this method to both of our baseline results in Section 3. Specifically, we apply the method detailed in remark 5 in Adao et al. [2019] extended to a panel setting as explained in section V.B in their paper.

Note that our firm-level employment regressions differ from the examples in Adao et al. [2019] in that the unit of observation is a firm-period rather than a region-period. Nevertheless Adao et al. [2019]'s method extends naturally to this situation.

Note also that the regional commodity price index used throughout the paper is the HP trend of the logarithm of the weighted average of individual commodity prices, defined in equation (1) and copied below (i.e. it is a transformation of a shift-share variable).

$$p_{rt} = \frac{\sum\limits_{c \epsilon C} p_{ct} \times e_{cr}}{\sum\limits_{c \epsilon C} e_{cr}}, \tag{A14}$$

Adao et al. [2019]'s method to compute standard errors does not apply to transformations of shift-share variables. To show that our results are robust to Adao et al. [2019]'s correction, we define the following regional commodity price index as a weighted average of the log of individual commodity prices:

$$p_{rt} = \frac{\sum\limits_{c \epsilon C} log(p_{ct}) \times e_{cr}}{\sum\limits_{c \epsilon C} e_{cr}}. \tag{A15}$$

The correlation with the price index used in the main text is very high (0.92).

Table A21 shows our results. As we discussed in the main text, the standard errors on the coefficients of interest (i.e. on the interaction terms) computed following Adao et al. [2019]'s procedure are lower than the standard errors in our baseline results. Note that Adao et al. [2019]'s correction does not necessarily imply larger standard errors.

Table A21: Firm-Level Employment: Cost and Wealth Channels

	Cost Channel	Cost Channel	Wealth Channel
	Tradable	Nontradable	Tradable
	(1)	(2)	(3)
(log) Price_{rt}	-0.044	0.016^{**}	-0.003
	(0.207)	(0.008)	(0.013)
Skill Intensity_i x (log) Price_{rt}	0.605^{***}	0.646^{***}	
	(0.127)	(0.011)	
Exporter_{ft}			0.138^{***}
			(0.0002)
Exporter_{ft} x (log) Price_{rt}			-0.043^{***}
			(0.001)
Tradability_i x (log) Price_{rt}			-0.021^{*}
			(0.012)
Observations	8,007,422	30,453,437	8,005,174

Note: This table reports the results of the estimation of equations (2) (in columns 1 and 2) and (3) (in column 3). Each regression includes firm as well as state-by-time (quarter) fixed effects. Column 3 includes the interaction between the regional commodity price index and the following firm-size dummies (as well as the uninteracted dummies): 5 to 50, 50 to 100, 100 to 500, 500 to 1000, and 1000 or more workers. Note we demean the commodity price index, skill intensity and tradability variables. Standard errors are computed following Adao et al. [2019] (see text). ***, **, and * denote statistical significance at a 1, 5 and 10 percent confidence level.

B Model Appendix

B.1 Nominal Exchange Rate Policy and Unemployment

In this section we characterize the equilibrium relationship between the nominal exchange rate and unemployment and derive the real downward wage rigidity constraint stated in the main text. Recall that $\left(w_t^{dl}\right)^*$ is the real wage that achieves full employment for skill-type d and region l. Recall also that $\epsilon_t \equiv \mathcal{E}_t/\mathcal{E}_{t-1}$ is the depreciation rate of the domestic currency.

As we mentioned in the main text, the exchange rate regime is characterized by a managed float. We assume the authority's goals are exchange rate stability and avoiding unemployment. We assume the authority operates under the following rule, which reflects a trade-off between these two goals. The authority mantains a fixed exchange rate if there is no unemployment under it. This happens when the full employment real wage in all labor markets is above a threshold defined by the rigidity parameter $\tilde{\chi}$. Specifically, when $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} \geq \tilde{\chi}$.[88] Otherwise, the authority sets a depreciation rate:

$$\epsilon_t = \left(\min_{\{d,l\}}\left\{\frac{w_t^{dl}}{w_{t-1}^{dl}}\right\}\right)^{-\phi} \tag{A16}$$

with $\phi \in [0,1]$. This depreciation rate is a function of the ratio $\frac{w_t^{dl}}{w_{t-1}^{dl}}$ between real wages in t and $t-1$ in the labor market in which this ratio is the lowest. The parameter ϕ captures the extent to which the authority is concerned about exchange rate stability relative to unemployment

Under this regime, we can distinguish three possible cases. First, full employment and a fixed exchange rate, $\epsilon_t = 1$. Second, full employment and $\epsilon_t > 1$. Third, unemployment and $\epsilon_t > 1$. Below we describe each of these cases.

Case 1: Full employment and a fixed exchange rate ($\epsilon_t = 1$): The downward nominal wage rigidity constraint does not bind for any labor market under $\epsilon_t = 1$. This implies the full employment real wages are such that $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} \geq \tilde{\chi}$. With no unemployment, the authority has no reason to change the nominal exchange rate.

Case 2: Full employment and $\epsilon_t > 1$: The authority would face unemployment at $\epsilon_t = 1$, which implies that the full employment real wages are such that $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} < \tilde{\chi}$. Nevertheless, a depreciation rate $\epsilon_t > 1$ according to equation (A16) can achieve full employment.

[88] The downward wage rigidity constraint in terms of real wages is $w_t^{dl} \geq \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}$. There is unemployment in a labor market if $\left(w_t^{dl}\right)^* < \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}$. Evaluated at $\epsilon = 1$ this is $\left(w_t^{dl}\right)^* < \tilde{\chi} w_{t-1}^{dl}$.

Given that under full employment the observed real wage w_t^{dl} is equal to the full employment real wage $\left(w_t^{dl}\right)^*$, the depreciation rate set by the authority can be written as a function of $\left(w_t^{dl}\right)^*$:

$$\epsilon_t^* = \left(\min_{\{d,l\}} \left\{ \frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}} \right\} \right)^{-\phi}$$

There is full employment in a labor market if $\left(w_t^{dl}\right)^* \geq \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}$. Replacing the depreciation rate set by the authority in this inequality indicates there is full employment in a given labor market if:

$$\left(w_t^{dl}\right)^* \geq \tilde{\chi}^{\frac{1}{1-\phi}} w_{t-1}^{dl}$$

Consequently, all labor markets are under full employment if:

$$\left(\min_{\{d,l\}} \left\{ \frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}} \right\} \right) \geq \tilde{\chi}^{\frac{1}{1-\phi}}$$

This inequality provides a lower bound for the full employment real wages. Summing up, for a range of values of the full employment real wages such that:

$$\tilde{\chi}^{\frac{1}{1-\phi}} \leq \min_{\{d,l\}} \left\{ \frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}} \right\} < \tilde{\chi}$$

, there is no unemployment and the depreciation rate is $\epsilon_t > 1$. In this case, the nominal wage rigidity constraint does not bind for any labor market.

Case 3: Unemployment and $\epsilon_t > 1$: In this case, the depreciation rate set by the authority (in equation (A16)) does not lead to full employment.

There is unemployment in a given labor market if $\left(w_t^{dl}\right)^* < \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}$. Replacing the depreciation rate set by the authority in this inequality indicates there is unemployment in a given labor market if:

$$\left(w_t^{dl}\right)^* < \tilde{\chi}^{\frac{1}{1-\phi}} w_{t-1}^{dl}$$

Consequently, there is unemployment at a national level if at least one labor market has unemployment. This occurs if:

$$\left(\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\}\right) < \tilde{\chi}^{\frac{1}{1-\phi}}$$

In this case, the real wage in at least one labor market is equal to the lower bound set by the downward wage rigidity constraint: $w_t^{dl} = \tilde{\chi}^{\frac{1}{1-\phi}} w_{t-1}^{dl}$, which will be binding. This implies that the depreciation rate set by the authority (in equation (A16)) takes a single value:

$$\epsilon_t = (\tilde{\chi})^{\frac{-\phi}{1-\phi}} \geq 1$$

Summing up, for a range of values of the full employment real wages such that:

$$\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} < \tilde{\chi}^{\frac{1}{1-\phi}}$$

, there is unemployment and the depreciation rate $\epsilon > 1$ is constant. In this case, the nominal wage rigidity constraint binds for at least one labor market.

Policy Preferences Recall that ϕ captures the extent to which the authority cares about exchange rate stability relative to unemployment.

Two policy extremes are worth noting. Consider first what happens as $\phi \to 1$. In this case, the authority's unique concern is unemployment, and the depreciation rate adjusts to achieve this goal. The second case discussed above, with full employment and a depreciation rate $\epsilon_t > 1$, holds for a range of values of the full employment real wages such that:

$$\tilde{\chi}^{\frac{1}{1-\phi}} \leq \min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} < \tilde{\chi}$$

.

As $\phi \to 1$, the lower bound in this inequality, $\tilde{\chi}^{\frac{1}{1-\phi}} \to 0$ and for any value of the full employment real wages the authority achieves full employment.

Consider now the other extreme, $\phi \to 0$. In this case, the authority cares exclusively about nominal exchange rate stability and mantains a fixed exchange rate under all circumstances. As $\phi \to 1$, $\tilde{\chi}^{\frac{1}{1-\phi}} \to \tilde{\chi}$ and thus the downward nominal wage rigidity fully translates into real rigidity.

This discussion illustrates how ϕ governs the pass-through of nominal to real rigidity. Therefore, χ is the result of a combination of exchange rate policy and nominal rigidity. Our quantitative analysis will span a wide spectrum for χ including a fully flexible regime. Note that the depreciation rate is bounded by $\epsilon_t \in \left[1, (\tilde{\chi})^{\frac{-\phi}{1-\phi}}\right]$, and periods with unemployment are characterized by $\epsilon_t = (\tilde{\chi})^{\frac{-\phi}{1-\phi}}$.

Complementary Slackness Conditions Finally, we can summarize the state of each labor market using the following complementary slackness conditions:

$$0 = \left(L_t^{dl} - h_t^{dl}\right)\left(w_t^{dl} - \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl}\right).$$

Either a labor market is at full employment and $w_t^{dl} = \left(w_t^{dl}\right)^* > \chi w_{t-1}^{dl}$ or the labor market exhibits unemployment and the wage is $w_t^{dl} = \chi w_{t-1}^{dl} > \left(w_t^{dl}\right)^*$.

Graphic Summary Figure A8 illustrates the three cases discused earlier. Consider first values of $\phi \in (0, 1)$, which corresponds to the top panel. The figure shows the depreciation rate set by the authority (vertical axis) as a function of $\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\}$. For values of the full employment real wages such that

$$\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} \geq \tilde{\chi}$$

the authority sets $\epsilon_t = 1$ and there is no unemployment (zone 1). For values of the full employment real wages such that

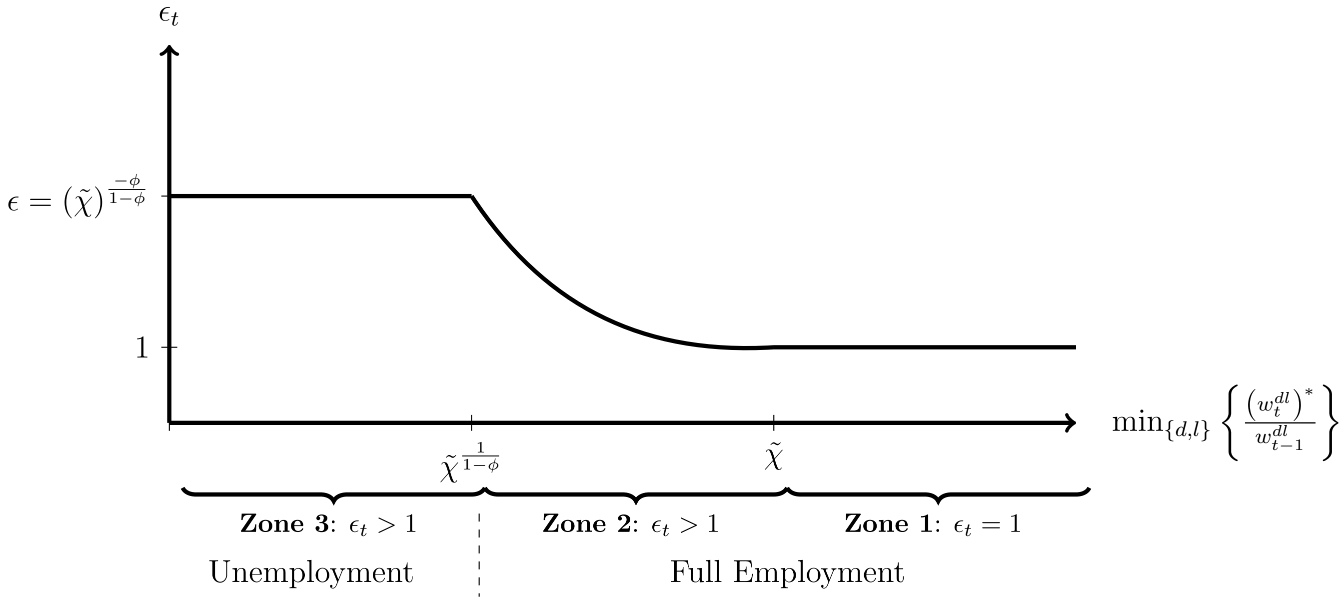
$$\tilde{\chi}^{\frac{1}{1-\phi}} \leq \min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\} < \tilde{\chi}$$

the authority sets $\epsilon_t > 1$ and achieves full employment. Finally, for values of the full employment real wages such that

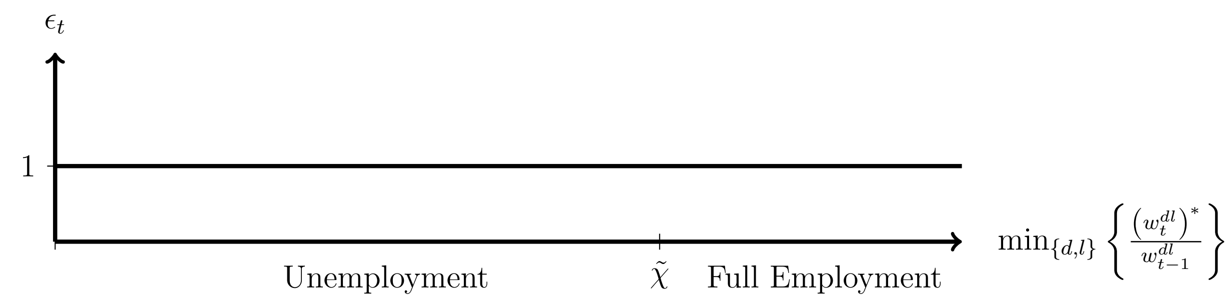
$$\left(\min_{\{d,l\}}\left\{\frac{\left(w_t^{dl}\right)^*}{w_{t-1}^{dl}}\right\}\right) < \tilde{\chi}^{\frac{1}{1-\phi}}$$

the authority sets a constant $\epsilon_t > 1$ and there is unemployment.

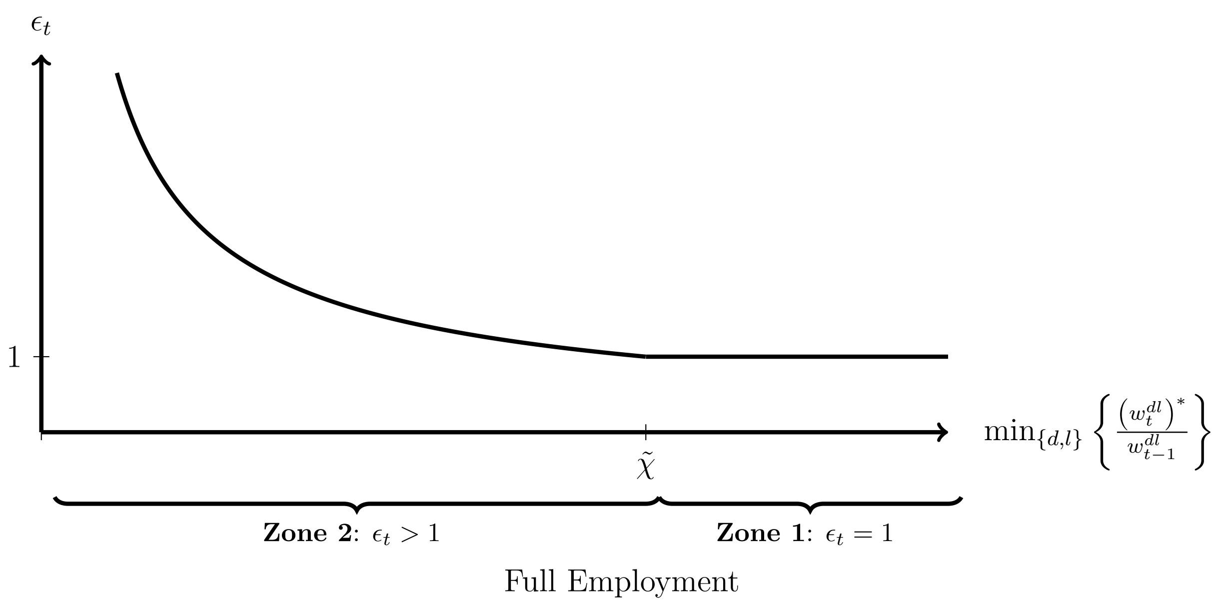
The next two panels consider the extreme examples in which the authority is concerned exclusively with exchange rate stability or exclusively with unemployment. In the former case (middle panel), the exchange rate is fixed and there can be unemployment. In the latter case (bottom panel), there is no unemployment and the authority adjusts the depreciation rate accordingly.



(a) Baseline: $\phi \in (0, 1)$



(b) Extreme case: Authority concerned exclusively about exchange rate stability ($\phi = 0$)



(c) Extreme case: Authority concerned exclusively about unemployment: ($\phi = 1$)

Figure A8: Exchange Rate Regimes and Unemployment

B.2 System of Dynamic Equations

This appendix describes the full system of dynamic equations and the definition of equilibrium.

