Assessing the economic effects, income redistribution and carbon emissions of Petrobras' fuel price shocks in Brazil: a dynamic CGE modelling approach[1]

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Abstract
In 2016, Brazil implemented an internal price parity (IPP) policy for fossil fuels, partially linking domestic prices to global markets. This policy increased fuel taxation, raising costs for consumers and industry. However, in 2023, Petrobras, the dominant fuel provider, abolished the IPP policy, directly impacting diesel and gasoline prices. This policy shift redirected resources, boosting consumer spending and potentially improving efficiency in transportation services heavily reliant on these fuels. Our research examines the economic impact of this fuel price change in Brazil using a dynamic general equilibrium model informed by data from the Brazilian Social Accounting Matrix (SAM). The model suggests that the policy change may exacerbate the tension between economic growth and environmental concerns. While it could boost production in certain sectors and increase overall household welfare, the impact on income inequality is likely to be modest. The policy change might also lead to a significant increase in demand for public transportation among middle- and low-income households, while wealthier households may shift towards increased private vehicle use. Overall, the policy does not contribute significantly to income deconcentration.

Resumo
Em 2016, o Brasil implementou a política de Paridade de Preços Internacionais (PPI) para combustíveis fósseis, vinculando parcialmente os preços domésticos aos mercados globais. Esta política aumentou os impostos sobre os combustíveis, elevando os custos para os consumidores e a indústria. No entanto, em 2023, a Petrobrás, principal fornecedora de combustíveis, aboliu a política de PPI, impactando diretamente os preços do diesel e da gasolina. Essa mudança de política realocou recursos, aumentando os gastos dos consumidores e potencialmente melhorando a eficiência dos serviços de transporte que dependem fortemente desses combustíveis. Nosso artigo analisa o impacto econômico desta alteração nos preços dos combustíveis no Brasil, utilizando um modelo dinâmico de equilíbrio geral baseado em dados da Matriz de Contabilidade Social (MCS) brasileira. O modelo sugere que a mudança de política pode exacerbar a tensão entre o crescimento econômico e as preocupações ambientais. Embora possa impulsionar a produção em certos setores e aumentar o bem-estar geral das famílias, o impacto na desigualdade de rendimentos será provavelmente modesto. A mudança de política poderá também levar a um aumento significativo da procura de transportes públicos entre as famílias de rendimentos médios e baixos, enquanto as famílias mais ricas poderão utilizar mais o automóvel particular. De modo geral, a política não contribui significativamente para a desconcentração da renda.

Keywords: Fuels. Price policy. Computable General Equilibrium.
Palavras- Chave: Combustíveis. Política de preços. Equilíbrio geral computável.
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1. Introduction

Fuel industries present a complex, systemic chain with a high degree of maturity in the Brazilian economy. These economic activities are characteristically capital-intensive, relying on extensive infrastructure for fuel storage and distribution. Their processing units are strategically located between raw material sources and consumer markets. To optimize costs across the supply chain, industrial processing, and distribution within a country (CADE, 2022; Mendes et al., 2018; Wagner et al., 2014). It is a sector susceptible to cyclical shocks capable of absorbing or transmitting systemic effects through the interaction of intermediate input demand (upstream) and fuel supply (downstream) (Baumeister & Kilian, 2016; EPE, 2021). In Brazil, the fuel sector is classified as a key due to its potential to generate upstream and downstream effects leading to above-average production (Betarelli Junior, 2022; IBGE, 2023).

Fuels as the second most important input in the Brazilian economy. Between 2018 and 2019, over half (about 58%) of Brazil's total fuel supply was used as intermediate input in economic activities (IBGE, 2023). Gasoline, fuel oil, diesel, and biofuels jointly accounted for 4.22% of the country's intermediate consumption, ranking behind only electricity (4.36%) and financial services (6.69%) in the year 1019. In addition to absorbing 58% of the total fuel supply in the form of intermediate consumption, the remaining 42% are demanded between the external market (13.20%) and household consumption (28.52%). Higher-income household demand fuel for their private vehicles and poorer families typically use public transport (Peng et al., 2008), whose service burns diesel and biofuels for circulation. This discrepancy directly impacts household budgets, varying according to income distribution and expenditure by a transport type (Proque et al., 2022). Due to the various policies implemented in Brazil since 2005, transport surpassed food and became the main consumption item in the Brazilian family budget in 2017 and 2019, according to the Consumer Expenditure Survey (CES)(IBGE, 2018). Transport reached 14.8% of total family expenditures, with expenditure on fuel, maintenance and acquisition of vehicles, and sporadic trips representing 12.2% (IBGE, 2019).

