Tax Reforms and Network Effects [*]

Bruno R. Delalibera [†]

Pedro Cavalcanti Ferreira [‡]

Diego B. P. Gomes [§]

Johann Soares [¶]

July 31, 2023

Abstract

This paper investigates the effects of a tax reform that eliminates tax rate heterogeneity and cumulative taxation using a general equilibrium model with multiple sectors with market power. Industries are connected through input-output linkages, and changes in taxation are not confined within industries. We calibrate the model to Brazil, a country with a highly distorted tax system. The revenue-neutral tax reform generates gains of 7.8% of GDP and 1.9% of welfare. Just eliminating VAT rate dispersion leads to a 5.9% increase in GDP. Due to propagation effects, in 10 sectors direct taxes increased but output and profits did not fall.

Keywords: tax distortions; input-output linkages; shock propagation; VAT dispersion.

1 Introduction

Despite considerable progress, especially in OECD nations, cumulativity and tax rate disparity remains prevalent across countries. Particularly, developing countries continue to exhibit a more distorted tax structure compared to their advanced counterparts. For instance, in 2018, nonmember countries included in OECD databases imposed an average taxation weight of 21.76% on specific products, a notably higher figure than that observed among OECD members. Additionally, non-OECD countries relied slightly more on cumulative taxes, accounting for about 1% of tax revenue, in contrast to the 0.31% reported by OECD members.

As it is well known, taxes levied on intermediate inputs have the potential to disrupt the efficient allocation of production factors, whereas uniform taxes do not interfere with individuals' consumption decisions. Moreover, taxing intermediate consumption not only discourages firm connections but also leads to cascading taxation, while heterogeneity in tax rates directly distorts relative prices. These distortions significantly influence the consumption choices of firms and households. Firms, in particular, adapt their connections, thereby altering the production network's structure and leading to less efficient resource allocations

In this article, we develop a general equilibrium model with multiple sectors, calibrated to Brazil, and quantify the aggregate and sectorial effects of tax rate heterogeneity across sectors. Brazil is a typical example of a country with high dispersion of Value-Added Tax (VAT) rates and extensive use of Cumulative Taxes (CT). For example, according to our estimates, VAT rates range from 33.76% (tobacco) to nearly zero (in some service sectors), whereas cumulative taxes range from 14.66% to zero and affect almost all sectors of the economy.

Our model includes a production network with several sectors that are linked through intermediate consumption, employ labor from a representative household, pay taxes, and have market power. A government collects taxes through a complex tax system, produces public goods, and makes transfers to households. Furthermore, because of input-output linkages, changes in tax rates are not confined within industries. They spread as a result of changes in relative prices and firm decisions. This propagation can either amplify or mitigate the overall or sectoral impact of a tax reform.

To the best of our knowledge, there is no quantitative evidence on the general equilibrium effects of a tax reform that takes into account the interconnection between sectors. We find that a revenue-neutral tax reform that eliminates VAT rate dispersion results in a 5.97% increase in GDP. When cumulative taxes are also removed, the output gain rises to 7.84%. In consumption equivalent units, the complete tax reform (homogeneous and noncumulative taxes) increases worker welfare by 1.86%.

The impact varies greatly across sectors. Those that were heavily taxed prior to the reform benefit the most, as their taxes are reduced dramatically. However, out of the 21 sectors that

suffer tax increases after the reform (out of a total of 66 sectors), only three see profits fall: they benefit from price reduction of inputs and increased demand for their products. Upstreamness also tends to increase in most sectors. After the reform, products undergo more transformations on average before reaching final consumption. In other words, tax distortions were leading to a shorter and inefficient production chain. We also find that the absence of network effects and cross-sector propagation would lead to a significantly smaller impact on GDP and welfare compared to the benchmark scenario. These results, along with other key outcomes from our study, serve to underscore the critical importance of utilizing a model that incorporates the network of intermediate goods when analyzing the effects of tax reforms.

This work is related to several strands of the literature. Our model follows the literature on production networks models and shocks propagation via input-output linkages, such as Acemoglu et al. (2012), Carvalho (2014), and Carvalho and Tahbaz-Salehi (2019). The general framework of these papers is used here with the following extensions. First, we introduce productive public sectors to distinguish the production of public goods from the production of private goods that are targeted by the reform. Second, we incorporate a complex tax system that allows for heterogeneous VAT rates and cumulative taxes. Finally, we include monopolistic competition in the goods market, as in Baqaee and Farhi (2020) and Acemoglu and Azar (2020).

In particular, the present work is inserted in the study of distortions in production networks. In this sense, Baqaee and Farhi (2020) develop a general theory of aggregation and growth decomposition for inefficient economies. Bigio and La'O (2020) study how sectoral distortions are manifested at the aggregate level through propagation via production networks. Liu (2019) analyzes the effect of industrial policies on economies with distorted input-output linkages. Baqaee (2018) analyzes the dynamics of firm entry and exit in an inefficient economy with production networks. However, these papers do not study tax reforms that eliminate distortions in the production network, and they do not include a productive public sector and a tax structure with VAT and cumulative taxation. In addition, we estimate from the input-output tables the different taxes paid by each sector.

Our paper also contributes to the empirical literature on tax reform and misallocation due to goods and services taxation. Chen (2017) studies the elimination of VAT rates dispersion across manufacturing industries in China. According to the study, a tax reform in this sense results in aggregate TFP gains of the order of 7.9% of GDP. However, the author does not use the production networks framework and therefore does not study the interactions between tax reforms and production networks. Fajgelbaum et al. (2019) study the elimination of spatial dispersion of tax rates in the United States, indicating gains of 4% of GDP in a cross-state tax reform. In addition to focusing on the spatial dimension, the paper also does not study the interaction of the tax reform with the production network.

Finally, we use the network statistics literature to capture some features of the productive

organization. First, we use the Bonacich-Katz centrality metric (Bonacich, 1987) to capture how tax reforms shape the relevance of sectors in the production network. Second, we use the upstreamness metric (Antràs et al., 2012) to understand how the reform changes the distance of sectors to final demand. Our reference regarding the use of these statistics is Grassi and Sauvagnat (2019), who show how to use them to aid economic policy. In particular, we apply this knowledge in the context of tax reforms.

The rest of the paper is organized as follows. Section 2 provides an overview of the Brazilian tax scenario. Section 3 presents the structure of the model used in the tax reform simulations. Section 4 describes the model parameterization strategy in detail. Section 5 presents the findings of the quantitative analysis of the tax reforms. Section 6 concludes.

2 Brazilian Tax Scenario

Brazil has one of the world's most complex tax systems. Its tax codes are, to put it mildly, byzantine. The regulation is excessive, and the legislation is often confusing, if not contradictory. There are thousands of complicated features and exceptions, as well as extremely expensive (and lengthy) bureaucratic procedures.[1] According to the most recent Tax Complexity Index data, Brazil ranks last out of the 100 countries surveyed.[2]

As a result of this environment, the country's attractiveness for the formation and operation of businesses is low. According to the most recent Tax Attractiveness Index data, Brazil ranks 89th out of the hundred countries studied, indicating a poor tax environment for doing business.[3] Between 2007 and 2018, the country dropped 17 positions in the ranking, indicating that it is not keeping up with the best tax practices. The potential impact of a tax reform on the economy is huge.

Brazil also stands out negatively when it comes to the taxation of goods and services when compared to other economies. In contrast to the majority of advanced economies, which in general have a single noncumulative and broad-based VAT, Brazil has five taxes on goods and services: ICMS, IPI, ISS, PIS, and COFINS. In many cases, they add up, so that taxes are levied on top of taxes, and rates vary significantly across goods and services.

This structure has several flaws. First, the tax base is highly fragmented across sectors. Second, the legislation is characterized by a large number of tax rates, tax exclusions, tax benefits, and special tax regimes. Third, there is a mix of purely cumulative taxes (ISS and a part of PIS and COFINS) and noncumulative taxes (ICMS, IPI, and a part of PIS and COFINS). Finally,

---

[1]Unsurprisingly, discussions on tax reform of goods and services have permeated the Brazilian public debate for a long time. According to historical archives from a major Brazilian newspaper, tax reforms have been debated since Brazil was an empire (Leite, 2018).

[2]See https://www.taxcomplexity.org/.

[3]See https://www.tax-index.org/.

there are strong restrictions on the reimbursement of tax credits accumulated by companies.[4]

The end result of all this, among other issues, is the high dispersion of tax rates on goods and services, as well as cumulative taxes. Take, for instance, the case of ICMS (Tax on the Circulation of Goods and Services, in Portuguese), the most important tax on goods at the state level. ICMS tax rates can be as low as 7%, in the case of rice, beans, and manioc flour in the state of Bahia, but as high as 39% in the case of beauty products in the state of Rio de Janeiro. The dispersion of ICMS is high even within states. In Rio de Janeiro, for example, the energy tax rate for electric public transportation is only 8%. However, it is 39% for cosmetics, 12% for meat and rice, and 18% for sodas. And this is only one of the five goods and services taxes.

No national tax data adds the various types of taxes at the sector level. As we will discuss in detail in Section 4, we estimate tax rates using the Input-Output tables. As one might expect, there is a great deal of variation in estimated tax rates. VAT rates range from nearly zero in many service sectors to 35% for tobacco. The average rate is 8.16%. The estimated cumulative tax rates are typically lower, averaging 3.16%. Although not as high as VAT rates, the dispersion in this case is also considerable: tax rates range from zero to 15%.

Another issue is that taxes on goods and services are the country's primary source of government revenue. According to official data from *Receita Federal do Brazil* (RFB), the Brazilian internal revenue service, taxation of goods and services represented 45% of total revenue in 2018 (Receita Federal do Brasil, 2020). This figure has remained stable at this level since 2009. The excessive dependence on revenue from taxes on goods and services places Brazil in a prominent position when compared to OECD countries. The same RFB report shows that Brazil's share of taxes on goods and services to GDP in 2017 trailed only 3 of the 36 OECD countries. The OECD average in 2017 was 11.1% of GDP, while for Brazil the figure was considerably higher, 14.3%.

3   The Economy

In this section, we describe the economic framework used to evaluate tax reforms in an economy permeated by an inter-sectoral trade network that emerges from the behavior of heterogeneous private and public sectors, consumers, and the central government. The environment follows the tradition of the multi-sector general equilibrium model of Long and Plosser (1983). We implement a variant popularized by Acemoglu et al. (2012), which is based on competitive markets, but we add price markups in the same way as Baqae and Farhi (2020) and Acemoglu and Azar (2020).

We augment this structure in two ways. First, we build a complex tax system that includes

---

[4]Furthermore, and less importantly for our purposes, the funds collected through the ICMS state tax are directed to the state where the purchase was made rather than the state where the good or service was produced.

both noncumulative VAT and cumulative taxes, as well as heterogeneous tax rates across sectors. This tax structure allows us to study the economy's reaction to different tax policies in a granular way, describing how policy changes affect different sectors, and therefore the whole economy, through network propagation. Second, we explicitly separate public and private sectors within the production network, incorporating differences in the provision of private products and public goods.[5] As do private sectors, public sectors also endogenously choose their production inputs, although not through profit maximization. However, unlike private products, public goods are not taxed and are not part of the price system. These features allow us to analyze how the provision of private products and public goods responds differently to changes in tax policy.

3.1 Model Structure

The supply side of the economy consists of n private sectors and m public sectors. We index private sectors by $i, j \in N \equiv \{1, \ldots, n\}$ and public sectors by $k \in M \equiv \{1, \ldots, m\}$, where N and M are, respectively, the sets of private and public sector indices. Private sectors seek profits and supply their products either for final consumption or as intermediate inputs in the production process of other sectors (private or public). Public sectors maximize the amount of public goods produced and deliver their production directly to consumers at no cost. Public goods are not used as intermediate inputs, only as final consumption.