B.2.1 Household Head

$$\lambda_t = \beta(1+r^\star)\lambda_{t+1} \tag{A17}$$

$$\lambda_t = \frac{H_t^{u,A} \cdot \left(\overline{U}_t^{u,A}\right)' (\tau_t^u) + H_t^{u,B} \cdot \left(\overline{U}_t^{u,B}\right)' (\tau_t^u)}{\left(H_t^{u,A} + H_t^{u,B}\right)} \tag{A18}$$

$$\lambda_t = \frac{H_t^{s,A} \cdot \left(\overline{U}_t^{s,A}\right)' (\tau_t^s) + H_t^{s,A} \cdot \left(\overline{U}_t^{s,B}\right)' (\tau_t^s)}{\left(H_t^{s,A} + H_t^{s,B}\right)} \tag{A19}$$

Prices

$$P_{\Omega,t}^l = P_{M,t}^l \left[1 + \left(\frac{\alpha_T \left(P_{M,t}^l\right)^{\theta_1}}{\left(P_{T,t}^l\right)^{\theta_1}}\right)^{\frac{1}{1-\theta_1}}\right]^{\frac{\theta_1-1}{\theta_1}} \tag{A20}$$

$$P_{G,t}^l = P_{\Omega,t}^l \left[1 + \left(\frac{\alpha_N \left(P_{X,t}^l\right)^{\theta_2}}{\left(P_{N,t}^l\right)^{\theta_2}}\right)^{\frac{1}{1-\theta_2}}\right]^{\frac{\theta_2-1}{\theta_2}} \tag{A21}$$

$$P_{A,t}^l = P_{C,t}^A \left[1 + \left(\frac{P_{C,t}^A}{P_{C,t}^B}\right)^{\frac{\theta_1}{1-\theta_1}}\right]^{\frac{\theta_1-1}{\theta_1}} \tag{A22}$$

$$P_t^l = P_{G,t}^l \left[1 + \left(\frac{\alpha_A \left(P_{G,t}^l\right)^{\theta_3}}{\left(P_{A,t}^l\right)^{\theta_3}}\right)^{\frac{1}{1-\theta_3}}\right]^{\frac{\theta_3-1}{\theta_3}} \tag{A23}$$

Expenditure and Consumption

$$E_t^{d,l} = w_t^{d,l} \cdot \frac{h^{u,l}}{H^{d,l}} + \tau_t^d \tag{A24}$$

$$c_t^{d,l} = \frac{E_t^{d,l}}{P_t^l} \tag{A25}$$

Demands

$$g_t^{d,l} = c_t^{d,l}\left[1+\left(\frac{\alpha_A\left(P_{G,t}^l\right)^{\theta_4}}{\left(P_{A,t}^l\right)^{\theta_4}}\right)^{\frac{1}{1-\theta_4}}\right]^{\frac{-1}{\theta_4}} \tag{A26}$$

$$\omega_t^{d,l} = g_t^{d,l}\left[1+\left(\frac{\alpha_N\left(P_{X_t}^l\right)^{\theta_2}}{\left(P_{N,t}^l\right)^{\theta_2}}\right)^{\frac{1}{1-\theta_2}}\right]^{\frac{-1}{\theta_2}} \tag{A27}$$

$$m_t^{d,l} = \omega_t^{d,l}\left[1+\left(\frac{\alpha_T\left(P_{M,t}^l\right)}{\left(P_{T,t}^l\right)^{\theta_1}}\right)^{\frac{1}{1-\theta_1}}\right]^{\frac{-1}{\theta_1}} \tag{A28}$$

$$a_t^{d,l} = \left(\frac{\alpha_A\cdot P_{G,t}^l}{P_{A,t}^l}\right)^{\frac{1}{1-\theta_4}}\cdot g_t^{d,l} \tag{A29}$$

$$t_t^{d,l} = \left(\frac{\alpha_T\cdot P_{M,t}^l}{P_T^l}\right)^{\frac{1}{1-\theta_1}}\cdot m_t^{d,l} \tag{A30}$$

$$n_t^{d,l} = \left(\frac{\alpha_N\cdot P_{X,t}^l}{P_{N,t}^l}\right)^{\frac{1}{1-\theta_2}}\cdot \omega_t^{d,l} \tag{A31}$$

$$c_{C,t}^{d,l,A} = a_t^{d,l}\left[1+\left(\frac{P_{C,t}^A}{P_{C,t}^B}\right)^{\frac{\theta_3}{1-\theta_3}}\right]^{\frac{-1}{\theta_3}} \tag{A32}$$

$$c_{C,t}^{d,l,B} = c_{C,t}^{d,l,A}\left(\frac{P_{C,t}^A}{P_{C,t}^B}\right)^{\frac{1}{1-\theta_1}} \tag{A33}$$

Migration

$$\frac{H_t^{d,l}}{\overline{H}^d} \equiv \sigma_t^{d,l} = \frac{\exp\left(\overline{U}\left(\frac{E_t^{d,l}}{P_t^l}\right)\right)^{1/\xi_d}}{\exp\left(\overline{U}\left(\frac{E_t^{d,l}}{P_t^l}\right)\right)^{1/\xi_d}+\exp\left(\overline{U}\left(\frac{E_t^{d,\neg l}}{P_t^{\neg l}}\right)\right)^{1/\xi_d}} \tag{A34}$$

B.2.2 Commodity Sector

Optimal Decisions

$$\hat{w}_{C,t}^l = \left[\phi_C(w_t^{u,l})^{1-\gamma}+(1-\phi_C)(w_t^{s,l})^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A35}$$

$$L_{C,t}^{l}=\left(\frac{\eta\cdot P_{C,t}^{l}}{\hat{w}_{C,t}^{l}}\right)^{\frac{1}{1-\eta}}\cdot R_{t}^{l} \tag{A36}$$

$$L_{C,t}^{u,l}=\phi_{C}\cdot\left(\frac{\hat{w}_{C,t}^{l}}{w_{C,t}^{u,l}}\right)\cdot L_{C,t}^{l} \tag{A37}$$

$$L_{C,t}^{s,l}=(1-\phi_{C})\cdot\left(\frac{\hat{w}_{C,t}^{l}}{w_{C,t}^{s,l}}\right)\cdot L_{C,t}^{l} \tag{A38}$$

$$P_{R,t}^{l}=(1-\eta)\cdot P_{C,t}^{l}\cdot\left(\frac{L_{C,t}^{l}}{R_{t}^{l}}\right)^{\eta} \tag{A39}$$

Aggregate

$$Y_{C,t}^{l}=\left(L_{C,t}^{l}\right)^{\eta}\left(R_{t}^{l}\right)^{1-\eta} \tag{A40}$$

B.2.3 Nontradable Sector

Optimal decisions

$$\hat{w}_{N,t}^{l}=\left[\phi_{N}(w_{t}^{u,l})^{1-\gamma}+(1-\phi_{N})(w_{t}^{s,l})^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A41}$$

$$p_{N,t}^{l}\left(z_{N}\right)=\frac{\hat{w}^{d,l}}{\rho z_{N}} \tag{A42}$$

$$q_{N,t}^{l}\left(z_{N}\right)=n_{t}^{l}\cdot\left(\frac{p_{N,t}^{l}\left(z_{N}\right)}{P_{N,t}^{l}}\right)^{-\sigma} \tag{A43}$$

$$l_{N,t}^{u,l}\left(z_{N}\right)=\phi^{N}\cdot\left(\frac{\hat{w}_{N,t}^{l}}{w_{t}^{u,l}}\right)^{\gamma}\cdot\left(\frac{q_{N,t}^{l}}{z_{N}}+f_{N}^{l}\right) \tag{A44}$$

$$l_{N,t}^{s,l}\left(z_{N}\right)=\left(1-\phi^{N}\right)\cdot\left(\frac{\hat{w}_{N,t}^{l}}{w_{t}^{s,l}}\right)^{\gamma}\cdot\left(\frac{q_{N,t}^{l}}{z_{N}}+f_{N}^{l}\right) \tag{A45}$$

Profit

$$\pi_{N,t}^{l}=\frac{p_{N,t}^{l}\left(z_{N}\right)\cdot q_{N,t}^{l}\left(z_{N}\right)}{\sigma}-\hat{w}_{N,t}^{l}\cdot f_{N}^{l} \tag{A46}$$

Value Function

$$W_{N,t}^{l}\left(z_N\right)=\max\left\{0,\pi_{N,t}^{l}\left(z_N\right)+(1-\delta_N)\beta\max\left\{0,W_{N,t+1}^{l}\left(z_N\right)\right\}\right\} \tag{A47}$$

Cutoff

$$0=W_{N,t}^{l}\left(\underline{z}_{N,t}^{l}\right) \tag{A48}$$

Free entry condition

$$\int_{\bar{z}_{Nt}^{l}}^{\infty}W_{N,t}^{l}\left(z\right)g_N\left(z_N\right)dz_N=\hat{w}_{N,t}^{l}\cdot\left\{f_{Ne}^{l}+\xi_{Ne}\left[\exp\left(\frac{\tilde{\mathcal{M}}_{N,t}^{l}-\overline{\mathcal{M}}_{N,e}^{l}}{\overline{\mathcal{M}}_{N,e}^{l}}\right)-1\right]\right\} \tag{A49}$$

Distribution of producers law of motion

$$\mathcal{M}_{N,t+1}^{l}\mu_{N,t+1}^{l}(z_N)=(1-\delta_N)\cdot\mathcal{M}_{N,t}^{l}\cdot\mu_t^{N}(z_N)\cdot\mathbb{I}_{\left\{z_N\geq\underline{z}_{N,t+1}^{l}\right\}}+\tilde{\mathcal{M}}_{N,t+1}^{l}\cdot g_N(z_N)\cdot\mathbb{I}_{\left\{z_N\geq\underline{z}_{N,t+1}^{l}\right\}} \tag{A50}$$

Mass of producers law of motion

$$\mathcal{M}_{N,t+1}^{l}=(1-\delta_N)\cdot\mathcal{M}_{N,t}^{l}\int_{\underline{z}_{N,t+1}^{l}}^{\infty}\mu_t^{N}(z_N)dz_N+\tilde{\mathcal{M}}_{N,t+1}^{l}\int_{\underline{z}_{N,t+1}^{l}}^{\infty}g(z_N)dz_N\,. \tag{A51}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$L_{N,p,t}^{u,l}=\mathcal{M}_t^{N}\int_{\underline{z}_{N,t}^{u,l}}^{\infty}l_{N,t}^{u,l}\left(z_N\right)\mu_{N,t}^{l}(z_N)dz_N$$
$$L_{N,p,t}^{s,l}=\mathcal{M}_t^{N}\int_{\underline{z}_{N,t}^{s,l}}^{\infty}l_{N,t}^{s,l}\left(z_N\right)\mu_{N,t}^{l}(z_N)dz_N$$

- Total skilled and unskilled labor for fixed entry cost

$$L_{N,e,t}^{u,l}=\phi_N^{u}\cdot\left(\frac{\hat{w}_{N,t}^{l}}{w_t^{u,l}}\right)^{\gamma}\cdot\left\{f_{Ne}^{l}+\xi_{Ne}\left[\exp\left(\frac{\mathcal{M}_{N,e,t}^{l}-\overline{\mathcal{M}}_{N,e}^{l}}{\overline{\mathcal{M}}_{N,e}^{l}}\right)-1\right]\right\}$$
$$L_{N,e,t}^{s,l}=\phi_N^{d}\cdot\left(\frac{\hat{w}_{N,t}^{l}}{w_t^{s,l}}\right)^{\gamma}\cdot\left\{f_{Ne}^{l}+\xi_{Ne}\left[\exp\left(\frac{\mathcal{M}_{N,e,t}^{l}-\overline{\mathcal{M}}_{N,e}^{l}}{\overline{\mathcal{M}}_{N,e}^{l}}\right)-1\right]\right\}$$

- Total skilled and unskilled labor demand

$$L^{u,l}_{N,t} = L^{u,l}_{N,p,t} + L^{u,l}_{N,e,t} \tag{A52}$$

$$L^{s,l}_{N,t} = L^{s,l}_{N,p,t} + L^{s,l}_{N,e,t} \tag{A53}$$

- Total output

$$Y^l_{N,t} = \mathcal{M}^N_t \left[\int_{\underline{z}^l_{N,t}}^{\infty} \left(q^l_{N,t}\left(z_N\right)\right)^{\rho} \cdot d\mu^l_{N,t}(z_N) \right]^{\frac{1}{\rho}} \tag{A54}$$

- Ideal price index

$$P^l_{N,t} = \left[\int_{\underline{z}^l_{N,t}}^{\infty} \left(p^l_{N,t}\left(z_N\right)\right)^{1-\sigma} d\mu^l_{N,t}(z_N) \right]^{\frac{1}{1-\sigma}} \tag{A55}$$

B.2.4 Tradable Sector

Optimal decisions

$$\hat{w}^l_{T,t} = \left[\phi_T (w^{u,l}_t)^{1-\gamma} + (1-\phi_T)(w^{s,l}_t)^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \tag{A56}$$

$$p^l_{T,t}\left(z_T\right) = \frac{\hat{w}^l_{T,t}}{\rho \cdot z_T} \tag{A57}$$

$$q^l_{T,t}(z_T) = \begin{cases} q^l_{d,t} = T^l_t \left[\frac{p^l_{T,t}(z_T)}{P^l_{T,t}}\right]^{-\sigma}, & \underline{z}^l_{d,t} < z_T < \underline{z}^l_{c,t} \\ q^l_{d,t} + q^l_{c,t} = T^l_t \left[\frac{p^l_{T,t}(z_T)}{P^l_{T,t}}\right]^{-\sigma} + T^{\neg l}_t \left[\frac{p^l_t(z_T)}{P^{\neg l}_{T,t}}\right]^{-\sigma}, & \underline{z}^l_{c,t} < z_T < \underline{z}^l_{xt} \\ q^l_{d,t} + q^l_{c,t} + q^l_{x,t} = T^l_t \left[\frac{p^l_{T,t}(z_T)}{P^l_{T,t}}\right]^{-\sigma} + T^{\neg l}_t \left[\frac{p^l_{T,t}(z_T)}{P^{\neg l}_{T,t}}\right]^{-\sigma} + \Gamma\left[p^l_{T,t}(z_T)\right]^{-\sigma}, & \underline{z}^l_{x,t} < z_T \end{cases} \tag{A58}$$

$$l^{u,l}_{T,t}(z_T) = \begin{cases} l^{u,l}_d = \phi_T \left(\frac{\hat{w}^l_{T,t}}{w^{ld}}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)}{z_T} + f^l_d\right], & \overline{z}^l_d < z_T < \overline{z}^l_c \\ l^{u,l}_d + l^{u,l}_c = \phi_T \left(\frac{\hat{w}^l_T}{w^{ld}}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)+q^l_{c,t}(z_T)}{z_T} + f^l_d + f^l_c\right], & \underline{z}^l_c < z_T < \underline{z}^l_x \\ l^{u,l}_d + l^{u,l}_c + l^{u,l}_x = \phi_T \left(\frac{\hat{w}^l_T}{w^{ld}}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)+q^l_{c,t}(z_T)+q^l_{x,t}(z_T)}{z_T} + f^l_d + f^l_c + f^l_x\right], & \underline{z}^l_x < z_T \end{cases} \tag{A59}$$

$$l^{s,l}_{T,t}(z_T) = \begin{cases} l^{s,l}_d = (1-\phi_T) \left(\frac{\hat{w}^l_{T,t}}{w^{s,l}_t}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)}{z_T} + f^l_d\right], & \underline{z}^l_d < z_T < \underline{z}^l_c \\ l^{s,l}_d + l^{s,l}_c = (1-\phi_T) \left(\frac{\hat{w}^l_{T,t}}{w^{s,l}_t}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)+q^l_{c,t}(z_T)}{z_T} + f^l_d + f^l_c\right], & \underline{z}^l_c < z_T < \underline{z}^l_x \\ l^{s,l}_d + l^{s,l}_c + l^{s,l}_x = (1-\phi_T) \left(\frac{\hat{w}^l_{T,t}}{w^{s,l}_t}\right)^\gamma \cdot \left[\frac{q^l_{d,t}(z_T)+q^l_{c,t}(z_T)+q^l_{x,t}(z_T)}{z_T} + f^l_d + f^l_c + f^l_x\right], & \underline{z}^l_x < z_T \end{cases} \tag{A60}$$

Profits

$$\pi^l_{T,t}(z_T) = \begin{cases} \pi^l_{d,t} = \frac{p^l_{T,t}(z_T)q^l_{d,t}(z_T)}{\sigma} - \hat{w}^l_{T,t}f^l_d, & \underline{z}^l_{d,t} < z_T < \underline{z}^l_{c,t} \\ \pi^l_{d,t} + \pi^l_{c,t} = \frac{p^l_{T,t}(z_T)\left[q^l_{d,t}(z_T)+q^l_{c,t}(z_T)\right]}{\sigma} - \hat{w}^l_{T,t}(f^l_d + f^l_c), & \underline{z}^l_{c,t} < z_T < \underline{z}^l_{x,t} \\ \pi^l_{d,t} + \pi^l_{c,t} + \pi^l_{x,t} = \frac{p^l_{T,t}(z_T)\left[q^l_{d,t}(z_T)+q^l_{c,t}(z_T)+q^l_{x,t}(z_T)\right]}{\sigma} - \hat{w}^l_{T,t}(f^l_d + f^l_c + f^l_x), & \underline{z}^l_{x,t} < z_T \end{cases} \tag{A61}$$

Value functions

$$W^l_{T,t}(z_T) = \max\left\{W^l_{d,t}(z_T), W^l_{c,t}(z_T), W^l_{x,t}(z_T)\right\} \tag{A62}$$

$$W^l_{d,t}(z_T) = \max\left\{0, \pi^l_{d,t}(z_T) + \beta(1-\delta_T)W^l_{T,t+1}(z_T)\right\} \tag{A63}$$

$$W^l_{c,t}(z_T) = \max\left\{0, \pi^l_{d,t}(z_T) + \pi^l_{c,t}(z_T) + \beta(1-\delta_T)W^l_{T,t+1}(z_T)\right\} \tag{A64}$$

$$W^l_{x,t}(z_T) = \max\left\{0, \pi^l_{d,t}(z_T) + \pi^l_{c,t}(z_T) + \pi^l_{x,t}(z_T) + \beta(1-\delta_T)W^l_{T,t+1}(z_T)\right\} \tag{A65}$$

Cutoffs

$$W^l_{d,t}(\underline{z}^l_{d,t}) = 0 \tag{A66}$$

$$\pi^l_{c,t}(\underline{z}^l_{c,t}) = 0 \tag{A67}$$

$$\pi^l_{x,t}(\underline{z}^l_{x,t}) = 0 \tag{A68}$$

Free entry condition

$$\int_{\bar{z}^{l}_{Tt}}^{\infty} W^{l}_{T,t}\left(z_T\right) g_T\left(z_T\right) dz_N = \hat{w}^{l}_{T,t} \cdot \left\{ f^{l}_{Te} + \xi_{Te} \left[\exp\left(\frac{\mathcal{M}^{l}_{T,e,t} - \overline{\mathcal{M}}^{l}_{T,e}}{\overline{\mathcal{M}}^{l}_{T,e}} \right) - 1 \right] \right\} \tag{A69}$$

Laws of Motion: Distribution and Mass of producers

$$\mathcal{M}^{l}_{T,t+1}\mu^{l}_{T,t+1}(z_T) = (1-\delta_T)\cdot \mathcal{M}^{l}_{T,t}\cdot \mu^{T}_{t}(z_T)\cdot \mathbb{I}_{\left\{z_T \geq \underline{z}^{l}_{d,t+1}\right\}} + \mathcal{M}^{l}_{T,e,t+1}\cdot g_T(z_T)\cdot \mathbb{I}_{\left\{z_T \geq \underline{z}^{l}_{d,t+1}\right\}} \tag{A70}$$

$$\mathcal{M}^{l}_{T,t+1} = (1-\delta_T)\mathcal{M}^{l}_{T,t}\int_{\underline{z}^{l}_{d,t+1}}^{\infty} \mu^{l}_{t+1}(z_T)dz_T + \mathcal{M}^{l}_{T,e,t+1}\int_{\underline{z}^{l}_{d,t+1}}^{\infty} g_T(z_T)dz_T \tag{A71}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$L^{u,l}_{T,p,t} = \mathcal{M}^{T}_{t}\int_{\underline{z}^{l}_{T,t}}^{\infty} l^{u,l}_{T,t}\left(z_T\right)\mu^{l}_{T,t}(z_T)dz_T$$
$$L^{s,l}_{T,p,t} = \mathcal{M}^{T}_{t}\int_{\underline{z}^{l}_{T,t}}^{\infty} l^{s,l}_{T,t}\left(z_T\right)\mu^{l}_{T,t}(z_T)dz_T$$

- Total skilled and unskilled labor for fixed entry cost

$$L^{u,l}_{T,e,t} = \phi^{u}_{T}\cdot\left(\frac{\hat{w}^{l}_{T,t}}{w^{u,l}_{t}}\right)^{\gamma}\cdot\left\{ f^{l}_{Te} + \xi_{Ne}\left[\exp\left(\frac{\mathcal{M}^{l}_{T,e,t} - \overline{\mathcal{M}}^{l}_{T,e}}{\overline{\mathcal{M}}^{l}_{T,e}}\right) - 1\right]\right\}$$
$$L^{s,l}_{T,e,t} = \phi^{d}_{T}\cdot\left(\frac{\hat{w}^{l}_{T,t}}{w^{s,l}_{t}}\right)^{\gamma}\cdot\left\{ f^{l}_{Te} + \xi_{Ne}\left[\exp\left(\frac{\mathcal{M}^{l}_{T,e,t} - \overline{\mathcal{M}}^{l}_{T,e}}{\overline{\mathcal{M}}^{l}_{T,e}}\right) - 1\right]\right\}$$

- Total skilled and unskilled labor demand

$$L^{u,l}_{T,t} = L^{u,l}_{T,p,t} + L^{u,l}_{T,e,t} \tag{A72}$$
$$L^{s,l}_{T,t} = L^{s,l}_{T,p,t} + L^{s,l}_{T,e,t} \tag{A73}$$

- Total tradable goods output produced in l that are sold domestically

$$\tilde{Y}^{l}_{T,t} = \left[\mathcal{M}^{l}_{t}\left(\int_{\underline{z}^{l}_{d,t}}^{\infty}\left[q^{l}_{d,t}(z_T)\right]^{\rho}\mu^{l}_{T,t}(z_T)dz_T + \int_{\underline{z}^{l}_{ct}}^{\infty}\left[q^{l}_{ct}(z_T)\right]^{\rho}\mu^{l}_{T,t}(z_T)dz_T\right)\right]^{\frac{1}{\rho}} \tag{A74}$$