Policy instruments directly affecting fuel market prices impact on relative price structures, production operations — especially in sectors intensive in fuel use — and the typical households' budget constraints, income flow composition, and payments among economic institutions (i.e., firms, households, and public administration). In this context, until 2023, fuel pricing in the Brazilian market was influenced by three main factors. First, the market structure stands out, characterized by a state-controlled monopoly. Second, the high density of oil extracted from Brazilian basins makes domestic refining more challenging, requiring the import of lighter oil for suitable composition. Although lighter oil exists in the pre-salt reserves, the country remains highly dependent on imports for refining (Lourenço, 2022). Lastly, the Import Parity Policy (IPP) implemented in 2016.

The IPP was a policy instrument implemented to generate profits for Petrobras and prevent distortions in the Brazilian fuel market. However, an unintended consequence was the increase in domestic prices in response to international market hikes, benefiting oil importers and affecting the competitiveness of the Brazilian state-owned company. This occurred due to a hypothetical scenario in which Brazil does not produce oil, resulting in companies acting as importers and incorporating additional costs to distributors. In this perspective, the policy adoption led to increased fuel and oil refining product prices' susceptibility to price asymmetries. Initially, policy adjustments were made monthly. However, in July 2016, prices started being adjusted daily, within a range of -7% to +7%. The rationale presented was that past changes could not keep up with international market volatility. In practice, adjustments did not occur daily but had higher frequency than before (Lourenço, 2022). There was then a gradual increase in final fuel prices, leading to a negative impact on household's cost of living and contributing to economic activity slowdown. This price policy impacted gasoline and diesel until 2023.

The transmission of these various economic and redistributive effects through direct and indirect channels among the production system, income and payment flows of economic institutions, and fuel price policies has been underexplored by applied research (e.g., Bhuvandas & Gundimeda, 2020; Proque, 2019), especially for Brazil. Hence, this is a gap our study aims to fill. Therefore, this article contributes to analyzing the economic, distributive, and environmental effects resulting from the end of IPP. To accommodate the main objective, we used a Computable General Equilibrium (CGE) model, which incorporates flows from the Brazilian Social Accounting Matrix (SAM). The model also intricately recognizes private and public transport markets and fuel markets, which were affected by changes in fuel pricing policies.

Furthermore, the model we employed incorporates an emission accounting module, capturing how policies impact Greenhouse Gas Emissions (GGE) reduction or increase. Previous studies also assess the relationship between fuel policies and their impacts on the economy (e.g., Arndt et al., 2008; Henseler & Maisonnave, 2018; Proque et al., 2022; Rahiminia et al., 2015; Yusuf & Resosudarmo, 2008) others relate them to greenhouse gas emissions (e.g., Guo et al., 2014; Kulmer & Seebauer, 2019; Li & Yao, 2020). Therefore, the methodology allows capturing the main secondary effects of fuel policies on households, firms, and investors, as well as analyzing the interaction of different taxes.

2. Fuel Policies – a Review of Approaches

The literature is rich in debates regarding the impacts of oil price shocks on energy efficiency, economic sectors, and national growth (e.g. Fan et al., 2007; Sánchez, 2011; Sun et al., 2022; Timilsina, 2015). These changes, lead to fluctuations in fuel prices, directly affecting household demand, prices, income, and well-being. For instance, increases in urban bus fares tend to exacerbate inequality, especially in urban areas, due to households' budget constraints.

Given the complexity and diversity of economic issues related to fuel policy, various methodologies have been employed, such as econometrics, input-output analysis, and panel data (e.g., Bakhat et al., 2017; Jiang & Ouyang, 2017; Liddle & Huntington, 2020; Wang et al., 2013). However, the Computable General Equilibrium (CGE) model offers a consistent and comprehensive framework for examining the economic and sectoral impacts of specific fuel policies. CGE models can integrate the Social Accounting Matrix (SAM) into the database structure, detailing income generation and appropriation through various sources and expenditure structures. CGE modeling has emerged as a widely utilized tool for examining the price effects stemming from fuel taxes and production subsidies, as delineated in Table 1. Some studies specifically focus on the distributive impacts of fuel price increases. For example, Yusuf & Resosudarmo (2008), analyzed the distributive impact of fuel price hikes implemented by the Indonesian government in October 2005, noting that such fuel price increases led to heightened inequality, especially in urban areas. Arndt et al. (2008), examined the macroeconomic and sectoral implications of global fuel and food price increases on

Mozambique's economy demonstrating significant negative impacts on the country's terms of trade.