All private sectors employ Cobb-Douglas production technologies, with constant returns to scale, to transform labor and intermediate inputs into final products. The output of private sector i, denoted by y_i, is given by

$$y_i = z_i l_i^{\alpha_i} \prod_{j \in N} x_{ij}^{\beta_{ij}}, \tag{1}$$

where z_i is the total factor productivity, l_i is the labor input measured in hours, and x_{ij} is the amount of private product j used in the production of output i. The technology parameter α_i measures the share of labor in production, and the parameter β_{ij} represents the share of product j in the production of output i. The constant returns to scale nature of the production technology implies that $\alpha_i + \sum_{j \in N} \beta_{ij} = 1$, where α_i and β_{ij} are strictly positive for all sectors i and j.

The revenue of all private sectors comes exclusively from the sale of its products. Sector i sells each unit of its production at price p_i, obtaining gross revenue of $p_i y_i$. The unit cost of labor hours is the same in all sectors and is denoted by w, which implies a total labor cost for each sector i equal to $w l_i$. The unit cost of intermediate inputs purchased from sector j is denoted by p_j, which is equal to the selling price of the j product. Then, sector i incurs a cost of $p_j x_{ij}$ for using inputs produced by sector j. Finally, each sector i bears a total tax cost of T_i that will be detailed below. Then, the total cost of private sector i, including input costs and taxes, is

---

[5]To establish a naming standard and simplify communication, we use the term "products" when referring to private sectors' output and "goods" when referring to public sectors' output.

given by

$$K_i = wl_i + \sum_{j \in N} p_j x_{ij} + T_i. \tag{2}$$

The government taxes the gross revenue of all private sectors using a noncumulative VAT and a cumulative tax, both levied at all stages of the production process. Furthermore, there is also a tax on profit that is equal among sectors. Both noncumulative VAT and the cumulative tax are sector specific, and the former is denoted by τ_i and the latter by λ_i for the cumulative tax. Then, gross taxes paid by sector i are equal to $(\tau_i + \lambda_i)p_i y_i$. The noncumulative nature of the VAT ensures that all private sectors receive tax credits for the tax collected due to the purchase of inputs. More specifically, when sector i purchases x_{ij} from sector j to use as input in production, it gets a tax credit of $\tau_j p_j x_{ij}$ that can be deducted from its gross taxes. As each sector can use multiple products as inputs, it can get tax credits from multiple purchases. Therefore, total net taxes paid by sector i, which equals gross taxes minus total tax credits, can be stated as

$$T_i = (\tau_i + \lambda_i)p_i y_i - \sum_{j \in N} \tau_j p_j x_{ij} + \tau_\Pi \Pi_i^B, \tag{3}$$

where Π_i^B is the profit for sector i before tax profit. Note that due to the presence of the cumulative tax, only a fraction of the total tax paid is deducted as a tax credit, configuring the presence of cascade taxation.

Consequently, the profit after taxes of private sector i, defined as gross revenues minus total costs, can be written as

$$\Pi_i = p_i y_i - K_i. \tag{4}$$

The optimal behavior of private sectors is a result of a two-stage process. They first choose the quantities of labor and intermediate inputs so as to minimize total costs (equation 2) subject to a certain level of production. Then, given their cost function, they set prices equal to an exogenous markup times marginal (or average) costs. The price-setting behavior of private sector i results in

$$p_i = (1 + \mu_i)k_i, \tag{5}$$

where μ_i is the markup and k_i the marginal cost.

All public sectors also employ Cobb-Douglas production technologies, with constant returns to scale, to transform labor and intermediate inputs into public goods. The output of public sector k, denoted by y_k, in given by

$$y_k = z_k l_k^{\alpha_k} \prod_{j \in N} x_{kj}^{\beta_{kj}}, \tag{6}$$

where all variables have the same meaning as those in equation (1), but with the indexing of

7

public sectors. The budget of each public sector k is denoted by G_k, which is equal to a fraction φ_k of the total tax revenue collected by the central government. Analogously with the private sectors, the total labor cost of the public sector k is given by wl_k, and its cost with intermediate inputs purchased from the private sector j is given by $p_j x_{kj}$. The public sectors pay no taxes. Then, the budget constraint of public sector k is defined as

$$wl_k + \sum_{j \in N} p_j x_{kj} \leq G_k. \tag{7}$$

The optimal behavior of public sectors consists in choosing the quantities of labor and intermediate inputs so as to maximize the production of public goods (equation 6) subject to the budget constraint (equation 7).

The demand side of the economy consists of a representative household that derives utility from the consumption of private products and public goods and derives disutility from labor supplied to the productive sectors. The utility is separable between consumption and labor. The consumption part is defined through a nested CES aggregator with different elasticities of substitution for private and public consumption. Therefore, the household's utility is represented by

$$u = \left\{ \sum_{j \in N} \omega_j c_j^{\frac{\theta-1}{\theta}} + \sum_{k \in M} \omega_k g_k^{\frac{\theta-1}{\theta}} \right\}^{\frac{\theta}{\theta-1}} - \rho \frac{L^{1+\nu}}{1+\nu}, \tag{8}$$

where c_j is the consumption of private product j, g_k is the consumption of public good k, and L is the labor time measured in hours. Parameters ω_j and ω_k are, respectively, the weights associated with the consumption of private product j and public good k. Parameter θ defines the elasticities of substitution between different types of consumption. The parameter ν defines the Frisch elasticity of labor supply, and ρ captures the weight of the disutility of work.

The resources to finance total consumption come from labor income wL, profits Π received from the private sectors, and a lump-sum government transfer T. Labor income is taxed at a rate of τ_w. Then, the household's budget constraint is given by

$$\sum_{j \in N} p_j c_j \leq (1 - \tau_w) wL + \Pi + T. \tag{9}$$

The optimal behavior of the representative household consists of choosing the consumption of all private products and labor time so as to maximize the utility (equation 8) subject to the budget constraint (equation 9).

We present the detailed equilibrium definition in Appendix A. The aggregation of the model economy is described in Appendix B. The solution method for finding equilibrium allocations is explained in Appendix C.

4 Model Parametrization

Our main sources of data are the 2015 Input-Output (IO) matrix and Supply and Use (SU) tables from the Instituto Brasileiro de Geogragia e Estatística (IBGE), the official statistics bureau of Brazil. The data includes details on 63 private sectors, 3 public sectors, and 126 products. It enables us to obtain information on goods and services produced in Brazil, which is useful given that our model represents a closed economy. We exclud the domestic services sector from our analysis because it has no links to the other sectors. We next describe the rationale for the parameters we can backout from the data, followed by the procedures for calibrating the parameters used to match data moments. This section concludes with a discussion of how some key parameter estimates relate to important characteristics of the economy.

4.1 Exogenous Parameters

A given sector in the IO matrix can produce more than one product, and a product can be produced by more than one sector. Because each sector in the model produces only one distinct product, our first task is to create a square IO matrix. We base this on the market share of each product that falls under each sector's purview. As a result, whenever a sector or final consumer spends resources on a product, whether through demand or taxation, we assume that these resources will be distributed among the sectors in accordance with their respective market shares. For instance, let $s_{i\ell}$ be the market share of product ℓ covered by sector i's production, $t_{v\ell}$ the total VAT paid due to the production of product ℓ, and $t_{c\ell}$ the total cumulative tax paid due to the production of product ℓ. Then, the total VAT and cumulative taxes allocated to sector i are respectively given by

$$T_{vi} = \sum_{\ell=1}^{126} s_{i\ell} t_{v\ell} \quad \text{and} \quad T_{ci} = \sum_{\ell=1}^{126} s_{i\ell} t_{c\ell}.$$

We used a similar approach to allocate intermediate and final consumption.

We start by backouting the tax rates using the square IO matrix. Let $Y_i \equiv p_i y_i$ be the gross revenue of sector i and $X_{ij} \equiv p_j x_{ij}$ the cost incurred by sector i with inputs produced by sector j. Note that we observe the variables T_{vi}, T_{ci}, Y_i, and X_{ij} in the squared IO matrix for all sectors. Then, from the model's definition of VAT, we have that

$$T_{vi} = \tau_i Y_i - \sum_{j \in N} \tau_j X_{ij}.$$

For ease of notation, define $A_i \equiv T_{vi}/Y_i$ and $B_{ij} \equiv X_{ij}/Y_i$. Let A be the vector of elements A_i, B the matrix of elements B_{ij}, and τ the vector of VAT rates. Then, by rearranging the VAT equation

above into matrix form, we can backout the VAT rates as

$$\hat{\tau} = (I - B)^{-1} A, \tag{10}$$

where I represents the identity matrix and the "hat" over the rates vector denotes its estimated counterpart. The cumulative tax rates can be easily recovered from the data as

$$\hat{\lambda}_i = \frac{T_{ci}}{Y_i}. \tag{11}$$

With the tax rates already estimated, we can now proceed to backout the parameters of the private sectors' production functions. To do so, we need labor cost values for each sector. Let $W_i \equiv wl_i$ be the labor cost of sector i. Note that we observe the variable W_i in the SU tables for all sectors. Then, using the first-order conditions of the cost minimization problems, the intermediate input shares can be calculated as

$$\hat{\beta}_{ij} = \frac{(1 - \hat{\tau}_j)X_{ij}}{W_i + \sum\limits_{n \in N} (1 - \hat{\tau}_n)X_{in}}. \tag{12}$$

Using the constant returns to scale property of the production technology, we can calculate the labor shares in production as

$$\hat{\alpha}_i = 1 - \sum_{j \in N} \hat{\beta}_{ij}. \tag{13}$$

To estimate the production parameters of public sectors, we first need values for those sectors' budgets. We interpret the revenue reported by the IO matrix for the public sectors as the budget available for the production of public goods, and we assign those values to each G_k. Then, based on the first-order conditions of the public sectors' optimization problems, we can calculate its intermediate input shares as

$$\hat{\beta}_{kj} = \frac{X_{kj}}{G_k}. \tag{14}$$

Using the constant returns to scale property once more, the labor shares of the public sectors are calculated as

$$\hat{\alpha}_k = 1 - \sum_{j \in N} \hat{\beta}_{kj}. \tag{15}$$

Before we can estimate the private sectors' markups and the shares of tax revenues allocated to each public sector budget, we must first assign values to the profits tax rate and to the amounts of pretax profits. According to Brazilian law, businesses that make more than R$20,000 per month are subject to a 34% profit tax rate, which is made up of two taxes: a 25% income tax rate and a 9% social contribution on net income. Therefore, we assume that $\hat{\tau}_\Pi = 0.34$. Using

the model structure and data from the squared IO matrix and SU tables, we can calculate the pretax profits as

$$\Pi_i^B = \left(1 - \hat{\tau}_i - \hat{\lambda}_i\right) Y_i - W_i - \sum_{j \in N} \left(1 - \hat{\tau}_j\right) X_{ij}.$$

Then, using the fact that total costs in the model are a linear function of output, we can backout the markups as

$$\hat{\mu}_i = \frac{(1 - \hat{\tau}_\Pi) \Pi_i^B}{\left(\hat{\tau}_i + \hat{\lambda}_i\right) Y_i + W_i + \sum_{j \in N} \left(1 - \hat{\tau}_j\right) X_{ij} + \hat{\tau}_\Pi \Pi_i^B}. \tag{16}$$

Furthermore, using its definition, the shares of tax revenues allocated to each public sector budget can be estimated as

$$\hat{\varphi}_k = \frac{G_k}{\sum_{i \in N} \left(T_{vi} + T_{ci} + \hat{\tau}_\Pi \Pi_i^B\right)}. \tag{17}$$

To estimate total factor productivities (TFPs), ideally we would need data on volumes traded across sectors. However, volume data is not widely available in general, and IBGE does not provide it. Therefore, we use the concept of revenue-based total factor productivity (TFPR) to approximate the TFP values. TFPR is a ratio of revenues to input costs, appropriately weighted according to their production elasticities. We normalize the estimated TFPs so that the least productive sector has TFP equals to unity. As a result, the TFPs can be estimated as

$$\hat{z}_i = \frac{Y_i}{W_i^{\hat{\alpha}_i} \prod_{j \in N} X_{ij}^{\hat{\beta}_{ij}}}. \tag{18}$$