- Total domestic tradable output supplied to region l:

$$Y_{T,t}^{l} = \left[\left(\int_{\underline{z}_{d,t}^{l}}^{\infty} \mathcal{M}_{t}^{l} \cdot \left[q_{d,t}^{l}(z_T) \right]^{\rho} \mu_{T,t}^{l}(z_T) dz_T + \int_{\underline{z}_{ct}^{\neg l}}^{\infty} \mathcal{M}_{t}^{\neg l} \left[q_{ct}^{\neg l}(z_T) \right]^{\rho} \mu_{T,t}^{\neg l}(z_T) dz_T \right) \right]^{\frac{1}{\rho}} \tag{A75}$$

- Value of tradable good output sold in foreign market

$$X_t^l = \mathcal{M}_{T,t}^{l} \int_{\underline{z}_{xt}^{l}}^{\infty} p_{T,t}^{l}(z_T) q_{xt}^{l}(z_T) \mu_{T,t}^{l}(z_T) dz_T \tag{A76}$$

B.2.5 Aggregation and Market Clearing

Population and Employment

$$\overline{H}^{d} = H_t^{d,A} + H_t^{d,B} \tag{A77}$$

$$H_t^l = H_t^{s,l} + H^{u,l} \tag{A78}$$

$$h_t^{d,l} = L_t^{d,l} \leq H_t^{d,l} \tag{A79}$$

$$0 = \left(L_t^{dl} - h_t^{dl} \right) \left(w_t^{dl} - \frac{\tilde{\chi}}{\epsilon_t} w_{t-1}^{dl} \right) \tag{A80}$$

Aggregate Demand for Goods

$$C_t^l = H_t^{u,l} \cdot c_t^{u,l} + H_t^{s,l} \cdot c_t^{s,l} \tag{A81}$$

$$M_t^l = H_t^{u,l} \cdot t_t^{u,l} + H_t^{s,l} \cdot t_t^{s,l} \tag{A82}$$

$$T_t^l = H_t^{u,l} \cdot t_t^{u,l} + H_t^{s,l} \cdot t_t^{s,l} \tag{A83}$$

$$A_t^l = H_t^{u,l} \cdot a_t^{u,l} + H_t^{s,l} \cdot a_t^{s,l} \tag{A84}$$

$$\Omega_t^l = H_t^{u,l} \cdot \omega_t^{u,l} + H_t^{s,l} \cdot \omega_t^{s,l} \tag{A85}$$

$$N_t^l = H_t^{u,l} \cdot n_t^{u,l} + H_t^{s,l} \cdot n_t^{s,l} \tag{A86}$$

$$G_t^l = H_t^{u,l} \cdot g_t^{u,l} + H_t^{s,l} \cdot g_t^{s,l} \tag{A87}$$

$$C_{C,t}^{l,A} = H_t^{u,l} \cdot c_{C,t}^{l,A} + H_t^{s,l} \cdot c_{C,t}^{l,A} \tag{A88}$$

$$C_{C,t}^{l,B} = H_t^{u,l} \cdot c_{C,t}^{l,B} + H_t^{s,l} \cdot c_{C,t}^{l,B} \tag{A89}$$

$$C_{C,t}^{A} = C_{C,t}^{A,A} + C_{C,t}^{B,A} \tag{A90}$$

$$C_{C,t}^{B} = C_{C,t}^{A,B} + C_{C,t}^{B,B} \tag{A91}$$

Market Clearing

$$Y_{N,t}^l = N_t^l \tag{A92}$$

$$Y_{T,t}^l = T_t^l \tag{A93}$$

$$\overline{R}_t^l = R_t^l \tag{A94}$$

Balance of Payments

$$X_t = P_{C,t}^A \left(Y_{C,t}^A - C_{C,t}^A\right) + X_{T,t}^A + X_{T,t}^A \tag{A95}$$

$$M_t = M_t^A + M_t^B \tag{A96}$$

$$TB_t = X_t - M_t \tag{A97}$$

$$B_{t+1} = (1 + r^*)\, B_t + TB_t \tag{A98}$$

B.2.6 Transition Equilibrium Definition

Given an exogenous sequence of commodity prices $\{P_{C,t}^l\}_{t=0}^T$, initial conditions for the net foreign asset (B_0) and sectoral firm distributions $(\mathcal{M}_{j,0}^l, \mu_{j,0}^l(z^j))_{j\in\{N,T\}}$, and the exchange rate regime, a competitive equilibrium consists of sequences of:

(i) firm value functions $\{(W_t^{j,l}(z^j))_{j\in\{N,T\}}\}_{t=0}^T$,

(ii) masses of producers and entrants $\{(M_{j,t}^l, M_{j,e,t}^l)_{j\in\{N,T\}}\}_{t=0}^T$,

(iii) cutoffs for domestic operation, interregional exports, and international exports $\{(\bar{z}_t^{j,l})_{j\in\{N,T\}}, \bar{z}_{c,t}^{T,l}, \bar{z}_{x,t}^{T,l}\}_{t=0}^T$,

(iv) firm distributions $\{\mu_{j,t}^l(z^j))_{j\in\{N,T\}}\}_{t=0}^T$,

(v) firm decision rules $\{p_{j,t}^{u,l}(z^j), q_{j,t}^{u,l}(z^j), l_{j,t}^{u,l}(z^j), l_{j,t}^{s,l}(z^j)_{j\in\{N,T\}}, L_t^{C,l,u}, L_t^{C,l,s}, R_t^l\}_{t=0}^T$

(vi) total firm outputs $\{Y_{T,t}^l,\, Y_{N,t}^l,\, Y_{C,t}^l\}_{t=0}^T$.

(vii) consumption decisions $\{m_t^l, t_t^l(\zeta)_{\zeta\in\mathfrak{Z}_t^l}, n_t^l(\varphi)_{\varphi\in\mathfrak{P}_t^l}, c_t^{lA}, c_t^{lB}\}_{t=0}^T$

(viii) household head's decisions $\{\tau_t^u, \tau_t^s\}_{t=0}^T$,

(ix) population $\{H_t^{u,l}, H_t^{s,l}\}_{t=0}^T$,

(x) employment $\{h_t^{u,l}, h_t^{s,l}\}_{t=0}^T$,

(xi) wages and prices $\{w_t^{u,l}, w_t^{s,l}, P_t^{N,l}, P_t^{T,l}, P_t^{R,l}\}_{t=0}^T$,

(xii) asset holdings $\{B_t\}_{t=0}^{T}$

such that for all $t = 1, ..., T$:

1. Given prices in (xi), the value functions (i), cutoff rules (iii), and decision rules (v) solve the firms' problems in each sector and location according to (A57), (A58),(A59),(A60), (A42), (A43),(A44),(A45), (A38),(A37), and (A39).

2. Given prices in (xi) and value functions (i), the masses of entrants in each sector and region satisfy the free-entry conditions (A49) and (A69).

3. Given prices in (xi), the sequences of firm distributions (iv) and firm masses (ii) are consistent with the firms' decisions. In particular, they follow the laws of motion from (A50), (A70), (A51), and (A71).

4. Given wages and prices in (xi) and transfers in (viii), the consumption decisions in (vi) solve the workers' static optimization problem from (A24)-(A33).

5. Given the sequence of wages and prices (x), the transfers in (viii) solve the household head's maximization problem. Namely, the transfers satisfy the first-order conditions in (A18) and (A19).

6. Given the sequence of wages, prices, transfers, employment, and population (v,viii,ix,x,xi), the law of motion for population is consistent with the individual workers' location choices in (A117).

7. All goods markets clear given total sectoral outputs ((A75)),(A54)), aggregate good demands ((A83),(A86)). In addition, the market for natural resources clear ((A39),(A94)).

8. The sequences of wages satisfy the complementary slackness conditions induced by the downward wage rigidity in both skilled and unskilled labor markets from (A80). In other words, either labor markets clear with full employment or the downward wage rigidity is binding.

9. The sequence of asset holding in (xi) solves the household head's dynamic optimization problem and is consistent with the balance of payments condition in the economy (A98). In addition, in period $t = T$, the economy has settled in the new steady state with a finite and stable net foreign asset position.

B.2.7 Transition Algorithm

Assumptions

- The economy is in stationary equilibrium at $t = 0$, associated with known $P^A_{C,0}$ and $P^B_{C,0}$.
- The economy is in stationary equilibrium at $t = \infty$, associated with known $P^A_{C,\infty}$ and $P^B_{C,\infty}$.
- Full sequence $\{P^A_{C,t}, P^B_{C,t}\}^{\infty}_{t=1}$ 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 $\{\lambda_t = \lambda\}^T_{t=1}$ from (A17) (permanent income).
3. For each level of λ, recover the implied new steady state.
4. **Inner Loop.** Guess sequences $\{w^{s,A}_t, w^{s,B}_t, w^{u,A}_t, w^{u,B}_t, P^A_{T,t}, P^B_{T,t}, P^A_{N,t}, P^B_{N,t}, h^{s,A}_t, h^{s,B}_t, h^{u,A}_t, h^{u,B}_t, H^{s,A}_t, H^{s,B}_t, H^{u,A}_t, H^{u,B}_t\}^T_{t=1}$.
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 $t = T, ..., 1$.
   - Recover prices of all good bundles from (A20), (A21), (A22), and (A23).
   - Solve (A18) and (A19) simultaneously for τ^u_t and τ^s_t.
   - Recover per capita expenditure and consumption from (A24) and (A25). With per capita consumption and prices, recover per capita demand for each good bundle from (A26)-(A33).
   - Evaluate the value functions (A62) and (A47), to get the productivity cutoffs for production, interregional exports, and international exports $(\underline{z}^l_{N,t}, \underline{z}^l_{d,t}, \underline{z}^l_{c,t}, \underline{z}^l_{x,t})$ using (A48),(A66), (A67), and(A68).
   - Given value functions and cutoffs, recover the masses of entrants from the free entry conditions (A69) and (A49).
6. **Forward Iteration Loop**. Use the initial masses and distributions, the guesses, and the cutoff rules, to iterate the sectoral distributions forward. For each $t = 1, ..., T$.

- Get the mass $\mathcal{M}^l_{N,t}$ and distribution $\mu^l_{N,t}(z_N)$ in the N sector using (A51) and (A50).
- Get the mass $\mathcal{M}^l_{T,t}$ and distribution $\mu^l_{T,t}(z_T)$ in the T sector using (A71) and (A70).

7. **Update Guesses**

- Get implied sequence $\{P^l_{T,t}\}_{t=1}^T$ from domestic tradable market clearing conditions (A93), using total regional supply and demand from (A75) and (A83).
- Get implied sequence $\{P^l_{N,t}\}_{t=1}^T$ from domestic tradable market clearing conditions (A92), using total regional supply and demand from (A54) and (A86).
- Get labor aggregates from (A37), (A38), (A52), (A53), (A72), and (A73).
- Get implied sequences $\{w_t^{u,l}, w_t^{s,l}\}_{t=1}^T$ jointly from both labor market clearings (A80), assuming that downward wage rigidity is not binding (full employment). Then, check and impose DWR on the implied wage sequences if necessary.
- Recover the implied sequences of population across regions $\{H_t^{u,A}, H_t^{s,A}, H_t^{u,B}, H_t^{s,B}\}_{t=1}^\infty$ from (A117).
- Recover the implied sequences of regional employments $\{h_t^{u,A}, h_t^{s,A}, h_t^{u,B}, h_t^{s,B}\}_{t=1}^\infty$ from (A79).
- Update guesses for wages, prices, population, and employment 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 total regional demand and supply for commodity goods from (A88)-(A91) and (A40).
- Compute total exports, imports, and trade balance from (A95), (A96), and (A97).
- Compute the implied net foreign assets by iterating the balance of payment equation (A98) 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 the guess for λ.
  - If the economy accumulates too much debt, increase the guess for λ.
- Go back to step 2 and repeat until convergence.

B.3 Steady State System

B.3.1 Household Head

$$1 = \beta(1 + r^\star) \tag{A99}$$

$$\lambda = \frac{H^{u,A} \cdot \left(\overline{U}^{u,A}\right)' (\tau^u) + H^{u,B} \cdot \left(\overline{U}_t^{u,B}\right)' (\tau^u)}{H^{u,A} + H^{u,B}} \tag{A100}$$

$$\lambda = \frac{H^{s,A} \cdot \left(\overline{U}^{s,A}\right)' (\tau^s) + H^{s,B} \cdot \left(\overline{U}_t^{s,B}\right)' (\tau^s)}{H^{s,A} + H^{s,B}} \tag{A101}$$

Prices

$$P_\Omega^l = P_M^l \left[1 + \left(\frac{\alpha_T \left(P_M^l\right)^{\theta_1}}{\left(P_T^l\right)^{\theta_1}}\right)^{\frac{1}{1-\theta_1}}\right]^{\frac{\theta_1 - 1}{\theta_1}} \tag{A102}$$

$$P_G^l = P_\Omega^l \left[1 + \left(\frac{\alpha_N \left(P_\Omega^l\right)^{\theta_2}}{\left(P_N^l\right)^{\theta_2}}\right)^{\frac{1}{1-\theta_2}}\right]^{\frac{\theta_2 - 1}{\theta_2}} \tag{A103}$$

$$P_A^l = P_C^A \left[1 + \left(\frac{P_C^A}{P_C^B}\right)^{\frac{\theta_1}{1-\theta_1}}\right]^{\frac{\theta_1 - 1}{\theta_1}} \tag{A104}$$

$$P_t^l = P_G^l \left[1 + \left(\frac{\alpha_A \left(P_G^l\right)^{\theta_3}}{\left(P_A^l\right)^{\theta_3}}\right)^{\frac{1}{1-\theta_3}}\right]^{\frac{\theta_3 - 1}{\theta_3}} \tag{A105}$$

Expenditure and Consumption

$$E^{d,l} = w^{d,l} \cdot \frac{h^{d,l}}{H^{d,l}} + \tau^d \tag{A106}$$

$$c^{d,l} = \frac{E^{d,l}}{P^l} \tag{A107}$$

$$\tag{A108}$$

Demands

$$g^{d,l} = c^{d,l}\left[1 + \left(\frac{\alpha_A\left(P^l_G\right)^{\theta_4}}{\left(P^l_A\right)^{\theta_4}}\right)^{\frac{1}{1-\theta_4}}\right]^{\frac{-1}{\theta_4}} \tag{A109}$$

$$\omega^{d,l}_t = g^{d,l}\left[1 + \left(\frac{\alpha_N\left(P^l_X\right)^{\theta_2}}{\left(P^l_N\right)^{\theta_2}}\right)^{\frac{1}{1-\theta_2}}\right]^{\frac{-1}{\theta_2}} \tag{A110}$$

$$m^{d,l} = \omega^{d,l}\left[1 + \left(\frac{\alpha_T\left(P^l_M\right)}{\left(P^l_T\right)^{\theta_1}}\right)^{\frac{1}{1-\theta_1}}\right]^{\frac{-1}{\theta_1}} \tag{A111}$$

$$a^{d,l} = \left(\frac{\alpha_A \cdot P^l_{G,t}}{P^l_{A,t}}\right)^{\frac{1}{1-\theta_4}} \cdot g^{d,l} \tag{A112}$$

$$t^{d,l} = \left(\frac{\alpha_T \cdot P^l_{M,t}}{P^l_T}\right)^{\frac{1}{1-\theta_1}} \cdot m^{d,l} \tag{A113}$$

$$n^{d,l} = \left(\frac{\alpha_N \cdot P^l_{X,t}}{P^l_N}\right)^{\frac{1}{1-\theta_2}} \cdot \omega^{d,l} \tag{A114}$$

$$c^{d,l,A}_C = a^{d,l}\left[1 + \left(\frac{P^A_C}{P^B_{C,t}}\right)^{\frac{\theta_3}{1-\theta_3}}\right]^{\frac{-1}{\theta_3}} \tag{A115}$$

$$c^{d,l,B}_C = c^{d,l,A}_C\left(\frac{P^A_C}{P^B_C}\right)^{\frac{1}{1-\theta_1}} \tag{A116}$$

Migration

$$\frac{H^{d,l}}{\overline{H}^d} \equiv \sigma^{d,l} = \frac{\exp\left(U\left(\frac{E^{d,l}}{P^l}\right)\right)^{1/\xi_d}}{\exp\left(U\left(\frac{E^{d,l}}{P^l}\right)\right)^{1/\xi_d} + \exp\left(U\left(\frac{E^{d,\neg l}}{P^{\neg l}}\right)\right)^{1/\xi_d}} \tag{A117}$$

B.3.2 Commodity Sector

Optimal Decisions

$$\hat{w}^l_C = \left[\phi_C(w^{u,l})^{1-\gamma} + (1-\phi_C)(w^{s,l})^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A118}$$

$$L_C^l = \left(\frac{\eta \cdot P_C^l}{\hat{w}_C^l}\right)^{\frac{1}{1-\eta}} \cdot R_t^l \tag{A119}$$

$$L_C^{u,l} = \phi_C \cdot \left(\frac{\hat{w}_C^l}{w_C^{u,l}}\right) \cdot L_C^l \tag{A120}$$

$$L_C^{s,l} = (1-\phi_C) \cdot \left(\frac{\hat{w}_C^l}{w_C^{s,l}}\right) \cdot L_C^l \tag{A121}$$

$$P_R^l = (1-\eta) \cdot P_C^l \cdot \left(\frac{L_C^l}{R^l}\right)^\eta \tag{A122}$$

$$\tag{A123}$$

Aggregate

$$Y_C^l = \left(L_C^l\right)^\eta \left(R^l\right)^{1-\eta} \tag{A124}$$

B.3.3 Nontradable Sector

Optimal decisions

$$\hat{w}_N^l = \left[\phi_N (w^{u,l})^{1-\gamma} + (1-\phi_N)(w^{s,l})^{1-\gamma}\right]^{\frac{1}{1-\gamma}} \tag{A125}$$

$$p_N^l\left(z_N\right) = \frac{\hat{w}^{d,l}}{\rho z_N} \tag{A126}$$

$$q_N^l\left(z_N\right) = n_t^l \cdot \left(\frac{p_N^l\left(z_N\right)}{P_N^l}\right)^{-\sigma} \tag{A127}$$

$$l_N^{u,l}\left(z_N\right) = \phi^N \cdot \left(\frac{\hat{w}_N^l}{w^{u,l}}\right)^\gamma \cdot \left(\frac{q_N^l}{z_N} + f_N^l\right) \tag{A128}$$

$$l_N^{s,l}\left(z_N\right) = \left(1-\phi^N\right) \cdot \left(\frac{\hat{w}_N^l}{w^{s,l}}\right)^\gamma \cdot \left(\frac{q_N^l}{z_N} + f_N^l\right) \tag{A129}$$

$$\tag{A130}$$

Profit

$$\pi_{N,t}^l = \frac{p_{N,t}^l\left(z_N\right) \cdot q_{N,t}^l\left(z_N\right)}{\sigma} - \hat{w}_{N,t}^l \cdot f_N^l$$

Value Function

$$W_N^l\left(z_N\right) = \max\left\{0, \frac{\pi_N^l(z_N)}{1-\beta\left(1-\delta_N\right)}\right\} \tag{A131}$$

Cutoff

$$0 = W_{N,t}^l\left(\underline{z}_N^l\right) \tag{A132}$$

Free entry condition

$$\int_{\bar{z}_{Nt}^l}^{\infty} W_{N,t}^l\left(z\right) g_N\left(z_N\right) dz_N = \hat{w}_{N,t}^l \cdot \left(f_{Ne}^l\right) \tag{A133}$$

Productivity Distributions and Firm Masses

$$\mu_N^l(z_N) = \begin{cases} \frac{g_N(z_N)}{1-G_N(\underline{z}_N^l)} & z_N \geq \underline{z}_N^l \\ 0 & \text{otherwise} \end{cases} \tag{A134}$$

$$\delta_N \cdot \mathcal{M}_N^l = \left[1 - G_N(\underline{z}_N^l)\right] \mathcal{M}_{N,e}^l \tag{A135}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$L_{N,p}^{u,l} = \mathcal{M}^N \int_{\underline{z}_N^{u,l}}^{\infty} l_N^{u,l}\left(z_N\right)\mu_N^l(z_N) dz_N \tag{A136}$$

$$L_{N,p}^{s,l} = \mathcal{M}^N \int_{\underline{z}_N^{s,l}}^{\infty} l_N^{s,l}\left(z_N\right)\mu_N^l(z_N) dz_N \tag{A137}$$