Table 1 – Summary of Fuel Policy Studies Using Computable General Equilibrium

Authors	Country/City	Method	Objectives	Main results and conclusions
Arndt *et al.* (2008)	Africa	CGE with Social Accounting Matrix (SAM)	Negative Economic Impacts of Global Fuel and Food Price Increases	The recorded global price increases in international markets constitute a substantial negative shock to Mozambique's terms of trade. Evidence from domestic price series indicates that the global price increases have been transmitted to the domestic economy.
Yusuf e Resosudarmo (2008)	Indonesia		Distributive Impact of Fuel Price Increases in October 2005	The increase in domestic fuel (kerosene) prices would tend to exacerbate inequality, particularly in urban areas. Through the comparison of various scenarios, it is concluded that adequate and effective compensation is necessary to mitigate the distributive cost or the reform's impact on poverty.
AlShehabi (2012)	Iran		Analyzing the Effects of Eliminating Crude Oil and Fuel Subsidies on the Labor Market	Redistributing the extra income back to households would not be sufficient to overcome these distortions. The labor market continues to suffer even as real GDP and household consumption increase. Directing income towards investment, however, significantly improves the labor market in the long term through increased capital accumulation. Therefore, a gradual implementation of subsidy elimination offers a smoother transition, minimizing short-term adverse effects on the labor market.
Chanthawong *et al.* (2012)	Thailand		Economic Impact of Biofuel Policies	The promotion of biofuels could have a positive impact on the Thai economy by boosting production and employment in renewable energy-related sectors.
Wianwiwat e Asafu-Adjaye (2013)	Thailand		Analyzing the macroeconomic and sectoral implications of implementing biofuel promotion measures	The development of biofuels in Thailand could contribute to the country's economic advancement and enhance energy security without compromising food security.
Guo *et al.* (2014)	China		Investigating the impacts of a carbon tax on China's economy and carbon emissions	The study yields three main conclusions: (1) Enhancing clean coal technology is pivotal in curtailing carbon emissions, given China's coal abundance and heavy reliance on it. (2) Implementing a carbon tax would boost clean energy utilization, significantly curbing coal and coke usage, or incentivizing the adoption of clean coal technology. (3) Simulation results suggest that a moderate carbon tax is an effective strategy for China to mitigate carbon emissions, albeit with a slight adverse impact on economic growth.
Rahiminia *et al.* (2015)	Iran		Fuel Subsidy Reallocation Impact	Stagflation emerges as a significant outcome across all scenarios examined, attributable to prevailing economic conditions and potential upticks in inflation rates.
Henseler e Maisonnave (2018)	South Africa		Impact of reallocating subsidies from fossil fuels to public transportation sector	Both options discussed in the text bring benefits to the economy of South Africa. Early implementation of these reallocation options could enable the promotion and development of public transportation, in anticipation of global oil prices resurging. Thus, they could contribute to sustainable economic growth in South Africa.
Shao, Ye e Pan (2022)	China		How fuel taxes can serve as a policy tool to reduce CO2 emissions	Fuel taxes can serve as an effective policy tool to curb vehicular pollution and foster environmental sustainability. However, the levies on fuel exhibit divergent impacts across Beijing's economic sectors and industries. Elevated taxes on production and imports may precipitate stagflation, whereas heightened taxes on consumption could precipitate a downturn.
Proque, Betarelli Junior e Perobelli (2022)	Brazil		Effects of fuel tax and cross-subsidy in passenger transportation on income distribution and consumption	Reducing fuel taxes and implementing cross-subsidization in public transportation can have a positive impact on the Brazilian economy, boosting real GDP and alleviating income inequality. Additionally, the study underscores the significance of accounting for diverse income groups when assessing public policies concerning passenger transportation.

Source: Own elaboration.

Given the potential economic development impacts, studies have also focused on climate policies and alternative fuel production, such as biofuels. Chanthawong et al. (2020) analyzed the impact of biofuel policies on Thailand's economy, finding positive effects on production and employment in renewable energy-related sectors. Wianwiwat & Asafu-Adjaye (2013) investigated the macroeconomic and sectoral implications of biofuel promotion measures outlined in the Thai government's alternative energy development plan, concluding that biofuel development could enhance economic advancement and energy security without compromising food security.

The CGE methodology has also been employed to assess the impacts of fuel subsidies. Henseler & Maisonnave (2018) investigated the effect of reallocating subsidies from fossil fuels to the public transport sector in South Africa, concluding that such reallocations could benefit the economy by promoting public transportation and preempting global oil price increases, thus contributing to sustainable growth. In Iran, Rahiminia et al. (2015) examined the effects of redirecting fuel subsidies, revealing stagflation and potential inflation rate increases induced by the policy. AlShehabi (2012) analyzed the effects of phasing out crude oil and fuel subsidies on the labor market, concluding that merely redistributing additional income to households was insufficient to address policy distortions, whereas directing income toward investments could improve the labor market in the long term.