We can backout the hourly wage rate from the household budget constraint combined with the central government's balanced budget. For that, we first need figures for total hours worked and gross domestic product (GDP). We use microdata from the Pesquisa Nacional por Amostra de Domicílios (PNAD) to calculate the average weekly hours worked in 2015, which is 39.9. According to the 2015 SU tables, the total number of occupations equals 95,563,854 people. Then, considering that a year has 52 weeks, we set $\hat{L} = 198,276$ million hours for 2015. We take the 2015 GDP value from the IO matrix. Then, we can backout the hourly wage rate as

$$\hat{w} = \frac{GDP - \sum_{i \in N} \Pi_i^B - \sum_{i \in N} \left(T_{vi} + T_{ci}\right)}{\hat{L}}. \tag{19}$$

We can estimate the household income tax rate by combining total labor income data from the SU tables and total household income tax revenue from Receita Federal do Brasil (2021). We set it at $\hat{\tau}_w = 0.247$. We use reference values from the literature to calculate the elasticity of substitution of household utility. Estimates range from 0.75 to 3.22 in Oberfield and Raval

Table 1: Summary of Exogenous Parameters

Parameter	Notation	Reference	Value
Value-added tax rates	τ_i	Equation (10)	Figure 1a
Cumulative tax rates	λ_i	Equation (11)	Figure 1b
Intermediate inputs elasticities	β_{ij}	Equations (12), (14)	–
Labor input elasticities	α_i	Equations (13), (15)	Figure 1d
Profits tax rate	τ_Π	Legislation	34.0%
Markups	μ_i	Equation (16)	Figure 1e
Shares of tax revenue	φ_k	Equation (17)	$\{0.28, 0.12, 0.07\}$
Total factor productivity	z_i	Equation (18)	Figure 1f
Total hours worked	L	PNAD and SU tables	198,276 million
Hourly wage rate	w	Equation (19)	$13.40
Labor income tax rate	τ_w	Receita Federal do Brasil (2021) and SU tables	24.7%
Elasticity of substitution	θ	Literature	1.5
Frisch elasticity	ν	Literature	1.0

(2021), Redding and Weinstein (2018), and Hobijn and Nechio (2019). We set $\hat{\theta} = 1.5$ to account for the disaggregation of the data we are using. Finally, we set the parameter that defines the Frisch elasticity of labor supply to $\hat{\nu} = 1$, although we acknowledge that the literature on intertemporal elasticity of labor supply argues that macro estimates of this elasticity can be larger than micro estimates (Keane and Rogerson, 2015).

Table 1 summarizes the set of exogenous parameters and Figure 1 presents the estimates of sectoral parameters. Figures 1a and 1b depict the estimated VAT and cumulative tax rates distributions across private sectors. Both have significant heterogeneity, particularly the VAT rates. Furthermore, VAT rates are typically higher than cumulative tax rates. Figure 1c shows the negative relationship between VAT and CT rates. In general, the industrial sectors have the highest VAT rates, while the service sectors have the highest CT rates. It also reveals significant sectoral heterogeneity in taxation, implying that removing these differences would result in economic gains.

The distribution of labor share in the production function is also highly heterogeneous (Figure 1d), whereas markups are more homogeneous, with a high concentration at lower
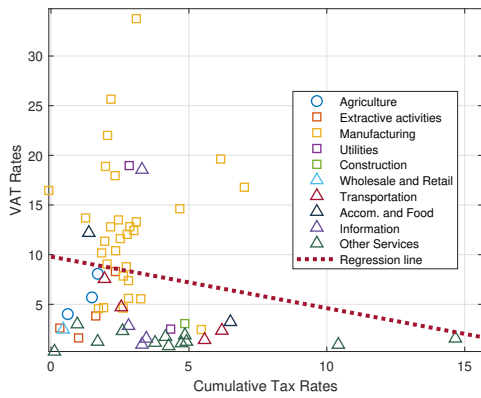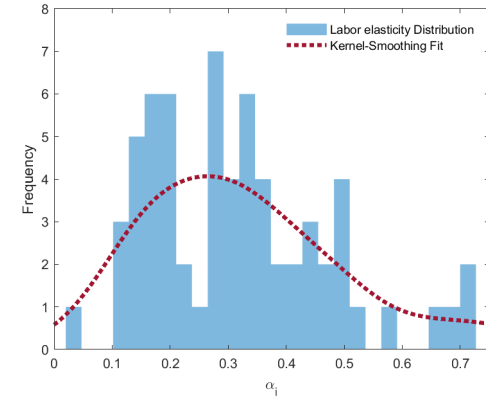
Figure 1: Estimates of Sectoral Parameters
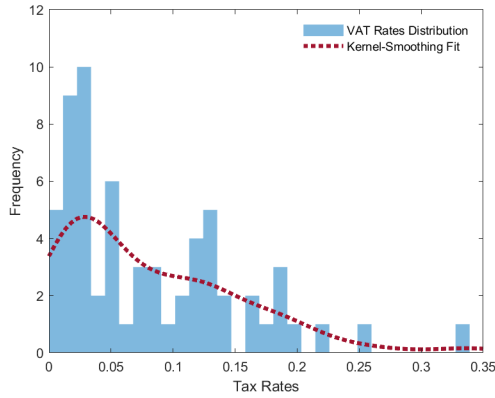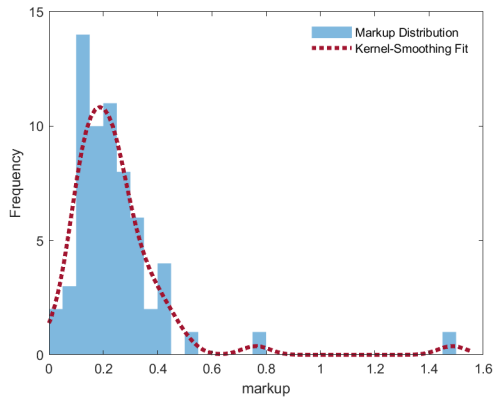

(a) Value-Added Tax (VAT) Rates
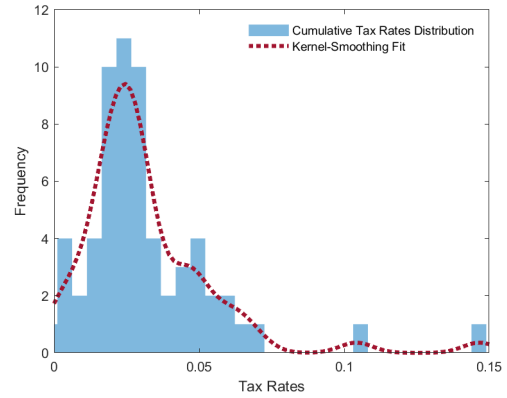
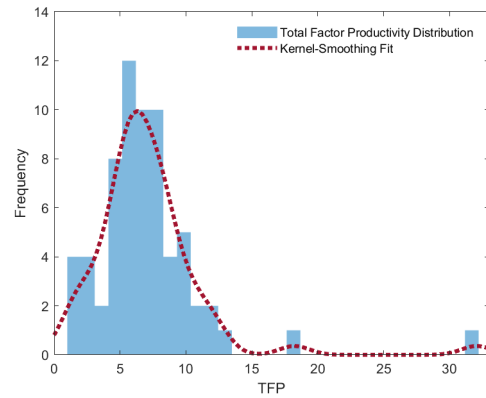(b) Cumulative Tax (CT) Rates

(c) VAT vs. CT

(d) Labor Shares

(e) Markups

(f) Total Factor Productivities

markup values (Figure 1e).[6] Sectors with a lower markup have a higher total tax. As a result, tax reform may benefit sectors with lower profit margins, reducing sectoral inequality.

Figure 1f depicts the estimated TFP distribution across all sectors. Real estate is the most

---

[6]Real estate is the most profitable sector. Its estimated markup is greater than one, indicating an outlier.

Table 2: Summary of Endogenous Parameters

Parameter	Notation	Value	Target	Error (%)
Preference weights	ω_i	Figure 2b	Final consumption by sector	8e-9
Disutility of labor	ρ	4.52e-09	Total hours worked	5e-15

Notes: The preference weights error is the average error across sectors.

productive sector, with an estimated TFP of 32. Extractive industries such as iron ore extraction and manufacturing industries such as cosmetics and cleaning products are also very productive. Among the less productive sectors, public administration, public health, and public education stand out.

4.2 Endogenous Parameters

The remaining parameters are structurally estimated to match key data figures. The labor disutility parameter is estimated to target total hours worked. The CES preference weights for the private products are estimated to target the final consumption of private sectors. Because we lack sufficient information to estimate the weights for public services, we assume they are equal. Therefore, assuming that the sum of weights equals one, we estimate the weights of public services as

$$\hat{\omega}_k = \frac{\left(1 - \sum_{i \in N} \hat{\omega}_i\right)}{m}.$$

Table 2 summarizes the set of endogenous parameters and Figure 2 depicts the structural estimation fit and preference weight distribution. It is important to note that the low value for the labor disutility parameter is due to the scale of our aggregate variables, which we do not normalize in order to preserve the data scale. Figure 2a demonstrates how well our estimation procedure targets the final demand shares from the data: all sectors are on the 45-degree line. Figure 2b presents the distribution of estimated preference weights across sectors, with only a few sectors being associated with high preference weights. Wholesale and retail trade as well as sectors related to food production have the highest estimated preference weights. On the other hand, some service sectors, such as security activities, are on the left part of the distribution.

Figure 2: Structural Estimation Results

(a) Final Demand Share: Model vs. Data

(b) CES Preference Weights
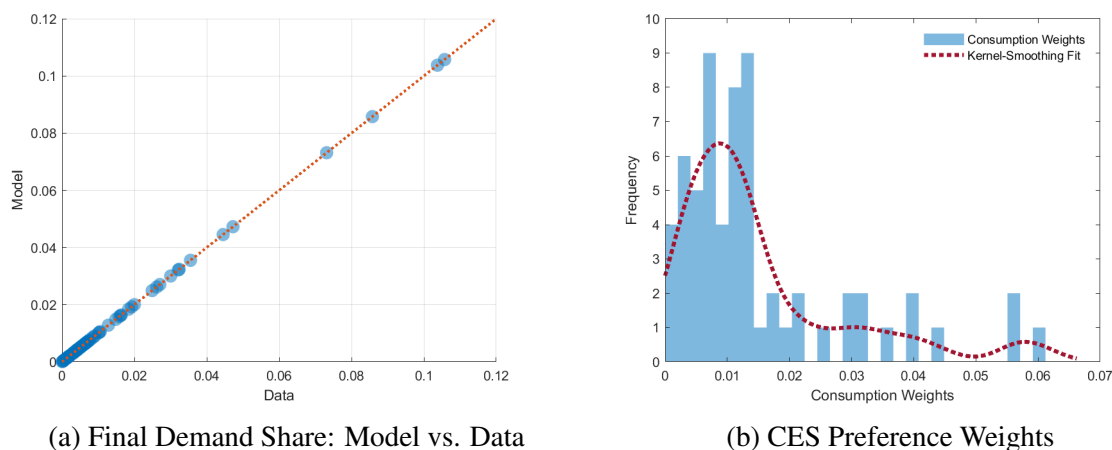
Appendix D displays the model's fit to relevant statistics of the data that were not directly targeted by the estimation procedure. For example, the model accurately replicates the gross and net revenues, value-added, profits, VAT revenues, cumulative tax revenues, and intermediate input costs. Some key production network statistics, such as Domar weights and upstreamness, are also well matched.

4.3 Discussion

We now discuss how the estimated tax rates relate to key characteristics of the economy. Figure 3 depicts the relationship between tax rates and TFPs, final demand shares, profits, and two network statistics. Figure 3a reveals that there is no clear correlation between TFPs and gross tax rates (VATs plus CTs). Figure 3b shows that lower gross tax rates are associated with disproportionately large sectors in terms of final demand. Furthermore, Figure 3c also suggests a distorted tax system in which more profitable sectors are associated with lower gross tax rates. This last feature is especially important for determining a low single revenue-neutral tax rate, which is critical to the tax reform's outcomes.