- Total skilled and unskilled labor for fixed entry cost

$$L_{N,e}^{u,l} = \phi_N^u \cdot \left(\frac{\hat{w}_N^l}{w^{u,l}}\right)^{\gamma} \cdot \left(f_{Ne}^l\right) \tag{A138}$$

$$L_{N,e}^{s,l} = \phi_N^d \cdot \left(\frac{\hat{w}_N^l}{w^{s,l}}\right)^{\gamma} \cdot \left(f_{Ne}^l\right) \tag{A139}$$

- Total skilled and unskilled labor demand

$$L_N^{u,l} = L_{N,p}^{u,l} + L_{N,e}^{u,l} \tag{A140}$$

$$L_N^{s,l} = L_{N,p}^{s,l} + L_{N,e}^{s,l} \tag{A141}$$

- Total output

$$Y_N^l = \mathcal{M}^N \left[\int_{\underline{z}_N^l}^{\infty} \left(q_N^l \left(z_N \right) \right)^{\rho} \cdot d\mu_N^l(z_N) \right]^{\frac{1}{\rho}} \tag{A142}$$

- Ideal Price Index

$$P_N^l = \left[\int_{\underline{z}_N^l}^{\infty} \left(p_N^l \left(z_N \right) \right)^{1-\sigma} d\mu_N^l(z_N) \right]^{\frac{1}{1-\sigma}} \tag{A143}$$

B.3.4 Tradable Sector

Optimal decisions

$$\hat{w}_T^l = \left[\phi_T (w^{u,l})^{1-\gamma} + (1-\phi_T)(w^{s,l})^{1-\gamma} \right]^{\frac{1}{1-\gamma}} \tag{A144}$$

$$p_T^l \left(z_T \right) = \frac{\hat{w}_T^l}{\rho \cdot z_T} \tag{A145}$$

$$q_T^l(z_T) = \begin{cases} q_d^l = T_t^l \left[\frac{p_T^l(z_T)}{P_T^l} \right]^{-\sigma}, & \underline{z}_{d,t}^l < z_T < \underline{z}_{c,t}^l \\ q_d^l + q_c^l = T_t^l \left[\frac{p_T^l(z_T)}{P_T^l} \right]^{-\sigma} + T^{\neg l} \left[\frac{p_t^l(z_T)}{P_T^{\neg l}} \right]^{-\sigma}, & \underline{z}_{c,t}^l < z_T < \underline{z}_x^l \\ q_d^l + q_c^l + q_x^l = T^l \left[\frac{p_T^l(z_T)}{P_T^l} \right]^{-\sigma} + T^{\neg l} \left[\frac{p_T^l(z_T)}{P_T^{\neg l}} \right]^{-\sigma} + \Gamma \left[p_T^l(z_T) \right]^{-\sigma}, & \underline{z}_x^l < z_T \end{cases} \tag{A146}$$

$$l_T^{u,l}(z_T) = \begin{cases} l_d^{u,l} = \phi_T \left(\frac{\hat{w}_{T,t}^l}{w^{ld}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)}{z_T} + f_d^l\right], & \overline{z}_d^l < z_T < \overline{z}_c^l \\ l_d^{u,l} + l_c^{u,l} = \phi_T \left(\frac{\hat{w}_T^l}{w^{ld}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)+q_c^l(z_T)}{z_T} + f_d^l + f_c^l\right], & \underline{z}_c^l < z_T < \underline{z}_x^l \\ l_d^{u,l} + l_c^{u,l} + l_x^{u,l} = \phi_T \left(\frac{\hat{w}_T^l}{w^{ld}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)+q_c^l(z_T)+q_x^l(z_T)}{z_T} + f_d^l + f_c^l + f_x^l\right], & \underline{z}_x^l < z_T \end{cases} \tag{A147}$$

$$l_T^{s,l}(z_T) = \begin{cases} l_d^{s,l} = (1-\phi_T) \left(\frac{\hat{w}_{T,t}^l}{w_t^{s,l}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)}{z_T} + f_d^l\right], & \underline{z}_d^l < z_T < \underline{z}_c^l \\ l_d^{s,l} + l_c^{s,l} = (1-\phi_T) \left(\frac{\hat{w}_T^l}{w^{s,l}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)+q_c^l(z_T)}{z_T} + f_d^l + f_c^l\right], & \underline{z}_c^l < z_T < \underline{z}_x^l \\ l_d^{s,l} + l_c^{s,l} + l_x^{s,l} = (1-\phi_T) \left(\frac{\hat{w}_T^l}{w^{s,l}}\right)^{\gamma} \cdot \left[\frac{q_d^l(z_T)+q_c^l(z_T)+q_x^l(z_T)}{z_T} + f_d^l + f_c^l + f_x^l\right], & \underline{z}_x^l < z_T \end{cases} \tag{A148}$$

Profits

$$\pi_T^l(z_T) = \begin{cases} \pi_d^l = \frac{p_T^l(z_T) q_{d,t}^l(z_T)}{\sigma} - \hat{w}_T^l f_d^l, & \underline{z}_d^l < z_T < \underline{z}_c^l \\ \pi_d^l + \pi_c^l = \frac{p_T^l(z_T)\left[q_d^l(z_T)+q_c^l(z_T)\right]}{\sigma} - \hat{w}_T^l (f_d^l + f_c^l), & \underline{z}_c^l < z_T < \underline{z}_x^l \\ \pi_d^l + \pi_c^l + \pi_{x,t}^l = \frac{p_T^l(z_T)\left[q_d^l(z_T)+q_c^l(z_T)+q_x^l(z_T)\right]}{\sigma} - \hat{w}_T^l (f_d^l + f_c^l + f_x^l), & \underline{z}_x^l < z_T \end{cases} \tag{A149}$$

Value functions

$$W_T^l(z_T) = \max\left\{W_d^l(z_T), W_c^l(z_T), W_x^l(z_T)\right\} \tag{A150}$$

$$W_d^l(z_T) = \max\left\{0, \frac{\pi_d^l(z_T)}{1-\beta(1-\delta_T)}\right\} \tag{A151}$$

$$W_c^l(z_T) = \max\left\{0, \frac{\pi_d^l(z_T) + \pi_c^l(z_T)}{1-\beta(1-\delta_T)}\right\} \tag{A152}$$

$$W_x^l(z_T) = \max\left\{0, \frac{\pi_d^l(z_T) + \pi_c^l(z_T) + \pi_x^l(z_T)}{1-\beta(1-\delta_T)}\right\} \tag{A153}$$

(A154)

Cutoffs

$$W_d^l(\underline{z}_d^l) = 0 \tag{A155}$$

$$\pi_c^l(\underline{z}_c^l) = 0 \tag{A156}$$

$$\pi_x^l(\underline{z}_x^l) = 0 \tag{A157}$$

Free entry condition

$$\int_{\bar{z}_{Tt}^l}^{\infty} W_{T,t}^l\left(z_T\right) g_T\left(z_T\right) dz_N = \hat{w}_{T,t}^l \cdot f_{Te}^l \tag{A158}$$

Productivity Distributions and Firm Masses

$$\mu_T^l(z_T) = \begin{cases} \frac{g_T(z_T)}{1-G_N(\bar{z}_d^l)} & z_T \geq \bar{z}_d^l \\ 0 & \text{otherwise} \end{cases} \tag{A159}$$

$$\delta_T \cdot \mathcal{M}_T^l = \left[1 - G(\bar{z}_d^l)\right] \mathcal{M}_{T,e}^l \tag{A160}$$

Aggregate variables

- Total skilled and unskilled labor for production

$$L_{T,p}^{u,l} = \mathcal{M}_t^T \int_{\underline{z}_T^l}^{\infty} l_T^{u,l}\left(z_T\right) \mu_T^l(z_T) dz_T \tag{A161}$$

$$L_{T,p}^{s,l} = \mathcal{M}_t^T \int_{\underline{z}_T^l}^{\infty} l_T^{s,l}\left(z_T\right) \mu_T^l(z_T) dz_T \tag{A162}$$

- Total skilled and unskilled labor for fixed entry cost

$$L_{T,e}^{u,l} = \phi_T^u \cdot \left(\frac{\hat{w}_T^l}{w^{u,l}}\right)^{\gamma} \cdot \left(f_{Te}^l\right) \tag{A163}$$

$$L_{T,e}^{s,l} = \phi_T^d \cdot \left(\frac{\hat{w}_T^l}{w^{s,l}}\right)^{\gamma} \cdot \left(f_{Te}^l\right) \tag{A164}$$

- Total skilled and unskilled labor demand

$$L_T^{u,l} = L_{T,p}^{u,l} + L_{T,e}^{u,l} \tag{A165}$$

$$L_T^{s,l} = L_{T,p}^{s,l} + L_{T,e}^{s,l} \tag{A166}$$

- Total tradable goods output produced in l that are sold domestically

$$\tilde{Y}_T^l = \left[\mathcal{M}^l \left(\int_{\underline{z}_d^l}^{\infty} \left[q_d^l(z_T)\right]^{\rho} \mu_T^l(z_T) dz_T + \int_{\underline{z}_c^l}^{\infty} \left[q_c^l(z_T)\right]^{\rho} \mu_T^l(z_T) dz_T\right)\right]^{\frac{1}{\rho}} \tag{A167}$$

- Total domestic tradable output supplied to region l:

$$Y_T^l = \left[\left(\int_{\underline{z}_d^l}^{\infty} \mathcal{M}^l \cdot \left[q_d^l(z_T)\right]^{\rho} \mu_T^l(z_T) dz_T + \int_{\underline{z}_c^{\neg l}}^{\infty} \mathcal{M}^{\neg l} \left[q_{ct}^{\neg l}(z_T)\right]^{\rho} \mu_T^{\neg l}(z_T) dz_T\right)\right]^{\frac{1}{\rho}} \tag{A168}$$

- Value of tradable good outputs sold in foreign market

$$X^l = \mathcal{M}_T^l \int_{\underline{z}_x^l}^{\infty} p_T^l(z_T) q_x^l(z_T) \mu_T^l(z_T) dz_T \tag{A169}$$

B.4 Aggregation and Market Clearing

Population and Employment

$$\overline{H}^d = H^{d,A} + H^{d,B} \tag{A170}$$

$$H^l = H^{s,l} + H^{u,l} \tag{A171}$$

$$h^{d,l} = L^{d,l} \leq H^{d,l} \tag{A172}$$

$$\tag{A173}$$

Aggregate Demand for Goods

$$C^l = H^{u,l} \cdot c^{u,l} + H^{s,l} \cdot c^{s,l} \tag{A174}$$

$$M^l = H^{u,l} \cdot t^{u,l} + H^{s,l} \cdot t^{s,l} \tag{A175}$$

$$T^l = H^{u,l} \cdot t^{u,l} + H^{s,l} \cdot t^{s,l} \tag{A176}$$

$$A^l = H^{u,l} \cdot a^{u,l} + H^{s,l} \cdot a^{s,l} \tag{A177}$$

$$\Omega^l = H^{u,l} \cdot \omega^{u,l} + H^{s,l} \cdot \omega^{s,l} \tag{A178}$$

$$N^l = H^{u,l} \cdot n^{u,l} + H^{s,l} \cdot n^{s,l} \tag{A179}$$

$$G^l = H^{u,l} \cdot g^{u,l} + H^{s,l} \cdot g^{s,l} \tag{A180}$$

$$C_C^{l,A} = H^{u,l} \cdot c_C^{l,A} + H^{s,l} \cdot c_C^{l,A} \tag{A181}$$

$$C_C^{l,B} = H^{u,l} \cdot c_C^{l,B} + H^{s,l} \cdot c_C^{l,B} \tag{A182}$$

$$C_C^A = C_C^{A,A} + C_C^{B,A} \tag{A183}$$

$$C_C^B = C_C^{A,B} + C_C^{B,B} \tag{A184}$$

Market Clearance

$$Y_N^l = N^l \tag{A185}$$

$$Y_T^l = T^l \tag{A186}$$

$$\overline{R}^l = R^l \tag{A187}$$

Balance of Payments

$$X = P_C^A \left(Y_C^A - C_C^A\right) + P_C^B \left(Y_C^B - C_C^B\right) + X_T^A + X_T^{\mathbf{A}} \tag{A188}$$

$$M = M^A + M^B \tag{A189}$$

$$TB = X - M \tag{A190}$$

$$B = -\frac{TB}{r^*} \tag{A191}$$

B.4.1 Steady State Algorithm

Assumption

- Symmetric regions.

Algorithm

1. Guess unskilled wages $\left(w^{u,A}, w^{s,A}\right)$ and import demands $\left(m^{A}, m^{B}\right)$. Given the skill premium, guesses for unskilled wages imply guesses for skilled wages.

2. Recover all good bundle prices from (A102)-(A105) and demands from (A109)-(A116). Also, compute aggregate demands for tradable, nontradable, and commodity bundles from (A176), (A177), (A183), and (A184).

3. Evaluate the firm value functions in the tradable and nontradable sectors using (A150) and (A131). Then, solve for the cutoffs for operation, interregional trade, and international exporting from (A132), (A155), (A156), and (A157).

4. Using the firm value functions, recover the fixed entry cost implied by the free-entry conditions (A133) and (A158).

5. Given operational cutoffs, define the steady state productivity distributions using (A134) and (A159). Then, compute the total firm masses using the market clearing conditions (A142), (A185), (A168), and (A186). Given firm masses, recover the mass of entrants from (A135) and (A160).

6. Recover total labor demands from tradable, nontradable, and commodity sectors using (A120), (A121), (A140), (A141), (A165), and (A166),

7. Compute the steady state net foreign asset position from (A191).

8. Update guesses until markets for skilled and unskilled labor clear and the net foreign asset position matches the target $\overline{B}$.

Terminal Steady State The terminal steady state is characterized by a value of λ. Given λ from the transition algorithm as well as the guesses for prices and wages, recover expenditure and consumption from (A106) and (A107). Then, guess the share of skilled and unskilled population in region A and recover aggregate demands for goods bundle. After computing labor demands from the three sectors, check if the distribution of skilled and unskilled population across regions is consistent with the initial guesses. If not, update the initial guesses as a convex combination of the previous guesses and the implied values until they are consistent with each other.

C Quantitative Appendix

In this appendix we document the robustness of our quantitative results to varying the value of key parameters, including the location preference, the fixed cost of interregional sales and the fixed cost of international exporting. In addition, we show the results are robust to different initial conditions of the ratio of net foreign assets to GDP, or to the inclusion of a bond-holding cost. Finally, we include additional results showing the evolution of productivity cutoffs, wages, and unemployment.

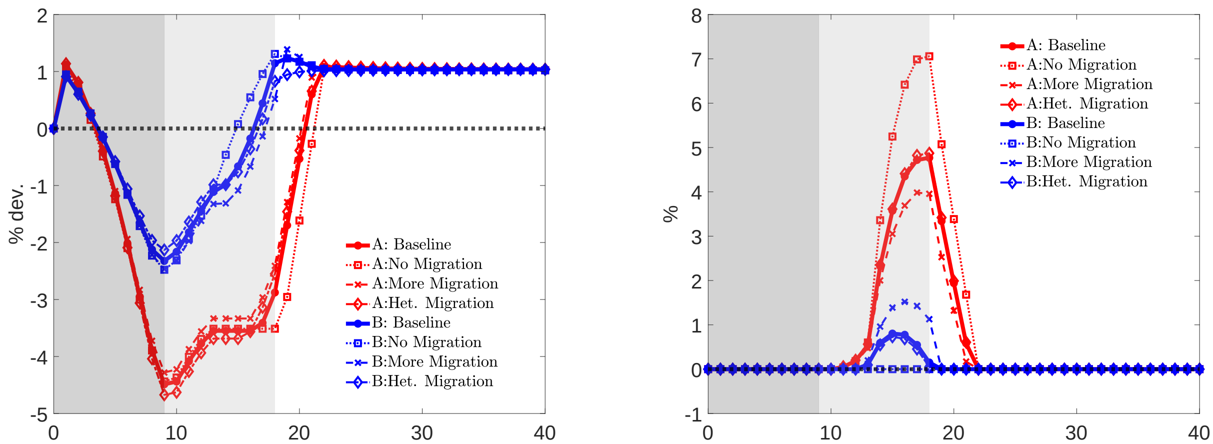
C.1 Location Preferences

A fundamental parameter in the model is the location preference ξ which we calibrated using microdata. Here we document the response of the model a commodity price cycle in an economy with a stronger or weaker location preference. We also allow heterogeneous location preferences between skilled and unskilled workers. The baseline value for this parameter in the main text was $\xi = 10$. We compare this to an economy with a lower location preference $\xi_{LOW} = 5$ and with an extreme case with no migration due to infinite location preference ($\xi_{HIGH} = \infty$). In the economy with heterogeneous location preferences we set this equal to $\xi_{skilled} = 4$ and $\xi_{unskilled} = 11$.

Figure A9 illustrates the response of the skill premium and the unemployment rate in regions A and B during a commodity price cycle, under each value of the location preference. For the skill premium, the response of each of these economies with different degrees of interregional mobility is fairly similar.

Figure A10a illustrates the dynamics of migration, showing the total population in region A. Evidently, under the infinite location preference, it remains constant. Comparing the baseline economy ($\xi = 10$) with the economy with a low location preferences ($\xi_{LOW} = 5$), in the latter the share of population in region A increases substantially more during the boom. Figures A10b and A10c indicate that these flows are driven by both skilled and unskilled workers. Finally, Figures A10d and A10e indicate that in the economy with no migration, the additional increase in (economy-wide) unemployment is similar for skilled and unskilled labor.

We also find that most aggregate outcomes do not vary significantly as the location preference changes (see Figure A11). One outcome that does show a difference is the unemployment rate. In the case with no migration (when the location preference is $\xi_{HIGH} = \infty$) the peak of the unemployment rate is one percentage point higher than in the baseline case. In other words, migration dampens unemployment. This larger unemployment rate in the no-migration economy



a) Skill Premium by Region

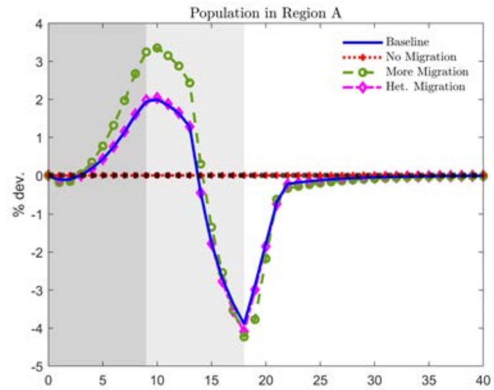
b) Unemployment by Region

Figure A9: Skill Premium and Unemployment under Different Location Preferences

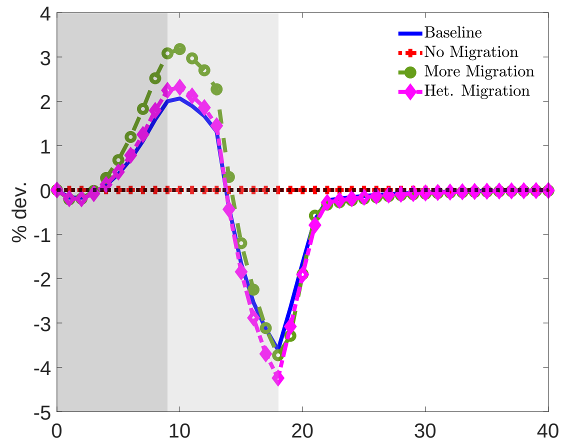
causes a larger (by 1 percentage point) decline in real GDP during the bust.

Note also that while reducing migration affects unemployment and GDP, allowing for differential location preferences between skilled and unskilled workers does not appear to have much of a macroeconomic impact.