Network statistics can also be useful to determine whether the taxation structure is distorted. Figure 3 also depicts the correlations of gross tax rates with Upstreamness and Bonacich-Katz (BK) centrality. The former represents the average distance of each sector from the final demand, while the latter conveys an idea of a sector's centrality in the production network. Figure 3d shows that sectors with higher taxation typically have a shorter distance to final consumption. However, some highly taxed sectors are central to the economy's production. For instance, Figure 3e shows that oil refining and coke production, electricity, natural gas, and other activities, as well as telecommunications are sectors with gross tax rates between 20% and 25% and are above the regression line. In other words, despite their importance to the economy's productive

15

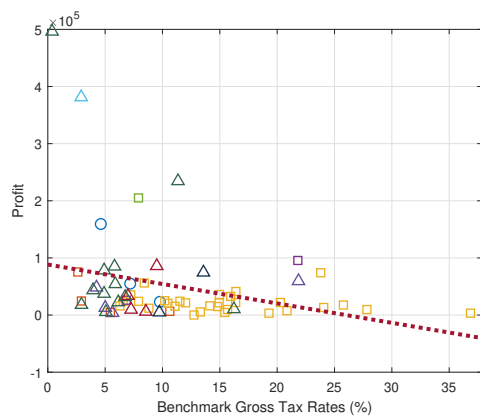structure, these sectors are heavily taxed.

Figure 3: Gross Tax Rates Correlations
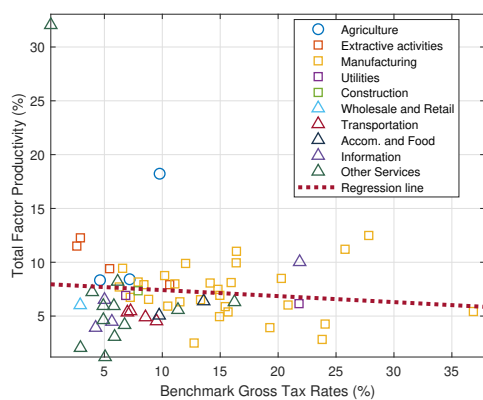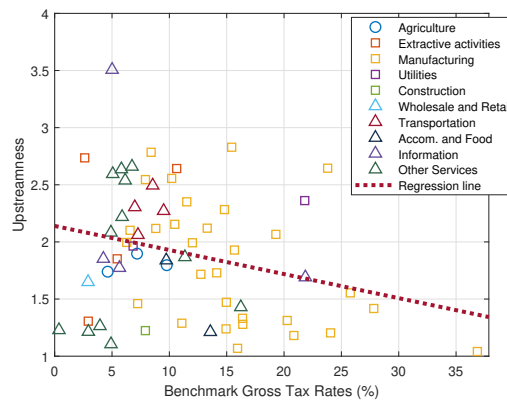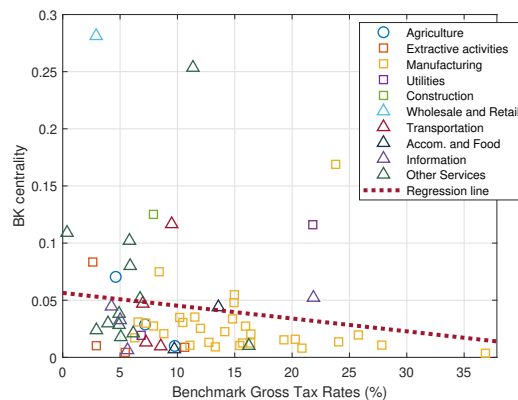

(a) TFP
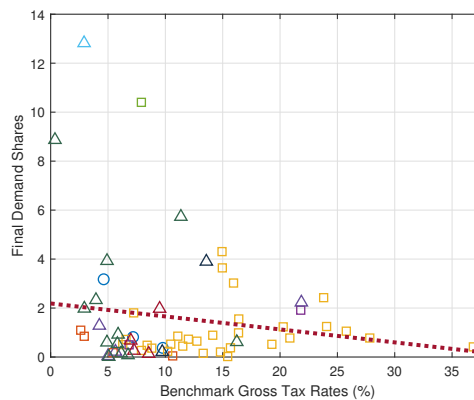
(b) Final Demand Shares

(c) Profits

(d) Upstreamness

(e) BK Centrality

5 Tax Reform

We simulate two distinct sets of tax reforms. First, we investigate a tax reform that eliminates two sources of distortion: tax rate heterogeneity and cumulative taxation. Second, in addition to eliminating the aforementioned distortions, we allow some sectors to be either subsidized or subject to higher tax rates.

5.1 Eliminating Distortions

Tax rate heterogeneity directly distorts relative prices. Furthermore, when there is cumulative taxation, intermediate inputs are taxed, discouraging connections and distorting relative prices in the most connected sectors through cascading taxation. Starting from our benchmark economy with heterogeneous tax rates and cumulative taxation, we first perform two quantitative exercises:

1. **Uniform Reform**: We eliminate the heterogeneity of both VAT and cumulative tax rates. Technically, we set $\tau_i = \tau^*$ and $\lambda_i = \lambda^*$ for all private sectors. The single tax rates are determined so that the model generates the same amount of total and cumulative tax revenues as the benchmark.

2. **Complete Reform**: We eliminate VAT tax rate heterogeneity and completely remove cumulative taxation. Technically, we set $\tau_i = \tau^*$ and $\lambda_i = 0$ for all private sectors. The single VAT tax rate is determined so that the model generates the same amount of total tax revenues as the benchmark.

It is worth noting that in order to avoid the influence of government size in the analysis, the tax reforms considered here are revenue neutral in real terms.

In summary, the simulated results indicate that distortionary taxation in Brazil involves tax rates that are significantly higher than the single revenue-neutral rates, pushing prices upward. As a result, the tax reforms lower the cost of the consumption basket. Households respond by increasing labor supply and substituting consumption in more expensive sectors for those with price reductions. These responses boost both GDP and welfare. We next go into greater detail about these findings.

Table 3 shows that the complete tax reform raises real GDP by 7.84%, increases total hours worked by 3.66%, and generates welfare gains of about 1.86% in terms of consumption equivalent variation (CEV).[7] Total profits in the economy increase by 2.27%, and the profits coefficient of variation decrease from 1.65 to 1.44. It is worth noting that only three sectors see their profits fall; while the majority of sectors benefited from the reform, not all did. Furthermore, the majority of gains are derived from eliminating taxation heterogeneity across sectors. Indeed,

---

[7]We obtain real GDP growth using a Laspeyres quantity index.

Table 3: Tax Reforms

	Units	Benchmark	Complete Reform	Uniform Reform
GDP	Δ%	–	+7.84	+5.97
Labor supply	Δ%	–	+3.66	+3.60
Welfare (CEV)	Δ%	–	+1.86	+1.69
Profits	Δ%	–	+2.27	+0.71
Profit-cutting sectors	#	–	3	7
Coefficient of variation of profits	–	1.65	1.44	1.49
τ (average)	%	8.16	6.96	3.16
λ (average)	%	3.16	0.00	2.72

Notes: Percentage change units (Δ%) represent variations from the benchmark.

the difference in outcomes between complete and uniform reforms is not that large. For example, the reform that equalizes rates across sectors could boost GDP by 5.97%. However, from a welfare standpoint, a complete reform is strictly preferable.

To understand these gains, we must examine the price changes induced by the tax reform. The restructuring of tax rates has an impact on the economy by changing the cost structure and relative prices of sectors. Each sector's price variation is determined by two mechanisms. The first is the immediate change in marginal costs (direct effect), regardless of input choices. The second comes from changes in suppliers' marginal costs (indirect effect), which affect supplier prices and, as a result, the cost of each sector's intermediate inputs, causing sectoral price changes. Figure 4 shows an inverse relationship between price variation after reforms and benchmark gross tax rates. Thus, sectors that were previously heavily burdened by a high gross tax rate benefit from the reform through tax relief. The vertical lines represent the revenue-neutral gross tax rates after the reforms. The manufacturing sectors face the greatest tax rate reductions in both reforms.

Figure 4: Price Changes

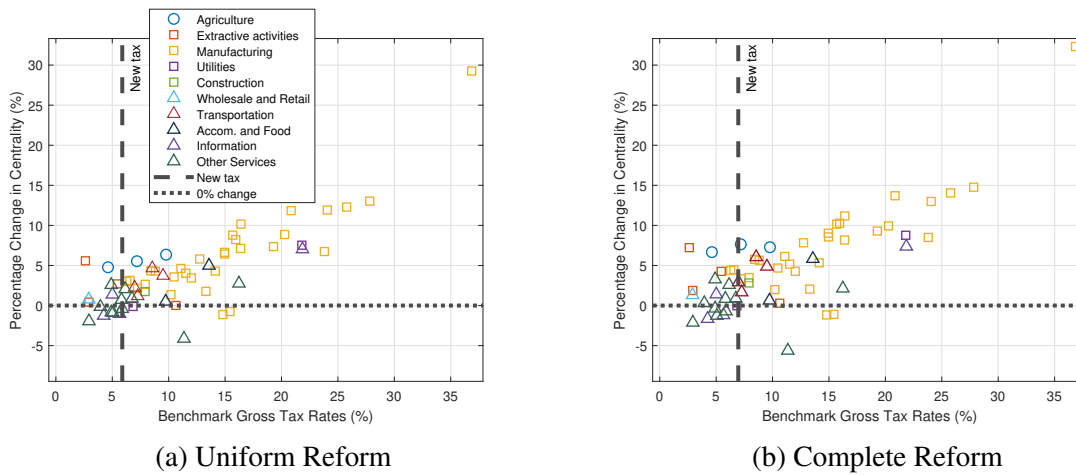(a) Uniform Reform   (b) Complete Reform
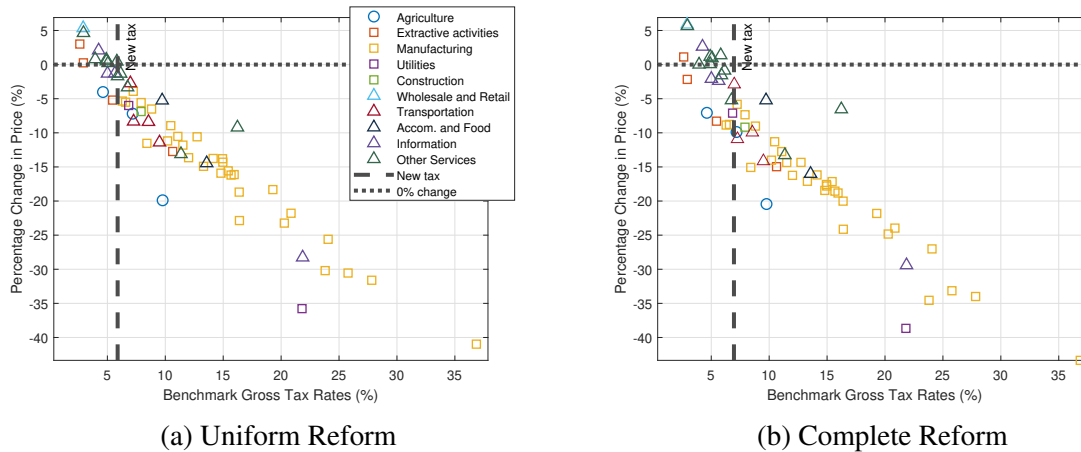
Notes: The real estate sector is omitted from the charts because it showed a significant price variation following the reforms (+226% in the complete reform), as it is an extremely low-taxed sector in the benchmark economy.

Tobacco production is the sector that stands out in the complete reform (Figure 4b), with a price reduction of 43.35%. The benchmark gross tax rate in this sector was 37%, compared to 6.97% after the complete reform and 5.88% after the uniform reform, explaining the significant impact on this sector. The gross tax rate is higher in the complete reform because the cumulative tax is zero, leaving only the VAT rate to target the benchmark's total revenue. Furthermore, cumulative taxation has a significant impact on the supply chain connection. Indeed, despite the fact that some sectors in the complete reform face higher new gross tax rates than the benchmark, their prices continue to vary negatively.