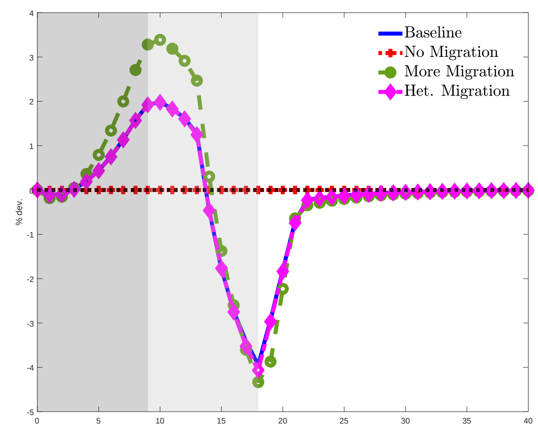
Last, Figure A12 shows that intersectoral labor reallocation as a result of the commodity cycle, captured by the ratio of employment in the tradable relative to the nontradable sector, does not depend meaningfully on the location preference.



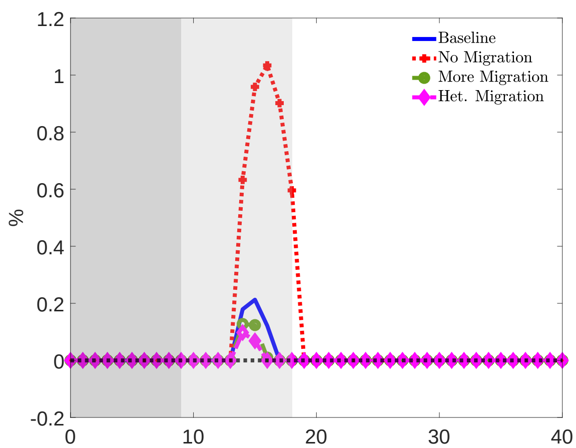
a) Total Population in Region A



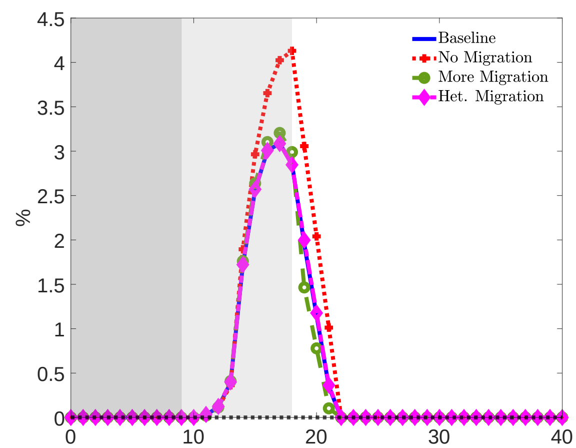
b) Skilled Population in Region A



c) Unskilled Population in Region A

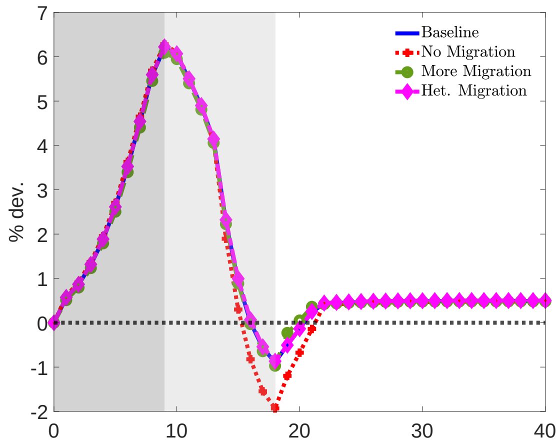


d) Skilled Unemployment (economy-wide)

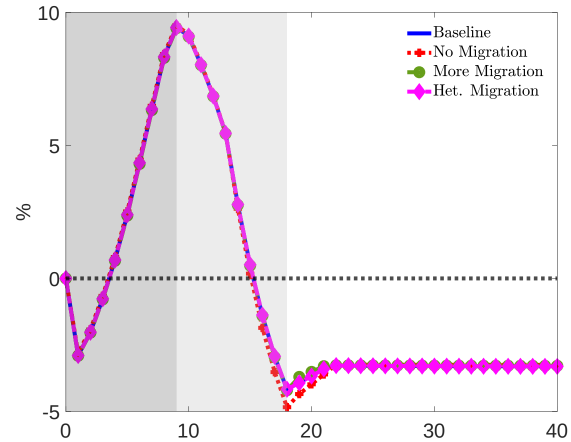


e) Unskilled Unemployment (economy-wide)

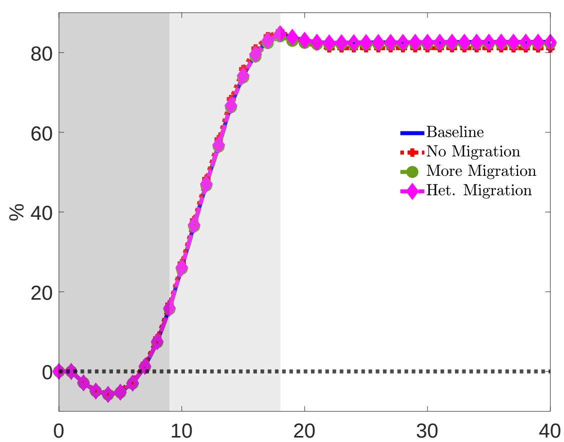
Figure A10: Population and Unemployment by Skill Type under Different Location Preferences



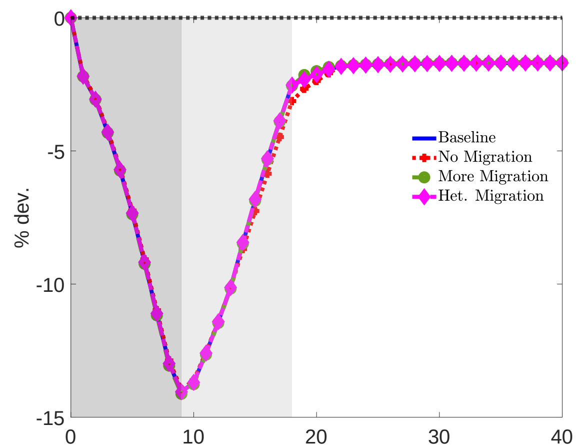
a) Real GDP



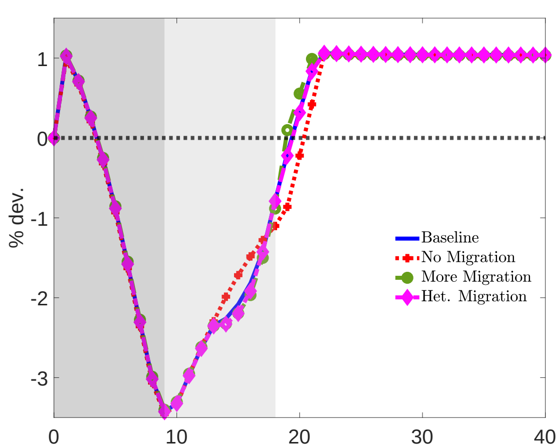
b) Trade Balance to GDP



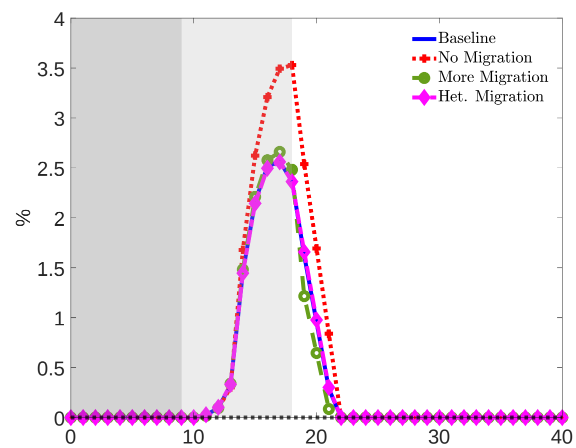
c) Net Foreign Asset to GDP



d) Real Exchange Rate



e) Skill Premium



f) Unemployment Rate

Figure A11: Macroeconomic Outcomes under Different Location Preferences

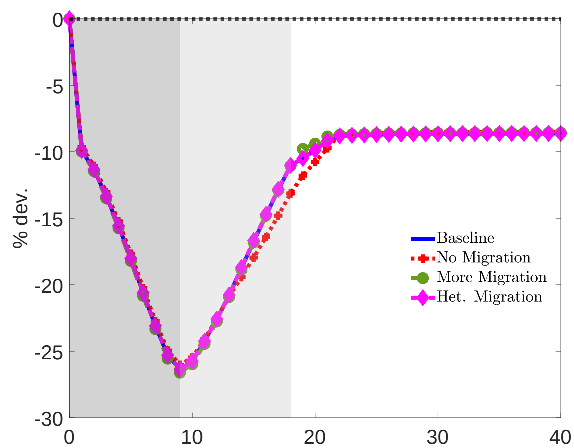


Figure A12: Relative Sectoral Employment under Different Location Preferences

C.2 The Fixed Cost of Interregional Exporting

In this section we document the sensitivity of our results to varying the fixed cost of interregional exporting (f_c). We compare the baseline economy with two other ones with a 25% higher and 25% lower values for this fixed cost. Recall that the interregional export fixed cost impacts aggregate trade flows through a selection effect; a higher fixed cost limits the set of firms that export to the other region. Figure A13 illustrates the total volume of interregional trade in Brazil (adding exports from region A to B and exports from B to A). The first message that emerges from this figure is that these large changes in the fixed cost of interregional exports result in small changes in trade flows. Intuitively, changes in interregional trade flows are smaller in magnitude in the economy with the larger fixed cost.

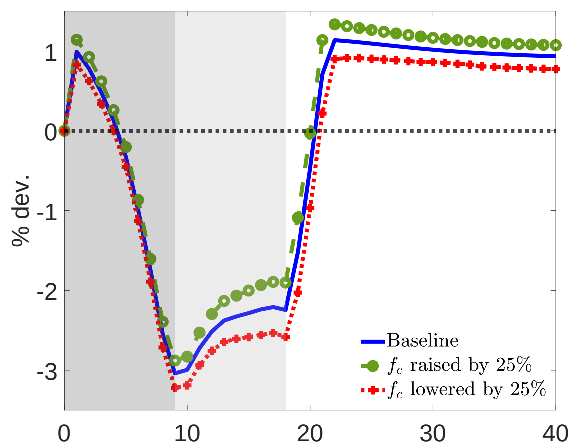


Figure A13: Interregional Trade Volume

Next, Figure A14 indicates that the macroeconomic effects from varying the interregional export fixed cost are very small. The unemployment rate is the only outcome for which we observe some difference. Peak unemployment during the bust reaches 2.8% (in % deviation from the steady state) in the high f_c economy and 2.4% in the low f_c economy.

Finally, Figure A15 illustrates the intersectoral labor reallocation as a result of the commodity cycle, plotting employment in the tradable relative to the nontradable sector. As with the other outcomes described earlier, the three economies behave very similarly during the boom and bust.

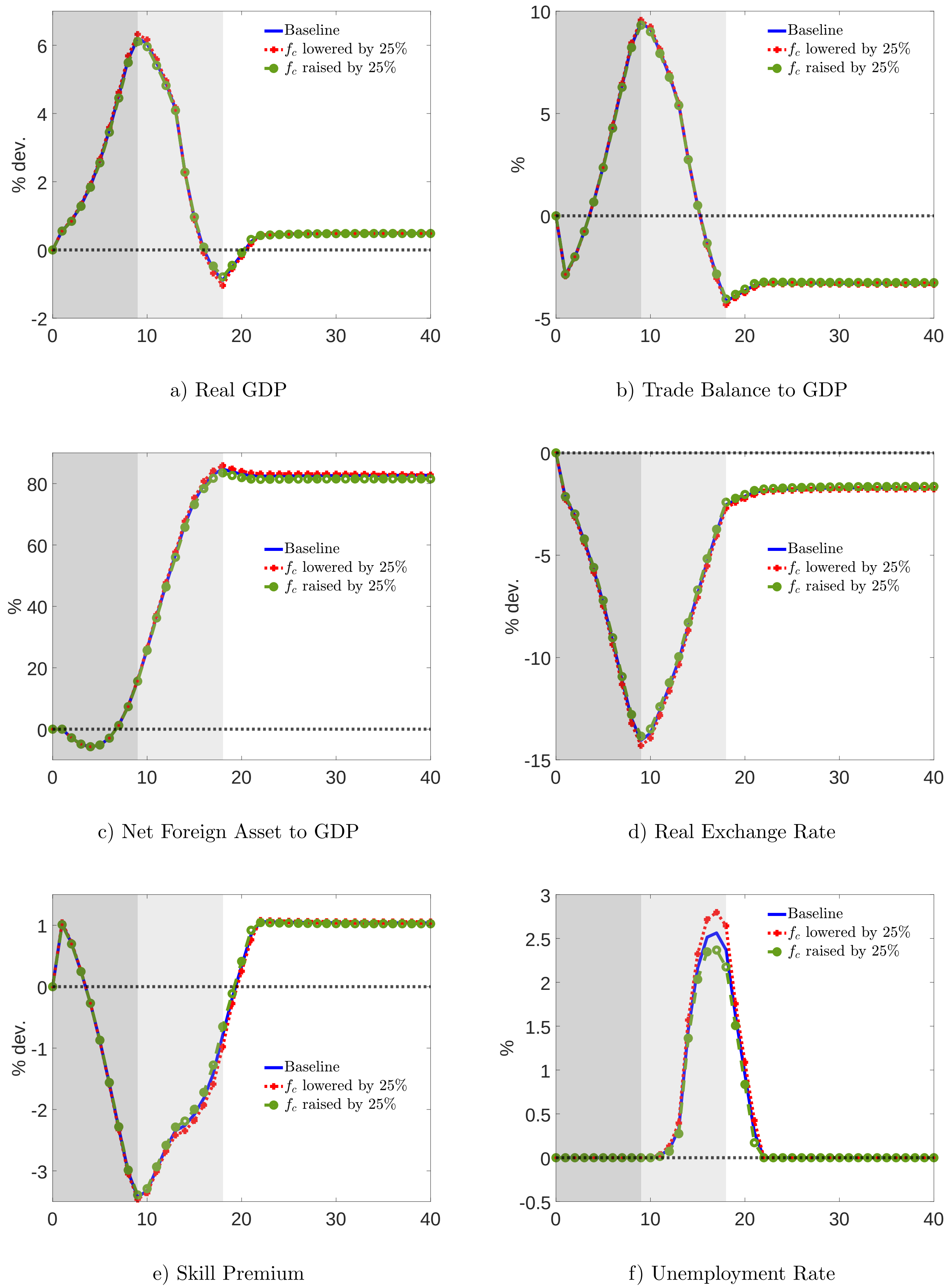


Figure A14: Macroeconomic Outcomes under Different Fixed Costs of Interregional Exporting

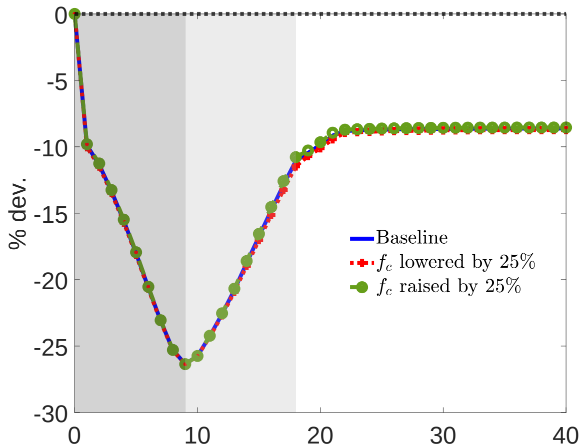


Figure A15: Relative Sectoral Employment under Different Fixed Costs of Interregional Exporting

C.3 The Fixed Cost of International Exporting

Another important parameter is the fixed cost of international exports (f_x). As in the previous case, we compare the baseline economy with two other ones with a 25% higher and 25% lower values for this fixed cost. Recall that the international export fixed cost impacts aggregate trade flows through a selection effect; a higher fixed cost limits the set of firms that export abroad.

Figure A17 indicates that the macroeconomic effects from varying the international export fixed cost are very small. For example, peak real GDP (in % deviation from the steady state) during the boom reaches about 7% in the economy with a high f_x and 5.5% in the economy with a low f_x. For the unemployment rate we observe a larger difference. Peak unemployment during the bust reaches 3.5% (again in % deviations from the steady state) in the high f_x economy and 1.5% in the low f_x economy.

Figure A16 illustrates the intersectoral labor reallocation as a result of the commodity cycle, plotting the relative employment in the tradable relative to the nontradable sector. As with the other outcomes described earlier, the three economies behave similarly during the boom and bust.

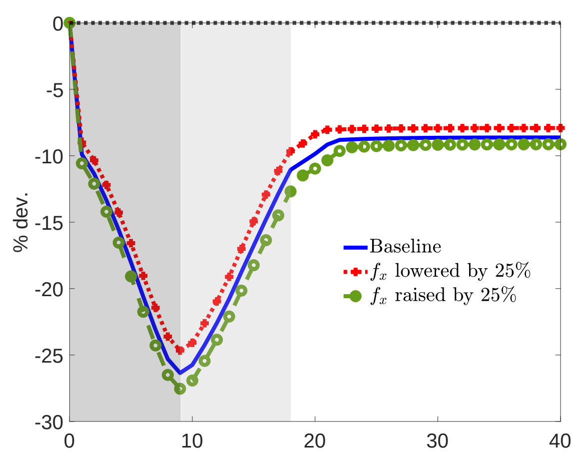
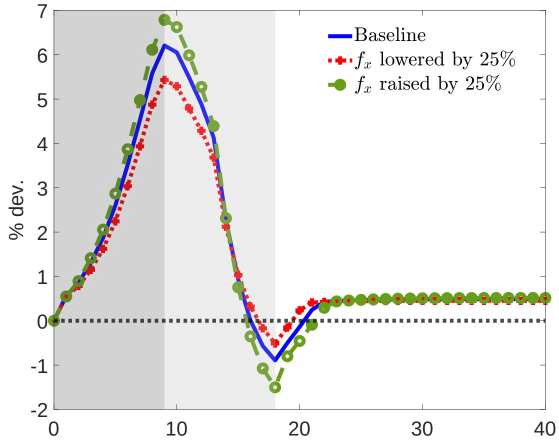
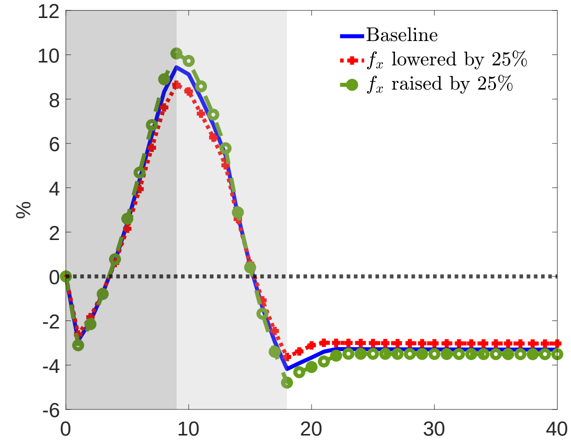


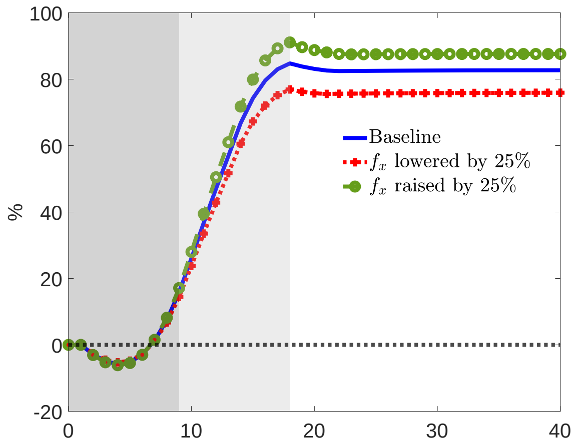
Figure A16: Relative Sectoral Employment under Different Fixed Costs of International Exporting



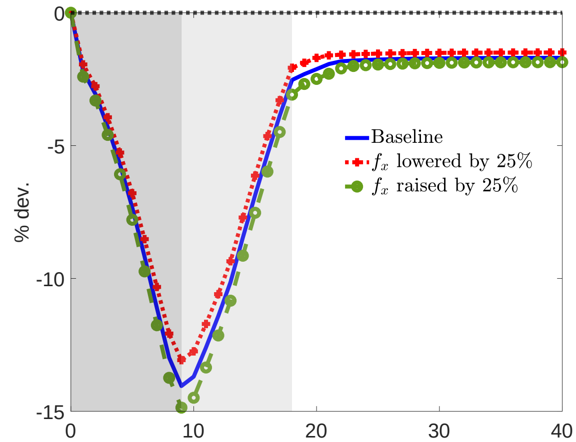
a) Real GDP



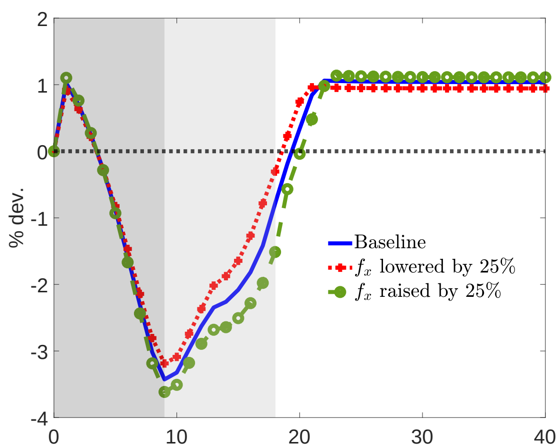
b) Trade Balance to GDP



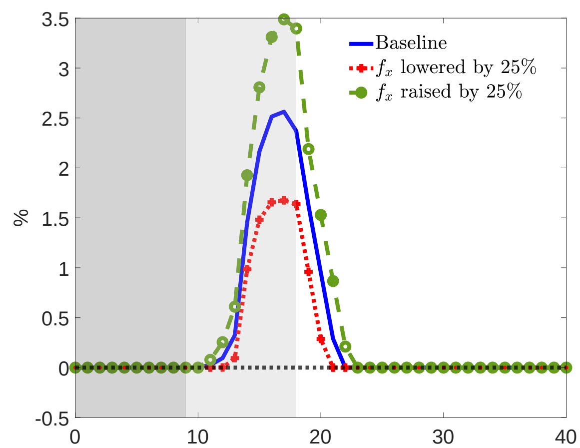
c) Net Foreign Asset to GDP



d) Real Exchange Rate



e) Skill Premium



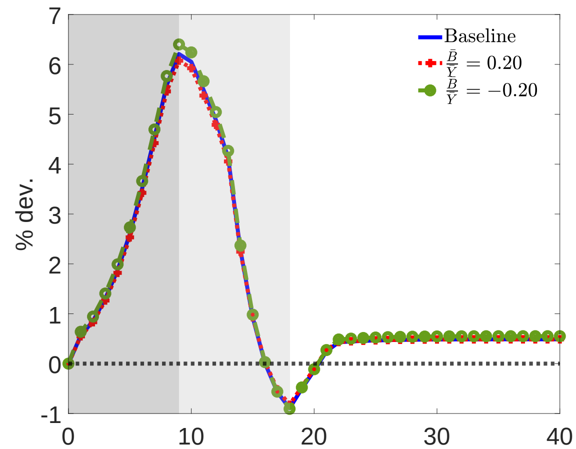
f) Unemployment Rate

Figure A17: Macroeconomic Outcomes under Different Fixed Costs of International Exporting

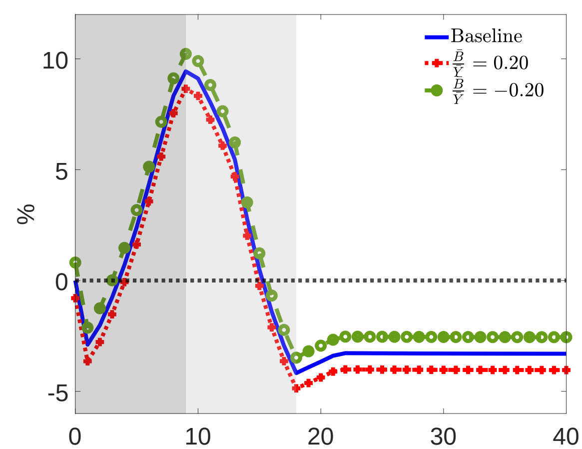
C.4 Initial Condition for Net Foreign Assets to GDP

In our baseline analysis we have assumed initial household debt to be zero. In this section we show that changes in this initial condition have practically no impact on the evolution of the skill premium, the unemployment rate, intersectoral labor reallocation, and various other outcomes. We simulate the baseline economy alongside two alternative economies with +20% and -20% initial net foreign assets to GDP. Figure A18 illustrates the path of macroeconomic outcomes, showing no differences between these three economies, except of course in the plot of net foreign assets to GDP which follow parallel paths and in the trade balance to GDP ratio. In the case of the trade balance to GDP ratio, note that an economy starting with higher net foreign assets to GDP accumulates higher holdings after the commodity cycle as well, and is able to sustain a larger trade deficit in the new steady state.

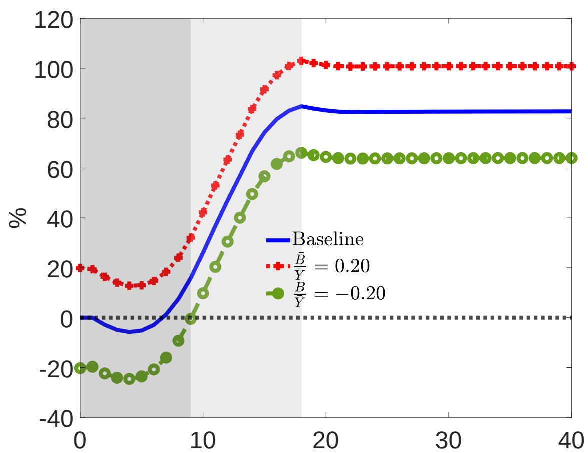
Figure A19 in turn illustrates the intersectoral labor reallocation as a result of the commodity cycle. It plots the relative employment in the tradable relative to the nontradable sector, showing the three economies behave similarly during the boom and bust.



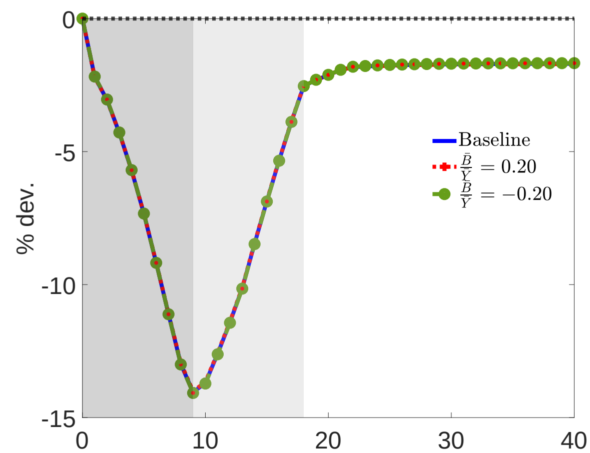
a) Real GDP



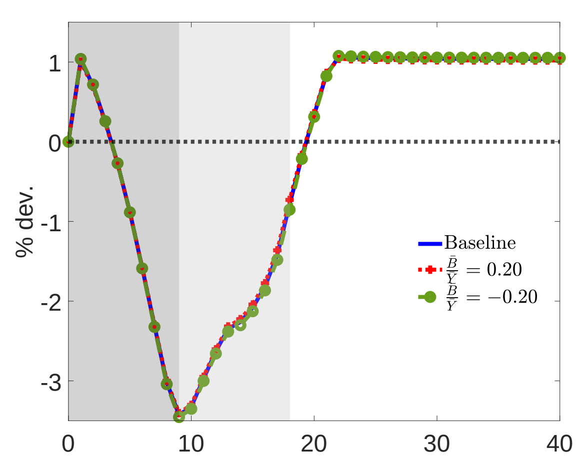
b) Trade Balance to GDP



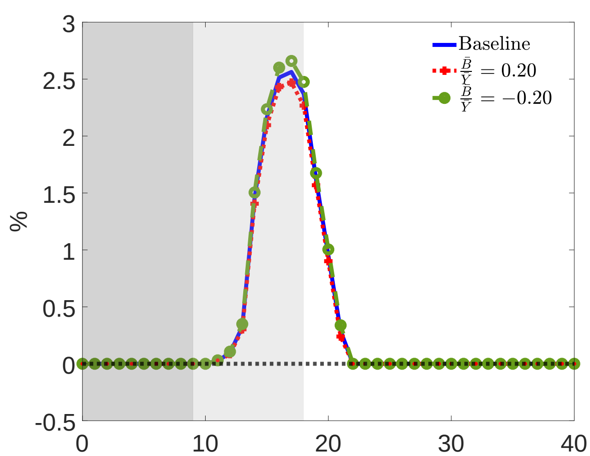
c) Net Foreign Asset to GDP



d) Real Exchange Rate



e) Skill Premium



f) Unemployment Rate

Figure A18: Macroeconomic Outcomes under Different Initial Conditions for Net Foreign Assets to GDP

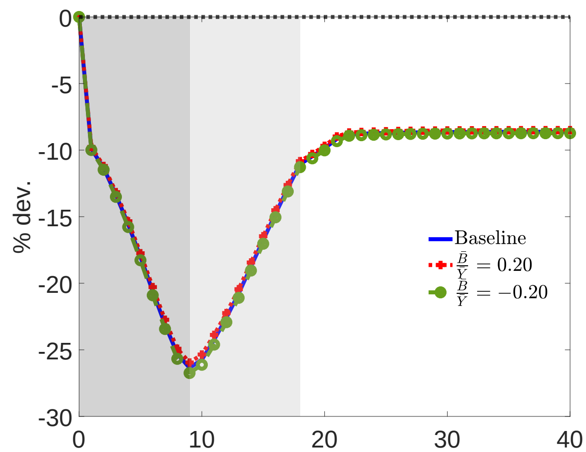


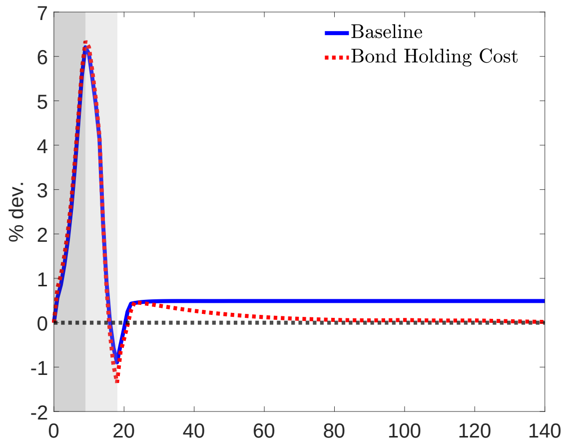
Figure A19: Relative Sectoral Employment under Different Initial Conditions for Net Foreign Assets to GDP

C.5 Including a Bond-Holding Cost

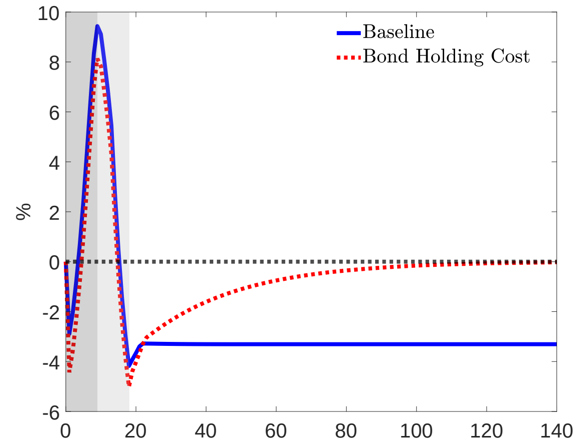
In this section we show our results are robust to adding a bond-holding cost. A bond-holding cost forces the economy to eventually converge to the original steady state. We thus show that our short and medium-run results are not driven by the permanent long-run divergence from the initial steady state in the baseline case. Specifically, the bond holding cost is quadratic in the amount of bond held ($\frac{\psi_B}{2}(B_t)^2$) and it is added to the household's budget constraint. The long-run steady state has $B = 0$, just like the initial condition. Note that the bondholding cost implies that there is no longer perfect consumption smoothing as saving is now costly. The household's consumption will thus be larger during the boom.

Figure A20 compares the evolution of macroeconomic outcomes in the baseline economy and the case with the bondholding cost. The main message from these plots is that while the two economies differ in the long-run values to which they converge, their behavior is very similar in the short and medium-run (during the boom and bust). The largest difference occurs for the peak unemployment rate observed during the bust, which is higher in the economy with a bond-holding cost. The reason is that the under the bond-holding cost the larger initial consumption (due to a lack of consumption smoothing) results in a larger increase in wages. During the bust, this leads to higher unemployment due to the downward wage rigidity constraint. Regarding the long-run steady state after the cycle, note that the the economy with a bond-holding cost accumulates less net foreign assets.

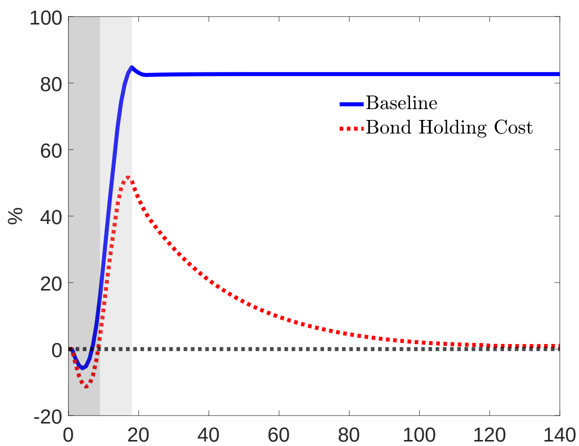
Figure A21 illustrates the intersectoral labor reallocation as a result of the commodity cycle. It plots the relative employment in the tradable relative to the nontradable sector. As with the other outcomes described earlier, the two economies behave similarly during the boom and bust.



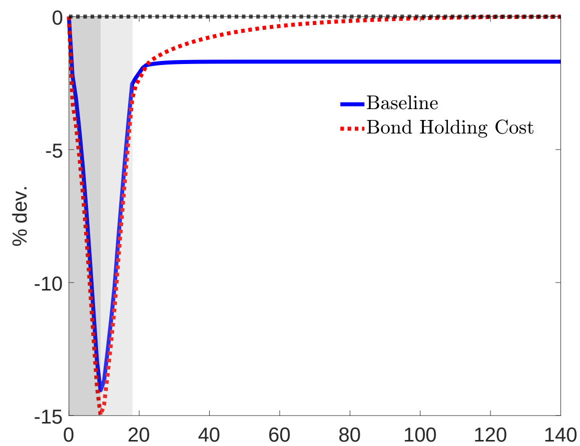
a) Real GDP



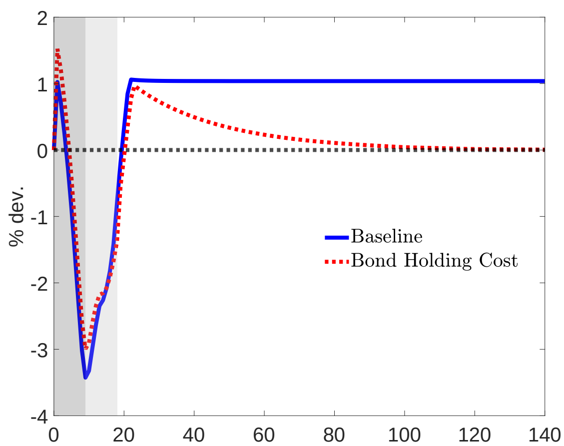
b) Trade Balance to GDP



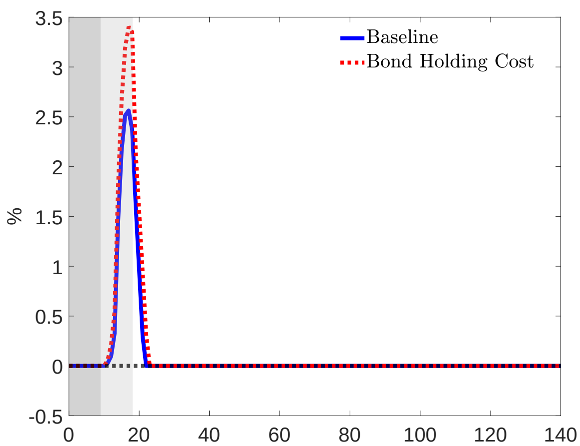
c) Net Foreign Asset to GDP



d) Real Exchange Rate



e) Skill Premium



f) Unemployment Rate

Figure A20: Macroeconomic Outcomes when Including a Bond-Holding Cost

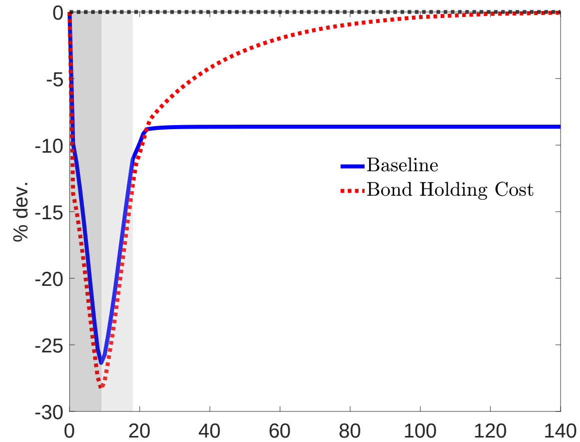


Figure A21: Relative Sectoral Employment when Including a Bond-Holding Cost

C.6 Welfare and Unemployment Comparison

In this section we compare outcomes between the various counterfactual economies simulated in sections C.1 through C.5. The first two columns show that the peak unemployment observed during the bust and the duration of unemployment (the number of periods with positive unemployment) vary relatively little across exercises. The peak unemployment reaches 2.56% in the baseline economy, 3.53% in the economy with no migration (the highest value we find) and 1.68% in the economy with a low fixed cost of international exports (the lowest value we find). Column 3 illustrates the long run value of net foreign assets to GDP, which ranges from 0.64 to 0.88 (except of course in the case with a bond-holding cost). Column 4 shows the consumption-equivalent welfare gain from the commodity cycle. Recall that this is the difference between the welfare gain of an economy exposed to the cycle versus that of one not exposed, 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 ranges from 1.57% in the case with a low fixed cost of international exports and 1.88 in the case with an initial net foreign assets to GDP ratio of -20%.

Table A22: Welfare Comparisons

	Peak Unemp.	Unemp. Duration	Long Run B/Y	CEQ Welfare (%)
Baseline	2.56%	11	0.83	1.74
$B_0/Y = 0.20$	2.47%	11	1.01	1.66
$B_0/Y = -0.20$	2.66%	11	0.64	1.88
Bond-holding cost	3.40%	11	0	1.66
High f_x	3.49%	11	0.88	1.83
Low f_x	1.68%	12	0.76	1.57
High f_c	2.37%	11	0.81	1.74
Low f_c	2.80%	11	0.82	1.77
Low location preference	2.66%	11	0.82	1.70
No Migration	3.53%	11	0.81	1.64
(Infinite Location Preference)				
Het. Location Preference	2.56%	11	0.83	1.75

C.7 Additional Outcomes: Productivity Cutoffs

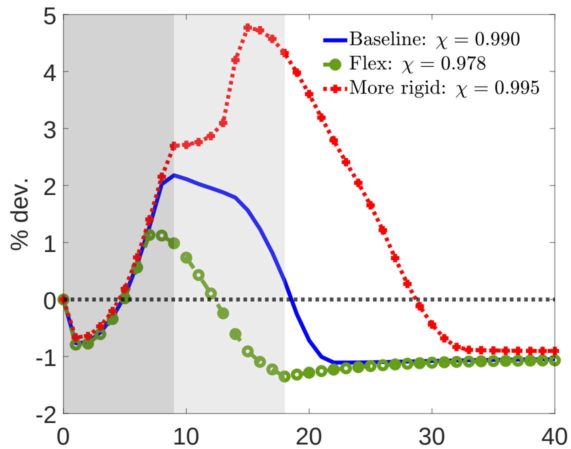
Our model generates rich entry and exit dynamics as a result of the commodity cycle. In this section we describe the evolution of the entry and exit productivity cutoffs that summarize the entry and exit margins. Note that in each region A and B there are three productivity cutoffs for firms in the tradable sector: for selling in a firm's own region, for interregional exporting, and for international exporting. Figure A22 illustrates this.