The effects on the production chain can be seen through the increase in the sectoral centrality index (Figure 5). The BK centrality index rises in the majority of sectors. Indeed, only 15 sectors experienced a decrease in centrality after the uniform reform, while 14 sectors experienced a decrease after the complete reform. It is worth noting that the manufacturing sectors have seen the greatest increases in the centrality index. For instance, beverages, tobacco products, apparel and accessories, footwear and leather goods, and cleaning products are the sectors in the complete reform that show at least a 12% increase in the centrality index.
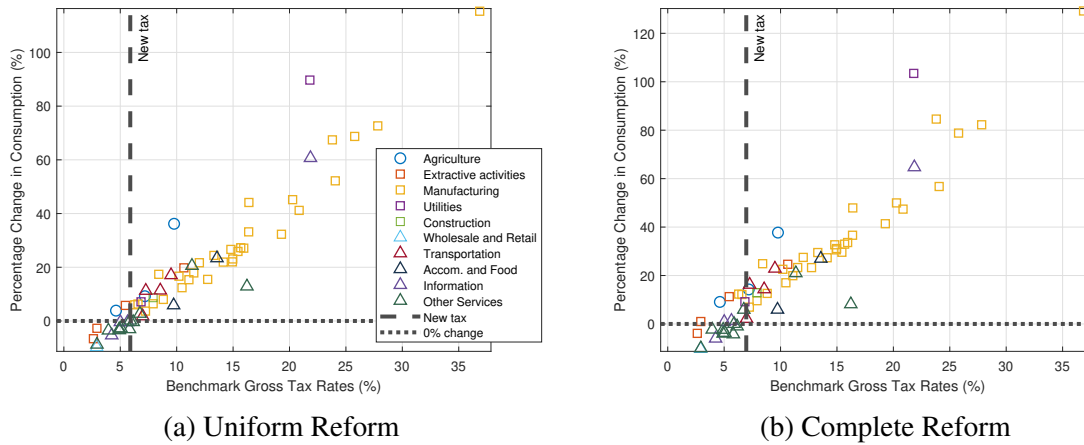
Figure 5: BK Centrality Changes

(a) Uniform Reform   (b) Complete Reform

Notes: The real estate sector is omitted from the charts because it showed a significant centrality variation following the reforms (-30.49% in the complete reform), as it is an extremely low-taxed sector in the benchmark economy.

Price changes caused by the tax reform, as expected, triggered changes in consumption. Figure 6 depicts a strong positive correlation between the benchmark gross tax rate and consumption changes. For both reforms, the correlation is approximately 0.9. Consumption in 11 sectors fell as a result of the complete reform, with real estate falling by 83%. Interestingly, 10 industries that saw their gross tax rates rise also saw an increase in consumption. This is due to positive changes in the suppliers to those sectors. Furthermore, 7 sectors experienced consumption growth of more than 50%. For example, we highlight electricity, natural gas, and other utilities (+103%) and oil refining and coke production (+85%).
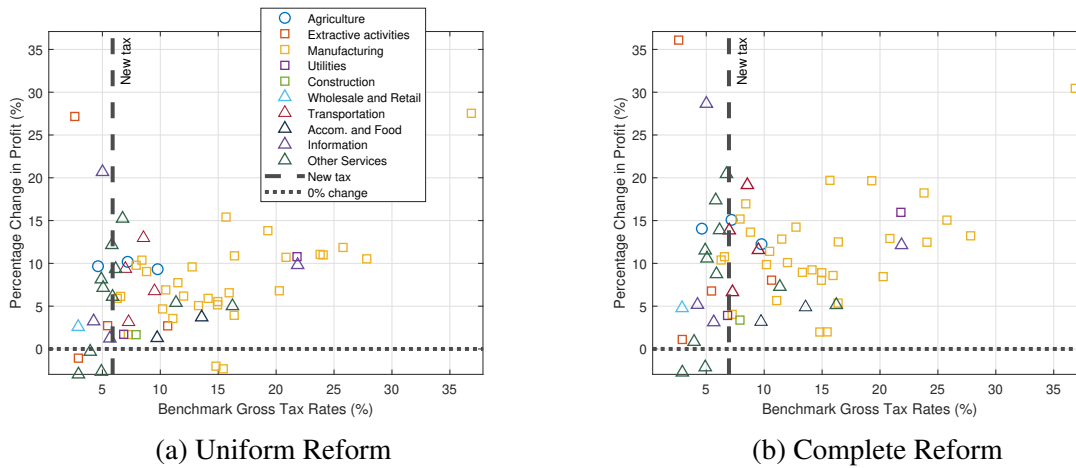
Figure 6: Consumption Changes

(a) Uniform Reform   (b) Complete Reform

Notes: The real estate sector is omitted from the charts because it showed a significant final consumption variation following the reforms (-83.43% in the complete reform), as it is an extremely low-taxed sector in the benchmark economy.

Profit growth is also positively correlated to the benchmark economy's gross tax rate (Figure 7). Sectors that were previously heavily taxed benefit from a lower tax rate, which increases their net revenue and thus their profits. However, some sectors become more profitable even when the tax rate is raised. In general, these are sectors that do not face significant tax increases and are suppliers to sectors that expanded following the tax reform. As a result, the increase in revenue from increased product supply more than offsets the revenue loss from paying higher taxes. The oil and gas extraction industry exemplifies how a sector can benefit from tax reform even if its tax rate rises. Despite facing the second-highest tax rate increase, its profit increases by 36%: the oil refinery sector, which is the main consumer of its products (responsible for approximately 82% of its demand), had one of the highest tax burdens prior to the reform and consequently saw a sizable tax reduction.

Figure 7: Profits Changes

(a) Uniform Reform

(b) Complete Reform

Notes: The real estate sector is omitted from the charts because it showed a significant profits variation following the reforms (-38.08% in the complete reform), as it is an extremely low-taxed sector in the benchmark economy.

We can decompose real GDP growth after reforms conditional on the sectors' markup levels. We first calculate the value-added growth rate of each sector weighted by its shares of pre-reform GDP. Note that the sum of these weighted growth rates equals 100%. We then group sectors based on markup quartiles. Finally, within each quartile, we sum up the weighted growth rates of the sectors that fall within it. Figure 8 presents the decomposition results for a given tax reform in which the sum of quartile bars equals 100%. After the tax reform, sectors in the first quartile of the markup distribution contribute the most to GDP growth. In contrast, sectors with the highest markups (fourth quartile) are those that contribute negatively. Because of the elimination of cascading tax effects from cumulative taxation, the negative contribution of high markup sectors is attenuated after complete reform.

Figure 8: GDP Growth Decomposition by Markup Quartiles
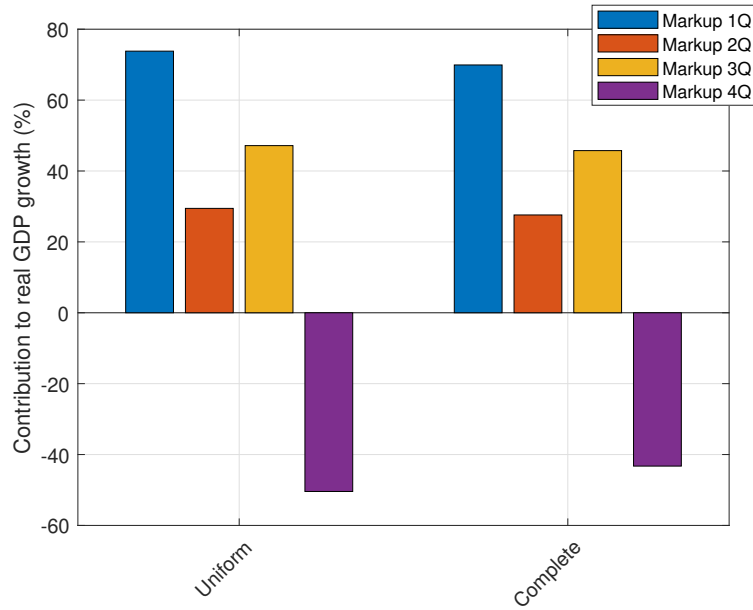
Despite having a negative impact on GDP growth, sectors with the highest markups saw a sharp rise in profits (Figure 9a). After the complete reform, sectors in the fourth quartile of the markup distribution experienced an average profit growth of 9.62%. Additionally, average consumption of the products from these sectors increased by 4.81% (Figure 9b). These high markup sectors also experienced, on average, an increase in prices (Figure 9d). Figure 9 also reveals that the sectors with the lowest markups experienced the highest average growth in profits, consumption, and labor demand. Furthermore, those are the sectors with the greatest price drops.

Figure 9: Average Growth Rates by Markup Quartiles

(a) Profits

(b) Consumption

(c) Labor Supply

(d) Prices
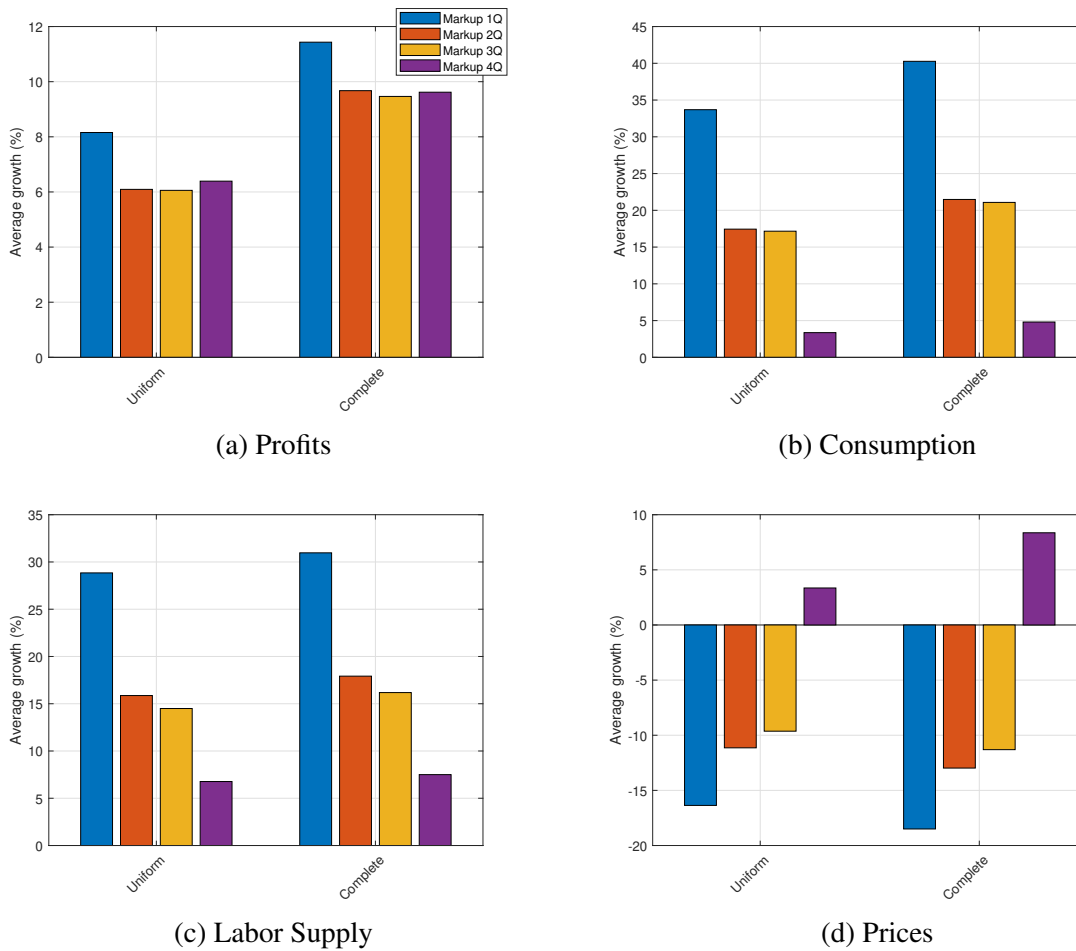
The simulations so far have assumed revenue-neutral tax reforms. We now assess the effects of the complete reform when real public revenue is 5% higher or lower than the benchmark revenue (Table 4). GDP could grow by 14.23% if government revenue increases by 5%, versus 1.66% if revenue decreases by 5%. Furthermore, the effects on labor supply, welfare, and profits are more pronounced in the revenue-growth scenario: as we let revenues rise, the break-even VAT rate (6.3%) falls below the revenue-neutral reform rate (6.96%). This lower rate contributes even further to the economy's performance. It is worth noting that the higher-revenue reform results in one sector incurring losses, whereas the lower-revenue reform results in nine sectors incurring losses. Overall, these findings indicate that tax reforms may be beneficial even in the case of expanding government size.