In region A, the first cutoff, for selling in a firm's own region (A) decreases on impact (as a result of consumption smoothing) and later increases during the boom due to the increase in wages. Additionally, because it is cheaper to produce in region B (as the wage increases less), region A individuals substitute their consumption towards region B tradable production, further contributing to the increase in region A's entry cutoff. In region B, this cutoff for selling in a firm's own region falls during the boom because it is cheaper to produce tradable goods in region B, shifting region B's consumption towards its own production. Note also that the degree of downward wage rigidity in the economy shapes the evolution of these cutoffs. In region A the three economies (baseline, flexible and more rigid) behave similarly during the boom when the rigidity constraint is not binding. During the bust, the productivity cutoff falls in the flexible economy, while it further rises in the more rigid economy. The reason is that in the more rigid economy wages remain persistently higher, increasing the cost of production, and in addition there is unemployment which lowers demand. In region B the three different economies behave more similarly because there is a smaller commodity boom and less unemployment.

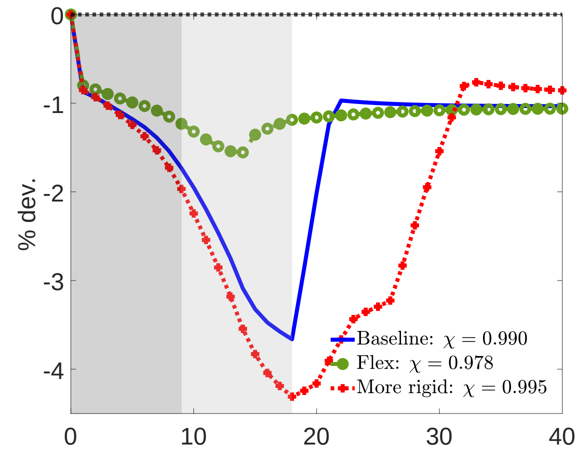
In region A again, the second cutoff, for interregional exporting, increases during the boom because it is cheaper to produce tradable goods in region B. As a result, region B consumes more of its own production and imports less from region A. At the same time, the cutoff for interregional exporting falls in region B during the boom because individuals in region A increase their demand goods produced in region B given that the wage increase is lower in region B than in region A.

Finally, the third cutoff, for international exporting, increases during the boom in both regions due to the increases in wages. Note that this effect is stronger in region A which experiences a larger commodity price boom.

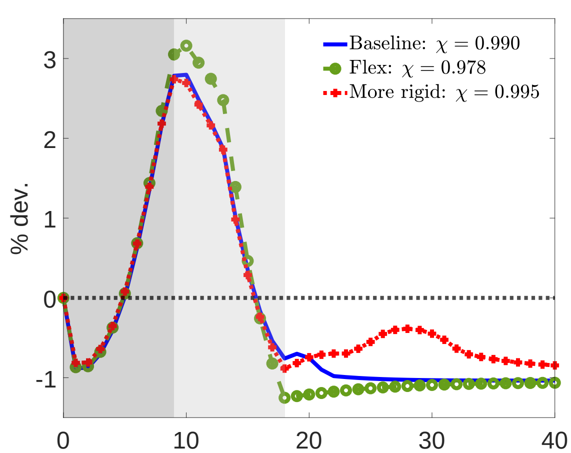
In the nontradable sector, there is a single cutoff, for selling in a firm's own region. The evolution of this cutoff in each region is shown in Figure A23. In both regions, the initial decline in this cutoff is due to the increase in nontradable consumption. The fact that wages increase during the boom however, also imply an increase in costs leading to an increase in the productivity cutoff. During the bust, the productivity cutoff falls in the flexible economy, while it further rises in the more rigid economy, similar to what occurs with the tradable sector. Once again, the reason behind this is that in the more rigid economy wages remain higher, increasing the cost of production, and unemployment lowers demand. In region B differences across the three economies bare smaller because the commodity boom is smaller and there is less unemployment.



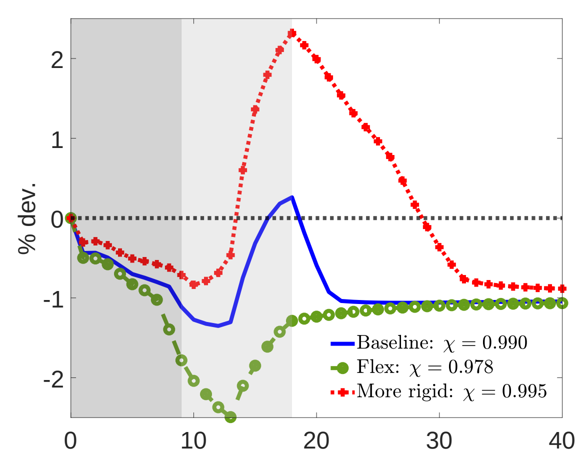
a) Entry Cutoff (Region A)



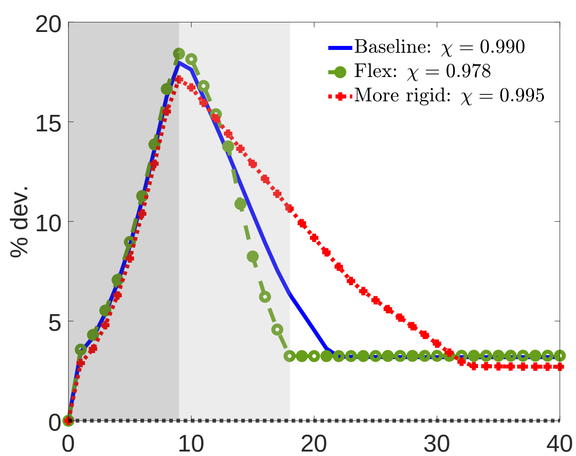
b) Entry Cutoff (Region B)



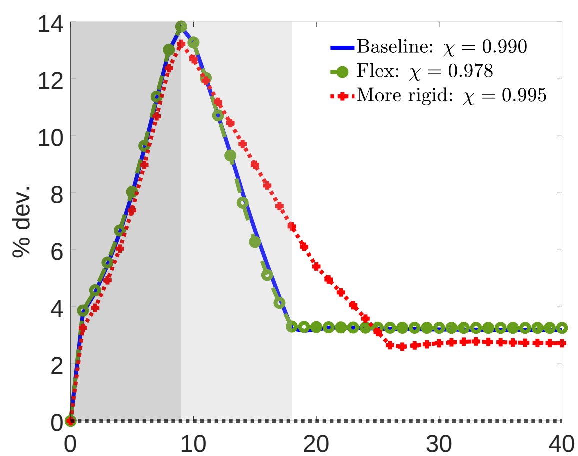
c) Interregional Trade Cutoff (Region A)



d) Interregional Trade Cutoff (Region B)

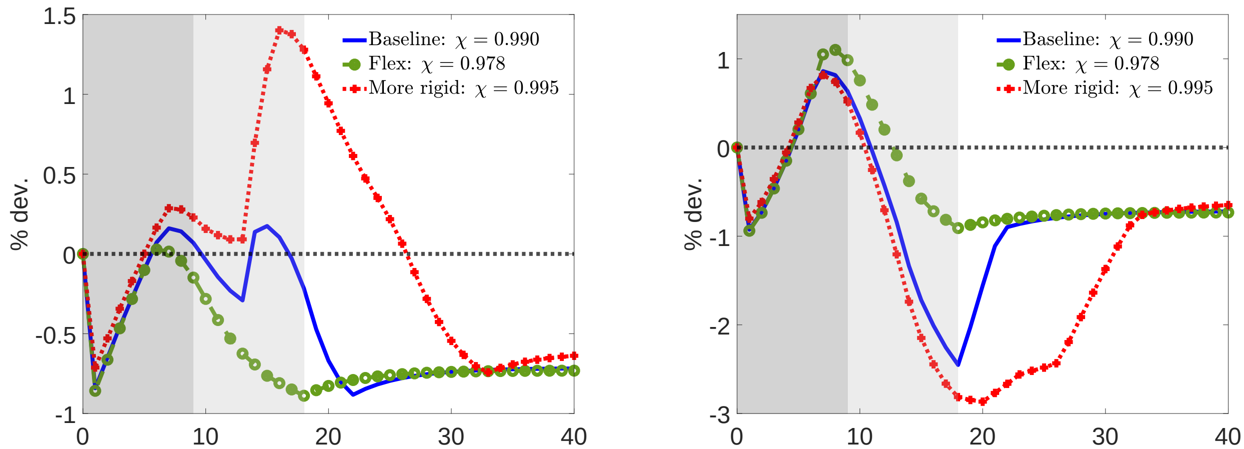


e) Exporting Cutoff (Region A)



f) Exporting Cutoff (Region B)

Figure A22: Tradable Sector Productivity Cutoffs



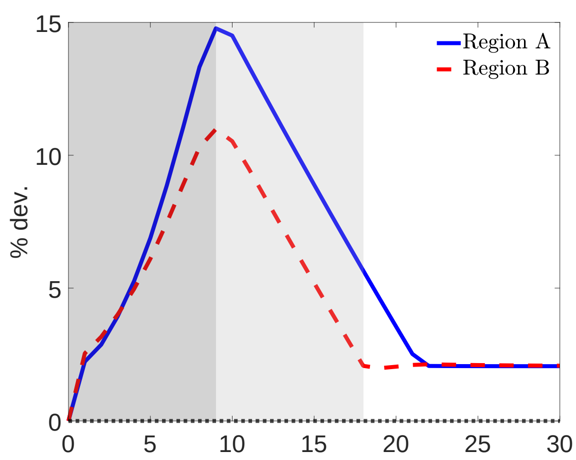
a) Entry Cutoff (Region A)　　　b) Entry Cutoff (Region B)

Figure A23: Nontradable Sector Productivity Cutoffs

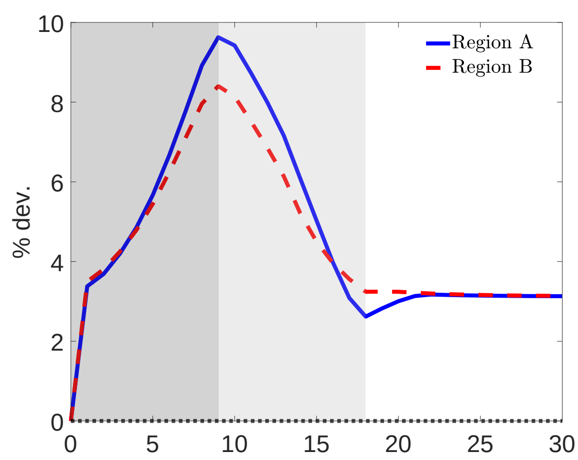
C.8 Additional Outcomes: Wages and Unemployment

In this section we include additional figures illustrating the evolution of wages and unemployment during the commodity cycle. Figure A24 plots unskilled and skilled wages in each region. The increase in wages during the boom is larger in region A, which faces the larger increase in the commodity price. The difference between both regions is larger for unskilled wages, which respond more to changes in commodity prices.

Figure A25 plots unemployment rates for unskilled and skilled wages in each region in the baseline economy and under the different degrees of downward wage rigidity simulated in Section 5.4. Figures A25b and A25b plot the unemployment rates for unskilled and skilled workers at a national level. In both cases there is a very large difference between the flexible economy (with no unemployment), the baseline economy ($\chi = 0.990$), and the more rigid economy ($\chi = 0.995$). Figures A25c and A25e compare unskilled unemployment between regions A and B. Unemployment rises substantially more in A because this region experiences a larger commodity boom, so wages increase further and consequently unemployment is higher in the bust due to the downward wage rigidity constraint. Similarly, Figures A25d and A25f compare skilled unemployment between both regions. The same pattern emerges: unemployment rises further in region A. In fact in region B, there is zero skilled unemployment in the baseline economy.

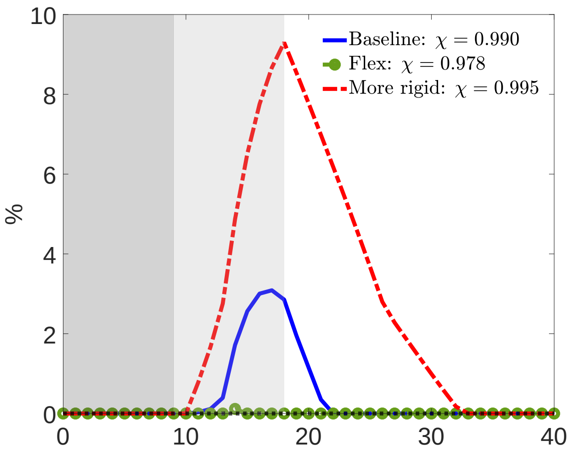


a) Unskilled Wages

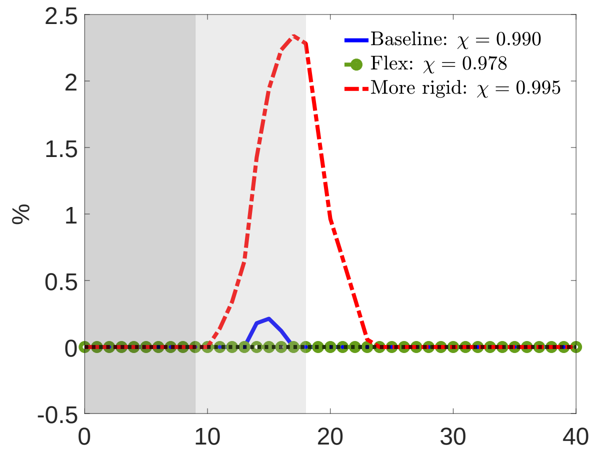


b) Skilled Wages

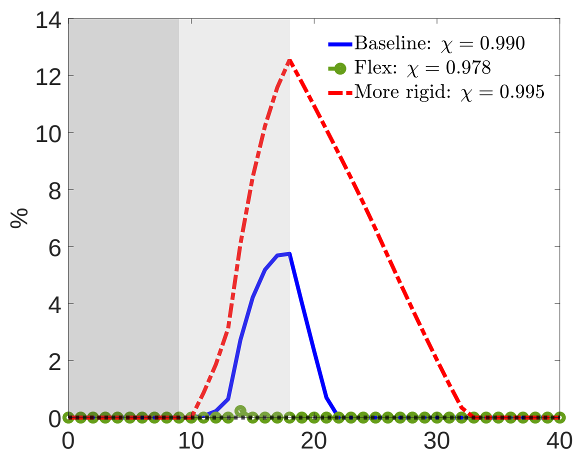
Figure A24: Wages by Region



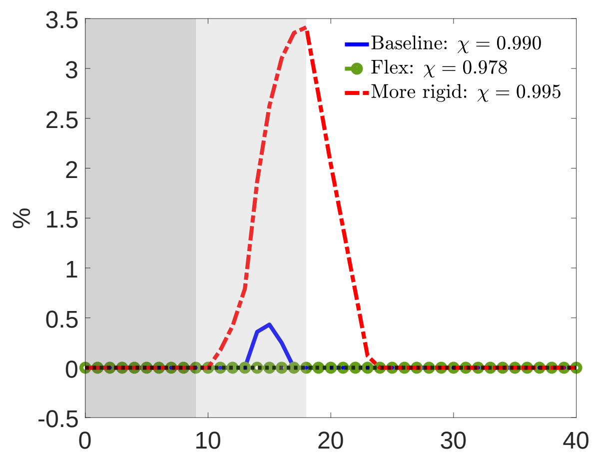
a) Unskilled Unemployment



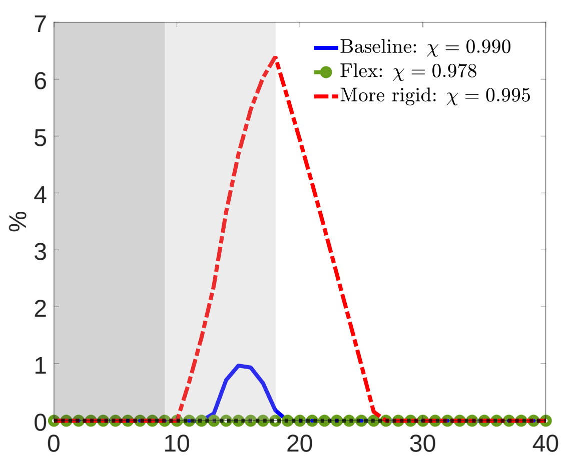
d) Skilled Unemployment



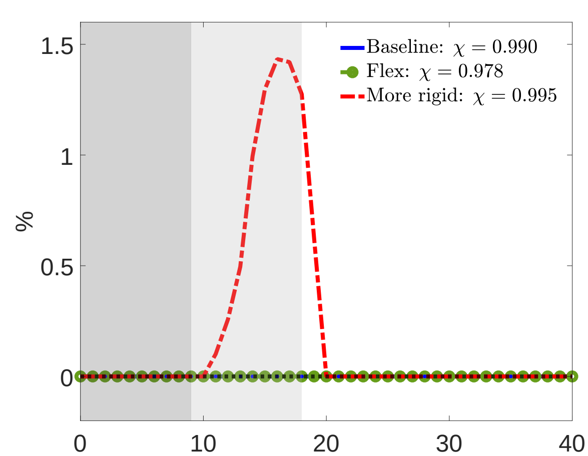
b) Unskilled Unemployment (Region A)



e) Skilled Unemployment (Region A)



c) Unskilled Unemployment (Region B)



f) Skilled Unemployment (Region B)

Figure A25: Unemployment under Different Degrees of Downward Wage Rigidity

C.9 Additional Outcomes: Intersectoral Reallocation

Figure A26 illustrates the path of the share of total employment, output, and the mass of entrants in the tradable and nontradable sectors under different degrees of wage rigidity. 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 these 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.