Table 4: Complete Tax Reforms with Lower and Higher Revenues

	Units	Complete	5% Higher	5% Lower
GDP	$\Delta\%$	+7.84	+14.23	+1.66
Labor supply	$\Delta\%$	+3.66	+7.56	-0.25
Welfare (CEV)	$\Delta\%$	+1.86	+8.07	-4.21
Profits	$\Delta\%$	+2.27	+6.59	-2.09
Profit-cutting sectors	#	3	1	9
Coefficient of variation of profits	–	1.44	1.43	1.46
τ (average)	%	6.96	6.30	7.57
λ (average)	%	0.00	0.00	0.00

Notes: Percentage change units ($\Delta\%$) represent variations from the benchmark.

5.2 The role of network and propagation

This section highlights the pivotal role of the sector network in propagating and amplifying the impacts of tax reform. Unlike conventional models, our framework considers the interconnectedness of economic sectors. Consequently, sectors that occupy central positions in the production network play a crucial role in shaping the overall economic performance, especially in response to tax reductions.

We start this section by decomposing the effect on GDP of the complete reform according to changes in centrality and upstreamness. Then, we analyze the direct contribution of intermediate goods for the results of the complete reform. Finally, we conclude by introducing a reform scenario in which we reduce the tax to zero for sectors with the highest centrality index.

When GDP growth is decomposed by changes in network characteristics, we find that sectors with the highest variation in the centrality index contribute significantly to GDP growth, offsetting the negative contribution from sectors with the lowest variation in centrality (Figure 10a). We also decompose GDP growth based on changes in upstreamness (Figure 10b). We find that sectors with the smallest increase in upstreamness contribute the most to GDP growth. This finding highlights how distorted the current tax system is, and how tax rate homogenization could benefit economic growth, despite a very heterogeneous contribution from economic sectors. Furthermore, the mechanism here implies that the degree of centrality has a larger role in determining the gains from tax reform than their upstreamness.

Figure 10: GDP Growth Decomposition by Quartiles of Network Statistics Changes

(a) BK Centrality Changes　　　　　　　　(b) Upstreamness Changes
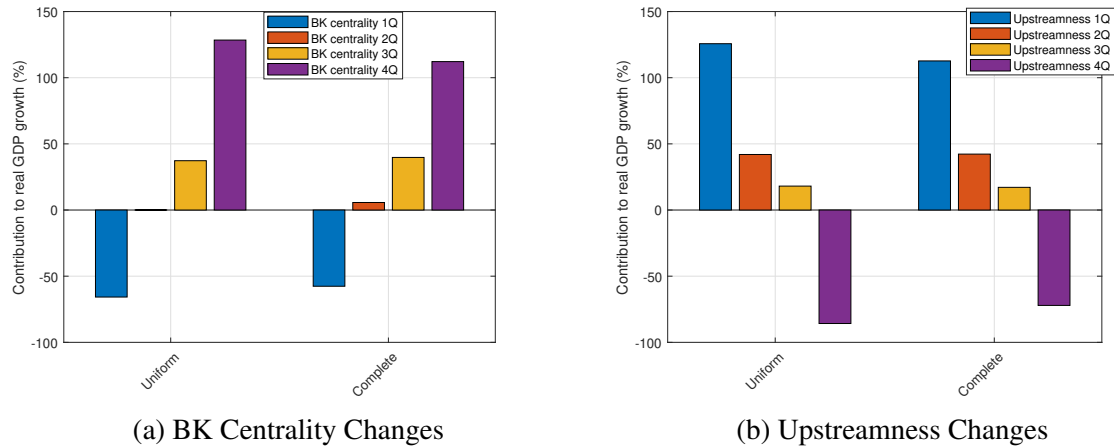
The isolated contribution of the network can also be evaluated by holding intermediate goods at the benchmark level while allowing other variables to change during the complete reform. In this exercise, we keep the intermediate goods at the same level as in the baseline case and assess the effect of the policy by considering the reallocation of workers among the sectors. Result presented in Table 5. Without modifications in the use of intermediate goods - which acts as a proxy for the absence of network effects and cross-sector propagation - the impact on GDP (+1.38%) and welfare (+0.78%) would be significantly smaller compared to the benchmark scenario with network and changes in the use of intermediate inputs.

Table 5: Complete Tax Reforms keeping constant the intermediate goods

	Units	Complete	W/o change in network
GDP	Δ%	+7.84	+1.38
Welfare (CEV)	Δ%	+1.86	+0.78

Notes: Percentage change units (Δ%) represent variations from the benchmark.

Finally, we also assess the significance of the network of intermediate goods in tax reforms by simulating an alternative policy wherein the sectors with higher centrality - specifically, those in the fourth quartile of the BK centrality distribution - are exempted from taxation. The idea is that the most important sectors of the economy are those with a strong link within the production chain, that is, those with a high demand for inputs and that are critical suppliers to other sectors. If network effects are not relevant the difference between this simulation and the benchmark scenario would be negligible.

Table 6 presents the results. This policy significantly increases the average VAT rate of other sectors (from 6.97% to 31.02%) to maintain constant real government revenue as in the

Table 6: Complete Tax Reforms with Targeted Policies

	Units	Complete	Centrality 4Q
GDP	Δ%	+7.84	+7.71
Labor supply	Δ%	+3.66	-0.97
Welfare (CEV)	Δ%	+1.86	+2.07
Profits	Δ%	+2.27	+8.47
Profit-cutting sectors	#	3	17
Coefficient of variation of profits	–	1.44	1.71
τ not targeted (average)	%	6.97	31.02
τ targeted (average)	%	–	0.00
λ (average)	%	0.00	0.00

Notes: Percentage change units (Δ%) represent variations from the benchmark.

benchmark. Indeed, sectors in the fourth quartile of the centrality distribution play an important role in the production chain, generating significant tax revenue for the government. Thus, the nontargeted sectors must contribute significantly more in a revenue-neutral exercise.

Even with this large variation of taxation, the change of GDP remained almost the same when comparing to the benchmark case, while welfare increased by more than 10% and profits expanded fourfold. In contrast, labor supply would now fall and the number of sectors experiencing reduction in profits would jump to 17, from just 3. Hence, this exercise, and the previous two, show that taking into account network effects and propagation across sectors is very important in the evaluation of the aggregate (and sectoral) effects of tax reforms.

Despite the significant increase in taxation rates, the impact on GDP remained relatively stable compared to the benchmark case, while the welfare of the population increased by 10%, and profits experienced a fourfold expansion. On the flip side, the labor supply declined, and the number of sectors facing reduced profits surged from a mere 3 to a substantial 17. These findings, and those in the two previous exercises, highlight the crucial significance of considering network effects and propagation across sectors when evaluating the overall and sector-specific repercussions of tax reforms. Without them results would be quite different.

5.3 Targeting Sectors

We now reevaluate the complete tax reform taking into account some cases where groups of sectors can be targeted to be subsidized or taxed more heavily. We are particularly interested in

assessing two types of targeted reforms:

1. **Sin Taxes**: We maintain the tobacco and beverage sectors' tax rates at the benchmark level. We do so because, following the original reforms, tax rates in these sectors fell dramatically, and tobacco consumption, for example, more than doubled. However, the reason these rates were initially so high was to discourage the consumption of these harmful to health goods. To avoid excessive growth in consumption of these products, we implement the complete reform while maintaining the tax rates in these two sectors at the benchmark level.

2. **ESG**: We chose the six sectors with the highest carbon emissions to be taxed more heavily. These sectors were selected based on the estimates from Zapparoli et al. (2018) and account for 10% of all private sectors.[8] This group's tax rate is set to be 50% higher than the tax rate for the other sectors. As before, we calculated the tax rate that produces the same amount of real public revenue as the benchmark in order to estimate the revenue-neutral tax rate.

All targeted reforms result in lower GDP growth than the original complete reform (Table 7). The results of the sin taxes and ESG reforms are still quite interesting because they do not cancel out the gains from the complete reform. For both policies, the new tax rate for nontarget sectors is similar to, but slightly lower than, the rate of the original complete reform. This tax reduction is explained by the fact that when the tax rate on targeted sectors increases, the tax burden on nontarget sectors decreases in order to achieve the same level of total public revenues.

6 Conclusion

This paper quantifies the effects of tax dispersion and cumulative rates on aggregate and sector real output, welfare, and the shape of the production chain. In a general equilibrium economy with input-output networks, we implemented a revenue-neutral tax reform in which heterogeneous tax rates and cumulative taxes were replaced by a single VAT rate applicable to all sectors. The model was calibrated to Brazil, a country with many distortions (e.g., high dispersion and multiple tax rates), and sector tax rates were estimated from the data.

Because the costs and benefits of tax reforms are not confined to specific sectors, it is necessary to consider the entire network of sectoral input-output linkages when studying and estimating their impact. The reforms' effects spread through the network, amplifying or mitigating the direct impact. The sectors' own tax rate is not the only determinant of winners and losers

---

[8]The sectors are (i) pig iron/ferroalloy production, steel, and seamless steel tubes; (ii) metallurgy of non-ferrous metals and metal smelting; (iii) manufacture of metal products, except machinery and equipment; (iv) land transport; (v) water transport; and (vi) air transport.

Table 7: Complete Tax Reforms with Targeted Policies

	Units	Complete	Sin Taxes	ESG
GDP	Δ%	+7.84	+7.45	+7.72
Labor supply	Δ%	+3.66	+3.55	+3.58
Welfare (CEV)	Δ%	+1.86	+1.78	+1.89
Profits	Δ%	+2.27	+2.07	+2.39
Profit-cutting sectors	#	3	3	3
Coefficient of variation of profits	–	1.44	1.45	1.45
τ not targeted (average)	%	6.97	6.88	6.89
τ targeted (average)	%	–	31.32	10.34
λ (average)	%	0.00	0.00	0.00

Notes: Percentage change units (Δ%) represent variations from the benchmark.

in the sectoral conflict that tax reforms represent. The tax rate of sectors that establish stronger connections with them also matters. Tax reforms, in addition, reshape the relationship between sectors, altering their size, relevance, and position in the production chain. With a tax reform, artificially enlarged sectors due to distortionary taxation tend to lose importance in the network.

The main exercise, the "complete" reform that eliminates tax dispersion and cumulative taxation, leads to gains in welfare and real GDP of 1.86% and 7.84%, respectively. When only heterogeneity is taken into account, these gains fall to 1.69% and 5.97%, respectively. At least in the case of Brazil, tax dispersion appears to be more problematic than cumulative taxation.

The network structure of the economy delivers some relevant results that would be impossible to observe in a standard model. Final output increased in 10 of the 21 industries that saw tax increases, while profits fell in only 3 of them. For example, the oil and gas extraction industry faced the second-highest tax rate increase, but its profits increased by 36%. This is the result of an increase in demand from its primary consumer, the oil refinery sector, which was one of the most taxed sectors in the benchmark economy.

We also found that sectors can become more relevant as suppliers as their products and the products of their downstream sectors become more competitive. In most cases, the latter is more important, so sectors in which final demand falls become more relevant as intermediate suppliers. Finally, the reforms we study can reshape the production chain by reducing distortions that affect the connection between sectors, as evidenced by the increase in centrality and upstreamness of most sectors.

Appendix A   Equilibrium Definition

The equilibrium of the model economy consists of prices $\{p_i\}$, a wage rate w, noncumulative VAT rates $\{\tau_i\}$, cumulative tax rates $\{\lambda_i\}$, a labor and profits income tax rate $\{\tau_w, \tau_\Pi\}$, private sector markups $\{\mu_i\}$, public sector budgets $\{G_k\}$, total private sector profits Π, and a lump-sum government transfer T such that the following conditions are satisfied:

1. Given prices, the wage rate, tax rates, and markups, the factor allocations $\{l_i\}$ and $\{x_{ij}\}$ are the solution to the optimization problems of the private sectors.

2. Given prices, the wage rate, and tax rates, the factor allocations $\{l_k\}$ and $\{x_{kj}\}$ are the solution to the optimization problems of the public sectors.

3. Given prices, the wage rate, the labor and profits income tax rate, the total private sector profits, and the lump-sum government transfer, the consumption allocations $\{c_j\}$ and labor time L are the solution to the optimization problem of the representative household.

4. All private product markets clear, that is, for each private sector j, we have that

$$y_j = c_j + \sum_{i \in N} x_{ij} + \sum_{k \in M} x_{kj}.$$

5. All public good markets clear, that is, for each public sector k, we have that $y_k = g_k$.

6. The labor market, considering all private and public markets, clears, that is,

$$L = \sum_{i \in N} l_i + \sum_{k \in M} l_k.$$

7. The central government budget is balanced, that is,

$$T + \sum_{k \in M} G_k = \tau_w w L + \sum_{i \in N} T_i.$$

Appendix B   Aggregation

The economy can be aggregated straightforwardly in equilibrium. Let V_{Pi} be the gross value-added at basic prices generated by private sector i. Then, from the definition of gross value-added, we have that

$$V_{Pi} = p_i y_i - \sum_{j \in N} p_j x_{ij} - T_i = \Pi_i + w l_i, \tag{20}$$

where the second equality comes from the definition of profits in equation (4). Similarly, let V_{Gk} be the gross value-added at basic prices generated by public sector k. Then, we have that

$$V_{Gk} = G_k - \sum_{j \in N} p_j x_{kj} = w l_k, \tag{21}$$

where the second equality comes from the definition of the public sectors' budget constraint in equation (7), which holds with equality in equilibrium. Note that the aggregate profit is the sum of the profits of all private sectors, that is, $\Pi = \sum_{i \in N} \Pi_i$. Then, using the labor market-clearing condition, we have that the total gross value-added generated in the economy is equal to

$$V = \sum_{i \in N} V_{Pi} + \sum_{k \in M} V_{Gk} = \sum_{i \in N} \Pi_i + \sum_{i \in N} w l_i + \sum_{k \in M} w l_k = \Pi + wL. \tag{22}$$

Define the total consumption expenditures with private products by $C = \sum_{j \in N} p_j c_j$ and the total government expenditure allocated to public sectors' budget by $G = \sum_{k \in M} G_k$. Therefore, the nominal gross domestic product of the economy can be calculated as

$$GDP = V + \sum_{i \in N} T_i = wL + \Pi + \sum_{i \in N} T_i = C + G. \tag{23}$$

The first equality is the definition of nominal GDP at producer prices. The second equality comes from equation (22). It gives the definition of nominal GDP from the income approach. The third equality comes from the balance of the central government budget and the household budget constraint in equation (9), which holds with equality in equilibrium. It gives the definition of nominal GDP from the expenditure approach.

Appendix C   Model Solution

Using equation (3) and the first-order conditions of the minimization cost problem, we get that labor, intermediate inputs demands, price and private production (y_i) are given by

$$l_i = \alpha_i \frac{(1-\tau_1)p_1}{w\beta_{i1}} x_{i1}, \tag{24}$$

$$x_{ij} = \frac{\beta_{ij}}{\beta_{i1}} \frac{(1-\tau_1)p_1}{(1-\tau_j)p_j} x_{i1}, \tag{25}$$

$$p_i = \frac{(1-\tau_\Pi)(1+\mu_i)}{1-(\tau_i+\lambda_i)(1-\tau_\Pi)(1+\mu_i)-\tau_\Pi(1+\mu_i)} \left[\frac{w^{\alpha_i}\prod_{j\in N}((1-\tau_j)p_j)^{\beta_{ij}}}{\alpha_i^{\alpha_i}\prod_{j\in N}\beta_{ij}^{\beta_{ij}}} \right] \frac{1}{z_i}, \tag{26}$$

$$y_i = z_i \left(\frac{\alpha_i}{w}\right)^{\alpha_i} \frac{(1-\tau_1)p_1}{\beta_{i1}} \frac{\prod_{j\in N}\beta_{ij}^{\beta_{ij}}}{\prod_{j\in N}((1-\tau_j)p_j)^{\beta_{ij}}} x_{i1}, \quad \forall i \in N. \tag{27}$$

Then, from the first-order conditions, the demands for labor and intermediate inputs of public sector k are given by

$$l_k = \frac{\alpha_k G_k}{w}, \tag{28}$$

$$x_{kj} = \frac{\beta_{kj} G_k}{p_j}. \tag{29}$$

From the first-order conditions of the consumer's problem, we get the demand for consumption and the labor supply:

$$c_i = \frac{\omega_i^\theta \left[(1-\tau_w)wL + \sum_i \Pi_i + T\right]}{p_i^\theta P}, \tag{30}$$

$$L = \left(\frac{\chi(1-\tau_w)w}{\rho}\right)^{\frac{1}{v}}, \tag{31}$$

where χ is the Lagrange multiplier.

We start by solving for the equilibrium prices. Then, by log-linearizing the price-setting function given by equation (26), we solve a linear system of prices, which is a function of the model's parameters.

Now that prices have been identified, we proceed to solve the rest of the variables. First, using the public products market-clearing equation and replacing equations (28) and (29) into equation (6), we write the public goods consumption as

$$g_k = y_k = \left[z_k \left(\frac{\alpha_k}{w}\right)^{\alpha_k} \prod_{j\in N} \left(\frac{\beta_{kj}}{p_j}\right)^{\beta_{kj}} \right] \varphi_k \left(\tau_w wL + \sum_{i\in N} T_i\right), \quad \forall k \in M. \tag{32}$$

In the case of private products, we substitute equations (25), (29), and (30) into the market-clearing equation to get that

$$y_i = \frac{\omega_i^\theta \left[(1 - \tau_w)wL + \sum_i \Pi_i + T \right]}{p_i^\theta P} + \sum_{j \in N} \frac{\beta_{ji} p_1 (1 - \tau_1)}{\beta_{j1} p_i (1 - \tau_i)} x_{j1} +$$

$$+ \sum_{k \in M} \frac{\beta_{ki} \varphi_k \left(\tau_w wL + \sum_{j \in N} T_j \right)}{p_i} \quad \forall j \in N. \tag{33}$$

Next, we substitute equations (3), (4), and (27) and the market-clearing equation of the central government budget into equation (33) to find

$$\phi_i x_{i1} = \varepsilon_i L + \sum_{j \in N} E_{ji} x_{j1} + \sum_{j \in N} F_{ij} x_{j1}, \tag{34}$$

where

$$\phi_i = z_i \left(\frac{\alpha_i}{w} \right)^{\alpha_i} \frac{(1 - \tau_1)p_1}{\beta_{i1}} \frac{\prod_{j \in N} \beta_{ij}^{\beta_{ij}}}{\prod_{j \in N} ((1 - \tau_j)p_j)^{\beta_{ij}}}$$

$$\varepsilon_i = \frac{\omega_i^\theta (1 - \tau_w \sum_{k \in M} \varphi_k)w}{p_i^\theta P} + \tau_w w \sum_{k \in M} \frac{\varphi_k \beta_{ki}}{p_i}$$

$$E_{ji} = \frac{\beta_{ji}}{\beta_{j1}} \frac{p_1(1 - \tau_1)}{p_i(1 - \tau_i)} + \frac{\omega_i^\theta D_j}{p_i^\theta P}$$

$$D_j = p_j \phi_j - \frac{\alpha_j p_1(1 - \tau_1)}{\beta_{j1}} - \sum_{\ell \in N} \frac{\beta_{j\ell} p_1(1 - \tau_1)}{\beta_{j1}(1 - \tau_\ell)} - B_j$$

$$B_j = \left(\sum_{k \in M} \varphi_k \right) \left\{ p_j \phi_j \left[(\lambda_j + \tau_j)(1 - \tau_\Pi) + \tau_\Pi \right] - \sum_{\ell \in N} \frac{\beta_{j\ell} p_1(1 - \tau_1) \left[\tau_\ell + \tau_\Pi(1 - \tau_\ell) \right]}{\beta_{j1}(1 - \tau_\ell)} - \frac{\tau_\Pi \alpha_j p_1(1 - \tau_1)}{\beta_{j1}} \right\}$$

$$F_{ij} = \left(\sum_{k \in M} \frac{\beta_{ki} \varphi_k}{p_i} \right) \left\{ p_j \phi_j \left[(\lambda_j + \tau_j)(1 - \tau_\Pi) + \tau_\Pi \right] - \sum_{\ell \in N} \frac{\beta_{j\ell} p_1(1 - \tau_1) \left[\tau_\ell + \tau_\Pi(1 - \tau_\ell) \right]}{\beta_{j1}(1 - \tau_\ell)} - \frac{\tau_\Pi \alpha_j p_1(1 - \tau_1)}{\beta_{j1}} \right\}.$$

Note that since equation (34) holds for all private sectors, we can build a system of n linear equations. To see that, first simply define the following vectors and matrices:

$$X_1 \equiv \begin{bmatrix} X_{11} \\ \vdots \\ X_{n1} \end{bmatrix}, \quad \varepsilon \equiv \begin{bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_n \end{bmatrix},$$

$$\Upsilon \equiv \begin{bmatrix} \Upsilon_{11} & \cdots & \Upsilon_{1n} \\ \vdots & \ddots & \vdots \\ \Upsilon_{n1} & \cdots & \Upsilon_{nn} \end{bmatrix} = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \phi_1 \\ \vdots \\ \phi_{n1} \end{bmatrix} - \begin{bmatrix} E_{11} + F_{11} & \cdots & E_{n1} + F_{1n} \\ \vdots & \ddots & \vdots \\ E_{1n} + F_{n1} & \cdots & E_{nn} + F_{nn} \end{bmatrix}.$$

Then, combining the above definitions with the n equations derived from equation (34), we can construct a linear system in matrix form represented by

$$X_1 = (\Upsilon)^{-1} \varepsilon L. \tag{35}$$

However, note that the system defined by equation (35) does not provide the solution of X_{i1}s because it is a function of L, which is given by equation (31). First, note that the consumption is a linear function of L:[9]

$$c_i = \frac{\omega_i^\theta \left[(1 - \tau_w \sum_{k \in M} \varphi_k) wL + \sum_{j \in N} D_j x_{j1} \right]}{p_i^\theta P} \quad \forall i \in N. \tag{36}$$

Furthermore, the net taxes (T_i) could be written by

$$T_i = \left\{ p_i \phi_i \left[(\lambda_i + \tau_i)(1 - \tau_\Pi) + \tau_\Pi \right] - \sum_{\ell \in N} \frac{\beta_{i\ell} p_1 (1 - \tau_1) \left[\tau_\ell + \tau_\Pi (1 - \tau_\ell) \right]}{\beta_{i1} (1 - \tau_\ell)} - \right.$$
$$\left. \frac{\tau_\Pi \alpha_i p_1 (1 - \tau_1)}{\beta_{i1}} \right\} x_{i1}, \quad \forall i \in N. \tag{37}$$

Thus, after some straightforward calculation we can see from equations (32), (35), (36), and (37) that c_i and g_k are also a linear function of L.