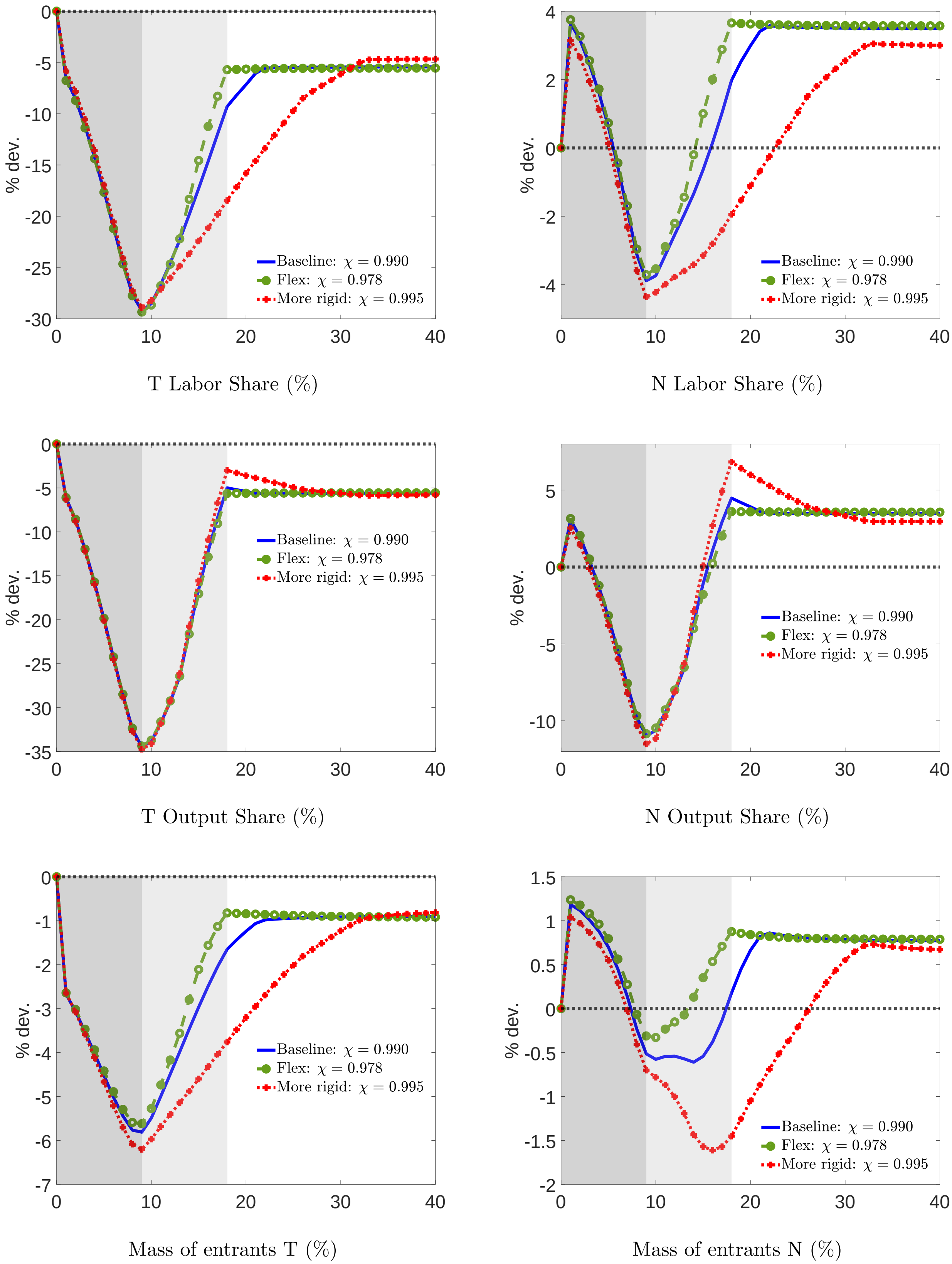
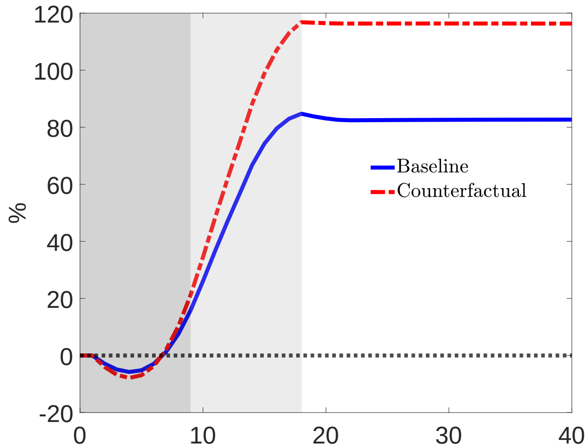
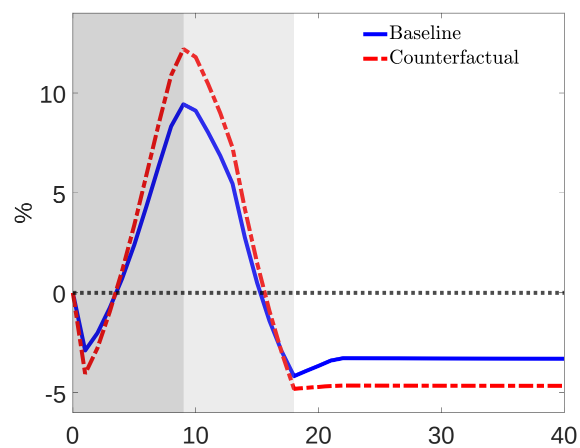


Figure A26: Intersectoral Reallocation under Different Degrees of Downward Wage Rigidity

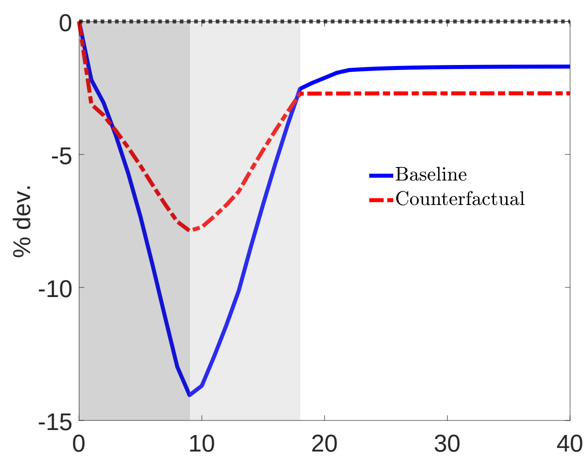
C.10 General Equilibrium Counterfactual: Additional Results



a) Net Foreign Assets to GDP ratio



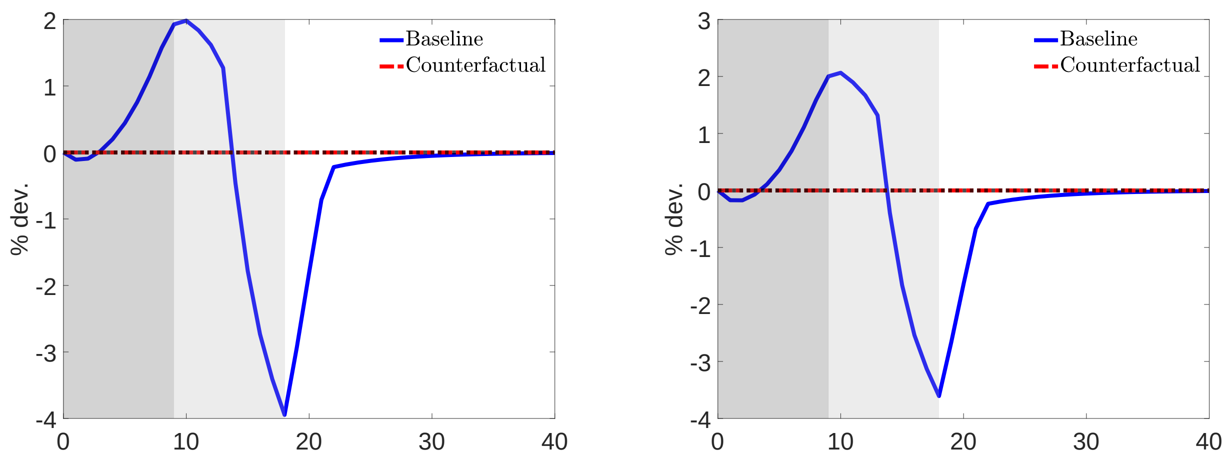
b) Trade Balance to GDP ratio



c) Real Exchange Rate

Figure A27: Macroeconomic Outcomes in the Baseline and Counterfactual Economies

NOTE: This figure shows the response of the net foreign assets to GDP ratio, the trade balance to GDP ratio and the real exchange rate to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red dotted line corresponds to the counterfactual economy.

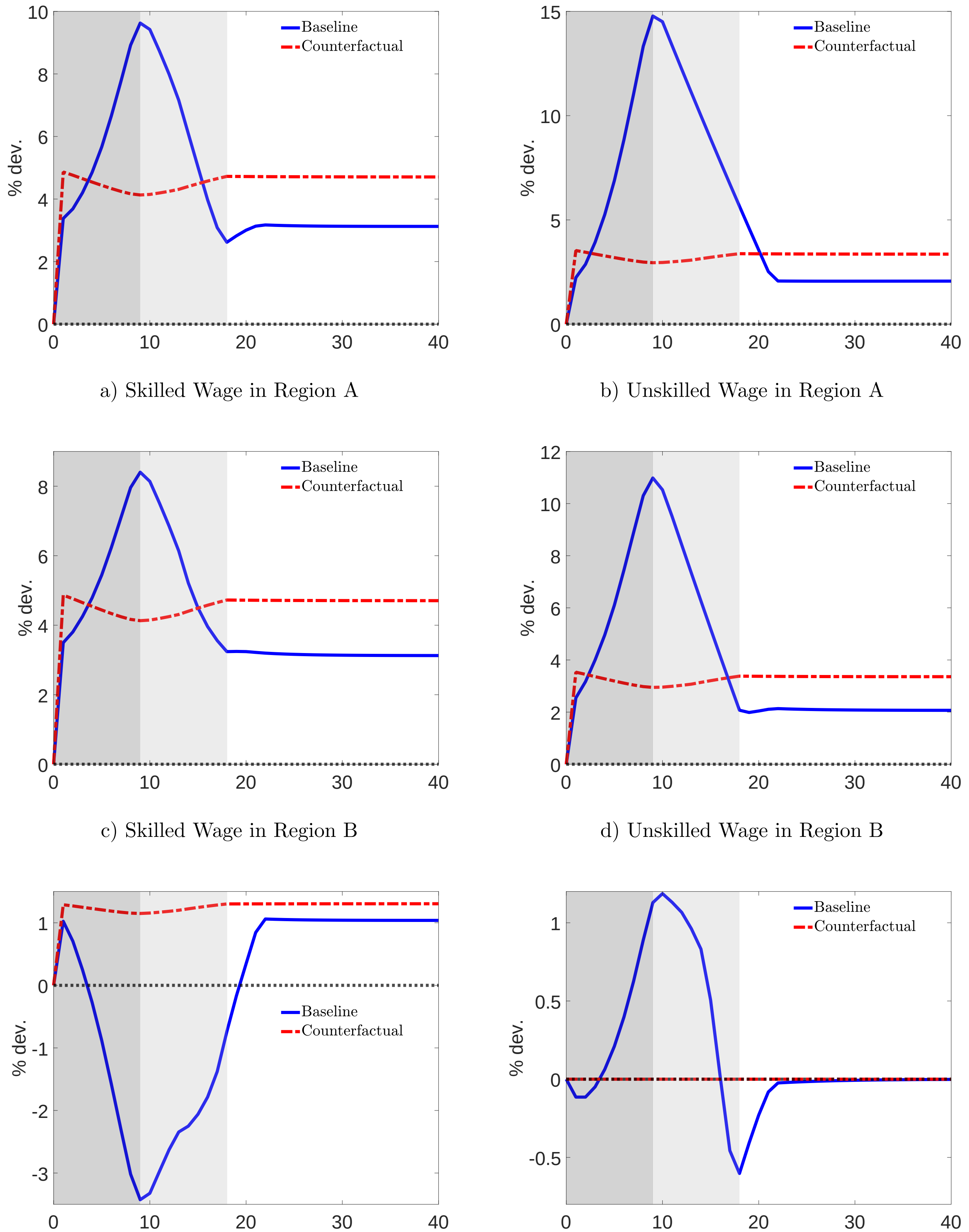


a) Unskilled Population in Region A

b) Skilled Population in Region A

Figure A28: Population in Region A in the Baseline and Counterfactual Economies

NOTE: This figure shows the response of the unskilled and skilled population in region A to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.



a) Skilled Wage in Region A

b) Unskilled Wage in Region A

c) Skilled Wage in Region B

d) Unskilled Wage in Region B

e) Skill Premium

f) Relative Skilled Wage between Regions A and B

Figure A29: Wages in the Baseline and Counterfactual Economies

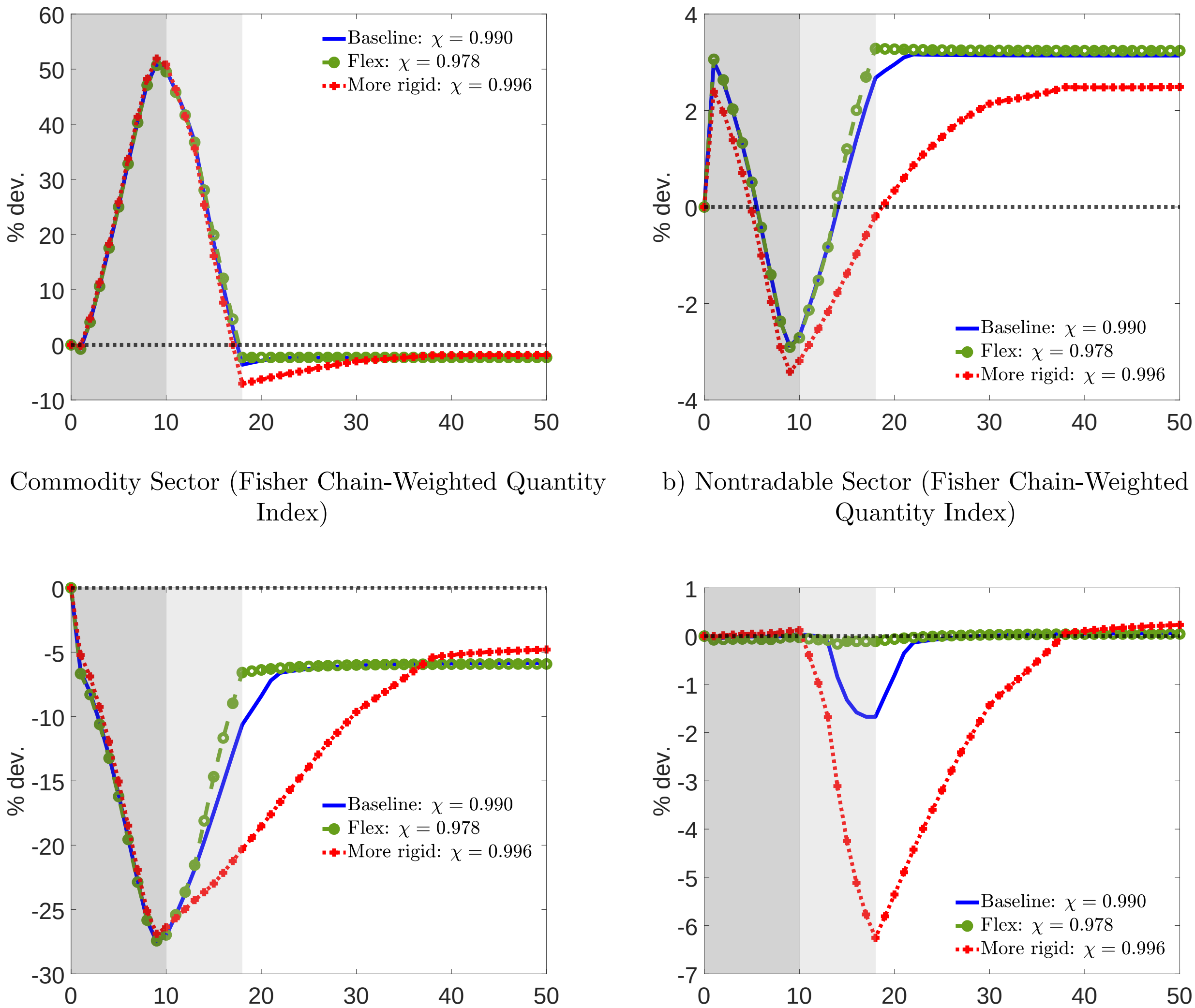
NOTE: This figure shows the response of the skilled and unskilled wages in regions A and B, the skill premium, and the relative skilled wage between regions A and B to the commodity price super-cycle shown in Figure 3. The blue solid line corresponds to the baseline economy and the red solid line corresponds to the counterfactual economy.

C.11 Real Outcomes and Alternative GDP Measure

This section describes the evolution of real GDP and sectoral production using Fisher chained weights as suggested by Kehoe and Ruhl [2008].

Real GDP is plotted in figure A30d. Consistent with Kehoe and Ruhl [2008], we see practically no response to commodity prices during the boom. As suggested by Kehoe and Ruhl [2008], the existence of frictions, in this case downward wage rigidity, leads to a large decline in real GDP during the bust. This is the result of the decline in employment during the bust.

Figures A30a, A30c, and A30a plot production in each sector of the economy. The large increase in production in the commodity sector is compensated by a decline in production in the tradable sector, and, after an initial expansion, of the nontradable sector.



a) Commodity Sector (Fisher Chain-Weighted Quantity Index)

b) Nontradable Sector (Fisher Chain-Weighted Quantity Index)

c) Tradable Sector (Fisher Chain-Weighted Quantity Index)

d) Real GDP (Fisher Chain-Weights)

Figure A30: Real Outcomes (Fisher Chain-Weights)

C.12 Construction of Moments Targeted in the Calibration

Our calibration uses moments for the two largest states in Brazil: Minas Gerais and Sao Paulo. We use data for 2001, which is the start of the boom. Note that in our calibration GDP includes the same commodity, tradable, and nontradable sectors used in the paper, and excludes goverment and quasi-public sectors.

Exogenous exit probabilities Given that we calibrate the model in the steady state, in which entry and exit rates are both equal to the exogenous exit probabilities, we average entry and exit rates in each sector. These entry and exit rates are computed from RAIS over the entire sample period.

Sectoral shares in GDP We use Brazil's regional accounts in 2001 obtained from IBGE, which report GDP by sector and state.

Sectoral employment shares Employment shares are computed for 2001 from RAIS. In the denominator, total employment includes the same commodity, tradable, and nontradable sectors used in the paper, and excludes goverment and quasi-public sectors.

Ratio of Unskilled to Skilled Employment by Sector This moments are computed from RAIS.

Exports to GDP ratio Exports are obtained from Brazil's (Ministry of Industry, Foreign Trade and Services) Foreign Trade Statistics. GDP is computed from Brazil's national accounts, obtained from IBGE.

Share of commodities in total exports This ratio is constructed from product-level exports obtained from Brazil's MDIC (Ministry of Industry, Foreign Trade and Services) Foreign Trade Statistics.

Fraction of exporting firms in the tradable sector This moment is computed from RAIS and the SECEX data on exporting firms, using the same firm-level panel as described in Section 2.

Skill premium The skill premium in each state is computed from RAIS defined exactly as in Section 3.

Migration Using a regression of state-level employment on the commodity price, we find that a one log point increase in the regional commodity price index is associated to an increase of 0.32 log points in total regional employment. Between 2002q2 and 2011q4, Sao Paulo had a 39 log point increase in the commodity price index (12.5 log point increase in employment) while Minas Gerais had a 53 log point increase in the commodity price index (17 log point increase in employment). Holding the total population in the model economy fixed, and assuming both regions start with a population equal to 50 in the initial steady state, these results imply that Minas Gerais (region A in the model) has a population of 51 at the peak of the boom while Sao Paulo (region B in the model) has a population of 49.

An equivalent exercise is used for unskilled and for skilled employment.

Interregional trade Data on interstate trade flows for 1999 is reported by Vasconcelos [2001] and recorded as a result of Brazil's state tax on the movement of goods and services (Imposto sobre Circulacao de Mercadorias e Servicos - ICMS). We use this data, and data on GDP from Brazil's regional accounts, to compute an interstate trade to GDP ratio.

C.13 Calibration of the Wage Rigidity Parameters

In this section we calibrate $\tilde{\chi}$ and χ. We then use these two parameters to infer a value for ϕ. To identify these parameters we follow the analysis in Schmitt-Grohé and Uribe [2016]. We described in Appendix A.1.10 that the evolution of unemployment and wages during the period 2012-2014 is indicative of downward wage rigidity. These years are part of a bust in commodity prices and are characterized by a managed floating exchange rate regime and rising unemployment. The fact that both nominal and real wages actually rise during this period is indicative of rigidities.

We use the evolution of wages during this period to identify the parameters $\tilde{\chi}$ and χ. Consider first the downward wage rigidity constraint expressed in terms of nominal wages (equation (8) in the main text). We assume this constraint was binding during the period 2012-2014 as discussed earlier.

$$\tilde{w}_t^{dl} \geq \tilde{\chi}\tilde{w}_{t-1}^{dl} \ ,$$

We thus compute the wage rigidity parameter $\tilde{\chi}$ as the annual growth rate in nominal wages between 2012-2014. Note that in the model nominal wages are expressed in terms of foreign currency, so here we express wages in dollar terms using the nominal exchange rate. Because our model does not include growth, we adjust the wage growth by the the long-term growth rate of Brazilian real per capita GDP, similarly to Schmitt-Grohé and Uribe [2016]. The annual growth rate of nominal wages is $\left(\frac{w^{2014}}{w^{2012}}\right)^{1/2} = 1.017$. The growth rate of Brazil's real per capita GDP between 1980 and 2010 is 1.95 percent per year. This implies:

$$\tilde{\chi} = \frac{\left(\frac{w^{2014}}{w^{2012}}\right)^{1/2}}{1.0195} = 0.997 \,. \tag{A192}$$

Consider next the downward wage rigidity constraint expressed in terms of real wages (equation 11 in the main text):

$$w_t^{dl} \geq \chi w_{t-1}^{dl} \ ,$$

where we had defined $\chi = \tilde{\chi}^{\frac{1}{1-\phi}}$. To calibrate χ, we adjust the annual wage growth during 2012-2014 by foreign inflation (in addition to Brazil's long-run growth rate as before). We use the growth rate of Brazil's import price index as a proxy for foreign inflation, which in this period equals 0.8 percent annually. This implies:

$$\chi = \frac{\left(\frac{w^{2014}}{w^{2012}}\right)^{1/2}}{1.0195 \cdot 1.008} = 0.990\ . \tag{A193}$$

Finally, having obtained values for both $\tilde{\chi}$ and χ, and using the identity $\chi = \tilde{\chi}^{\frac{1}{1-\phi}}$, we can solve for a value for ϕ. Recall that ϕ captures the preference of the authority for unemployment relative to exchange rate stability. We find $\phi = 0.76$

Note that in our simulations in the main text, we use a wide range of values for χ centered around the value computed in this appendix.