The first-order condition of the consumer's problem can be written as

$$\chi = \frac{\omega_i c_i^{-\frac{1}{\theta}} \left[\sum_{j \in N} \omega_i c_j^{\frac{\theta-1}{\theta}} + \sum_{k \in M} \omega_k g_k^{\frac{\theta-1}{\theta}} \right]^{\frac{1}{\theta-1}}}{p_i}, \quad \forall i \in N. \tag{38}$$

Note that if c_i and g_k are linear functions of L, then χ is an independent function of L. Therefore, define $\tilde{x}_{i1} = x_{i1}/L$, $\tilde{c}_i = c_i/L$ and $\tilde{g}_k = g_k/L$ and find χ using equations (32), (35),

---

[9]As shown in equation (35), x_{j1} is a linear function of L.
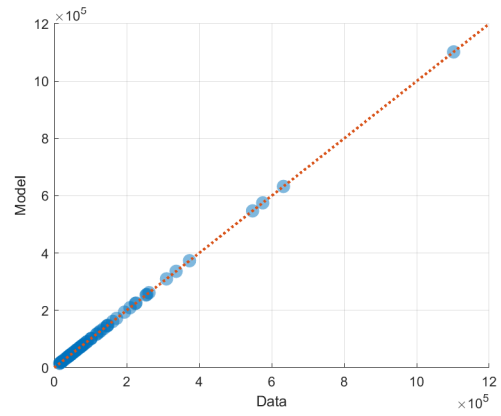
(36), and (37). With the Lagrange multiplier, equation (38), and prices, it is easy to solve equation (31) and find L. Thus, we can calculate the equilibrium values for all endogenous variables with the last equations.
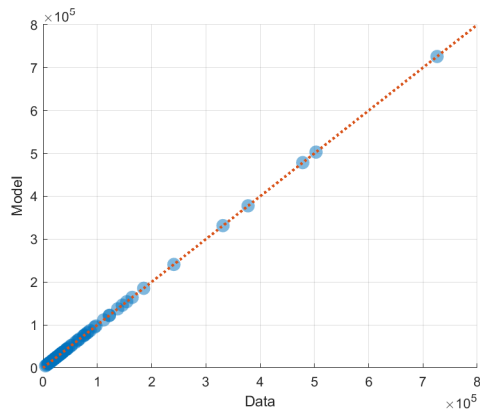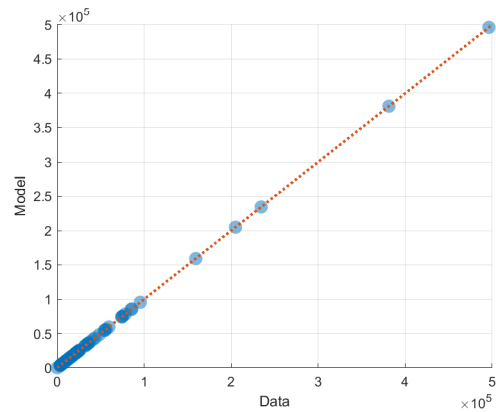
Appendix D   Model Fit
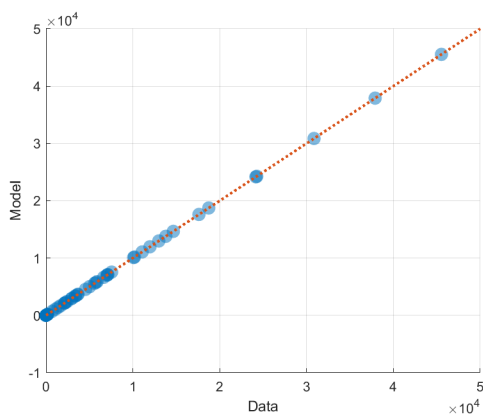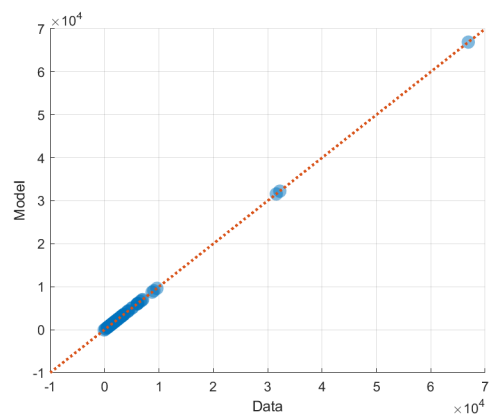
Figure 11: Model vs. Data
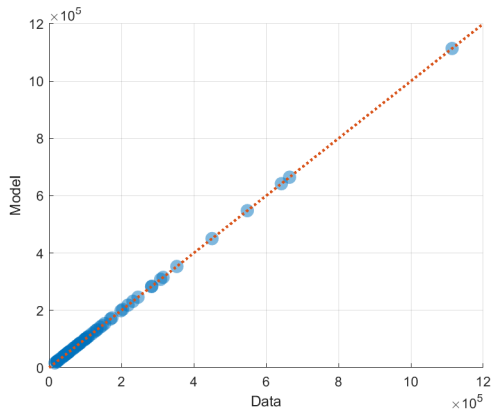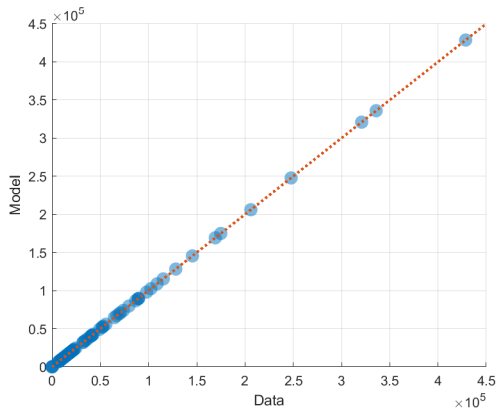

(a) Gross Revenue

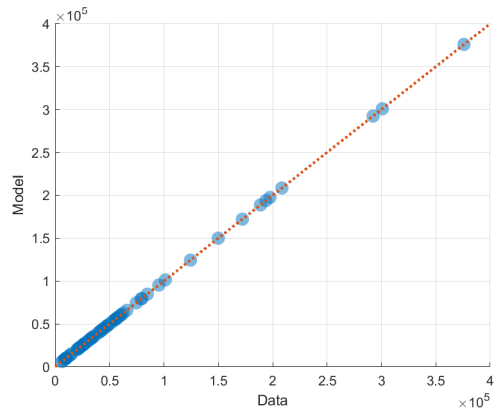(b) Net Revenue

(c) Value-Added
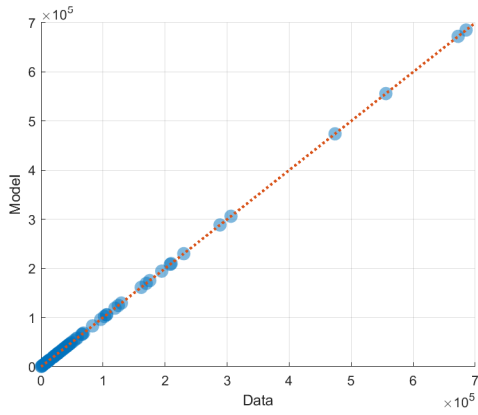
(d) Profits

(e) VAT Revenue

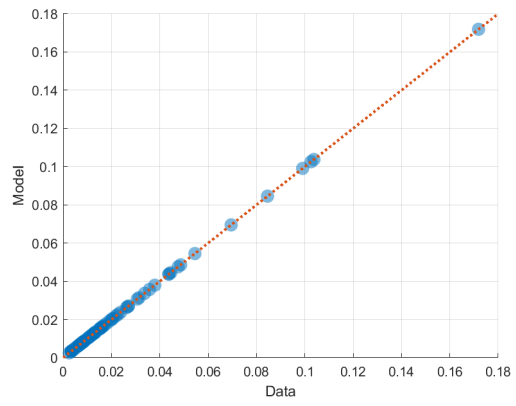(f) Cumulative Tax Revenue
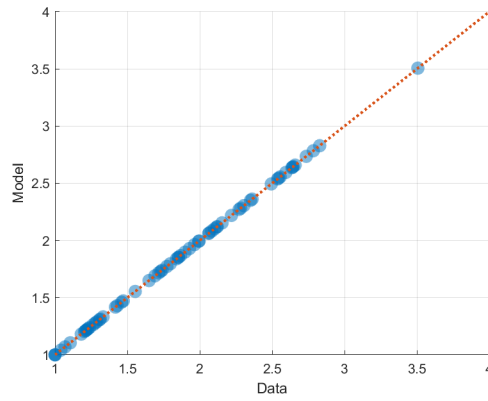
(a) Intermediate Inputs Cost

(b) Sales to Other Sectors

(c) Sales to Households

(d) Domar Weight

(e) Upstreamness

References

Acemoglu, Daron and Pablo D. Azar (2020), "Endogenous Production Networks." *Econometrica*, 88, 33–82.

Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi (2012), "The Network Origins of Aggregate Fluctuations." *Econometrica*, 80, 1977–2016.

Antràs, Pol, Davin Chor, Thibault Fally, and Russell Hillberry (2012), "Measuring the Upstreamness of Production and Trade Flows." *American Economic Review*, 102, 412–416.

Baqaee, David Rezza (2018), "Cascading Failures in Production Networks." *Econometrica*, 86, 1819–1838.

Baqaee, David Rezza and Emmanuel Farhi (2020), "Productivity and Misallocation in General Equilibrium." *The Quarterly Journal of Economics*, 135, 105–163.

Bigio, Saki and Jennifer La'O (2020), "Distortions in Production Networks." *The Quarterly Journal of Economics*, 135, 2187–2253.

Bonacich, Phillip (1987), "Power and Centrality: A Family of Measures." *American Journal of Sociology*, 92, 1170–1182.

Carvalho, Vasco M. (2014), "From Micro to Macro via Production Networks." *Journal of Economic Perspectives*, 28, 23–48.

Carvalho, Vasco M. and Alireza Tahbaz-Salehi (2019), "Production Networks: A Primer." *Annual Review of Economics*, 11, 635–663.

Chen, Shawn Xiaoguang (2017), "VAT Rate Dispersion and TFP Loss in China's Manufacturing Sector." *Economics Letters*, 155, 49–54.

Fajgelbaum, Pablo D., Eduardo Morales, Juan Carlos Suárez Serrato, and Owen Zidar (2019), "State Taxes and Spatial Misallocation." *The Review of Economic Studies*, 86, 333–376.

Grassi, Basile and Julien Sauvagnat (2019), "Production Networks and Economic Policy." *Oxford Review of Economic Policy*, 35, 638–677.

Hobijn, Bart and Fernanda Nechio (2019), "Sticker Shocks: Using VAT Changes to Estimate Upper-Level Elasticities of Substitution." *Journal of the European Economic Association*, 17, 799–833.

Keane, Michael and Richard Rogerson (2015), "Reconciling Micro and Macro Labor Supply Elasticities: A Structural Perspective." *Annual Review of Economics*, 7, 89–117.

Leite, Edmundo (2018), "Reforma Tributária é Debatida desde o Império." *O Estado de S. Paulo*.

Liu, Ernest (2019), "Industrial Policies in Production Networks." *The Quarterly Journal of Economics*, 134, 1883–1948.

Long, John B., Jr. and Charles I. Plosser (1983), "Real Business Cycles." *Journal of Political Economy*, 91, 39–69.

Oberfield, Ezra and Devesh Raval (2021), "Micro Data and Macro Technology." *Econometrica*, 89, 703–732.

Receita Federal do Brasil (2020), "Carga Tributária no Brasil 2018: Análise por Tributos e Base de Incidência." Technical report, Receita Federal do Brasil.

Receita Federal do Brasil (2021), "Arrecadação das Receitas Federais - 1994 a 2021." Technical report, Receita Federal do Brasil.

Redding, Stephen J. and David E. Weinstein (2018), "Accounting for Trade Patterns." Mimeo.

Zapparoli, Irene Domenes, Adriano Martins de Souza, Umberto Antonio Sesso Filho, Paulo Rogério Alves Brene, and Márcia Regina Gabardo da Câmara (2018), "Análise dos transbordamentos nas emissões de dióxido de carbono: Brasil, Rússia, India e China - BRIC." *Revista Econômica do Nordeste*, 49, 149–164.