Moreover, some studies focus on tax policies related to fuels. In Brazil, Proque et al. (2022) used dynamic CGE methodology to evaluate the effects of fuel taxation and cross-subsidization on income distribution and consumption, finding potential benefits for real GDP and income disparity mitigation. In China, Guo et al. (2014) investigated the impacts of a carbon tax on the economy and emissions. While Shao et al. (2022) explored fuel taxes as a policy tool to reduce vehicle pollution, finding that while effective, such taxes could lead to stagflation or economic depression depending on the tax structure.

The studies comprehensively address fuel-related policies, with an emphasis on disaggregated analysis by household groups. This approach allows for comparing the diverse impacts of these policies across different income strata, as well as evaluating the economic feasibility of these measures for less privileged socioeconomic groups. The computable general equilibrium model provides a consistent framework for analyzing new fuel policies, while also offering a comprehensive description of the economy, including the incorporation of an SAM that covers both direct and indirect effects of policy changes. In this regard, our study adopts a dynamic CGE model that enables exploration of potential changes in fuel policy, analyzing impacts in terms of macroeconomic, sectoral, greenhouse gas emissions, and household-related aspects.

In addition to this introduction, the article comprises three other sections. The second section presents the dynamic computable general equilibrium (CGE) model with the Social Accounting Matrix (SAM) and outlines the simulation designs for policy analysis. The third section discusses macroeconomic and sectoral projections. Finally, the fifth section summarizes the findings and highlights some policy implications for the Brazilian economy.

3. The CGE Model

The CGE model used in our study represents an extension of the conventional ORANIGRD model (Horridge, 2002) which incorporates a budget balance and flow of payments module into its theoretical and empirical framework. This module is integrated seamlessly via a Social

Accounting Matrix (SAM), derived from the input-output matrix and adhering to the principles of double-entry accounting. The demand of economic agents is modeled by a system of equations, assuming they are cost minimizers and price takers (Horridge, 2000, 2003). Economic sectors are structured into a production function that relates to the composition of manufactured products, demand for intermediate inputs, and factors of production, interconnected by sectoral activity levels. Producers' demand structure is represented by Leontief and CES-type functions, as evidenced by Dixon (1982)

In the first level of the production structure, industries produce one or more goods that combine intermediate inputs (X_i) and primary factors (V_i) in fixed proportions, defined by a Leontief function. At the second hierarchical level, each composite derives from a CES function. Using this function implies imperfect substitution between inputs or production factors due to their different characteristics Armington (1969), which depend on the relative prices of domestic (D) and imported (M) inputs. This applies to both production and investment. On the other hand, value added in production results from imperfect combinations of production factors: labor (T), land (L) and physical capital (K). The nested structure of production at two levels is defined by Betarelli Junior et al. (2020) as:

$$Z_i = min\left(\frac{X_i}{a_i^X}, \frac{V_i}{a_i^V}\right) \quad (1)$$

where $V_i = \left[\sum_{i=1}^{f} \delta_{f,i} V_{f,i}^{-\rho^V}\right]^{\frac{-1}{\rho^V}} \forall \quad f = (L, T, K)$ and $X_i = \left[\sum_{i=1}^{s} \delta_{s,i} X_{s,i}^{-\rho^X}\right]^{\frac{-1}{\rho^X}} \forall \quad s = (D, M)$.

The variable Z_i represents the product, the terms a_i^X and a_i^V represent the productive efficiency of each factor; X_i denotes intermediate inputs and V_i represents value added. The parameter δ satisfies $\sum_{i=1}^{f} \delta_{f,i} = 1$ or $\sum_{i=1}^{s} \delta_{s,i} = 1$ and ρ represents a substitution parameter between the factors X_i and V_i in the industry. The theoretical formulation is uniform across all sectors, with variations only in substitution elasticities and input and primary factor proportions (Betarelli Junior et al., 2020).This nested structure of two-level production is similar for investment demand in our model, that is, investors (I_i) combine inputs that minimize costs to create capital, but they don't directly use primary factors as inputs (Betarelli Junior et al., 2021). There is a link between investment and capital according to the dynamic mechanism of capital accumulation in each period $t + 1$ (Horridge, 2012):

$$K_{i,t+1} = (1 - \varphi_i)K_{i,t} + I_{i,t} \quad (2)$$

where $K_{i,t}$ is the quantity of capital stock available to sector *i* in period *t*, and ϕ_i is the rate of depreciation (constant over time). The base year quantity of capital stock is provided exogenously, and the calibration procedures are described in Betarelli Junior et al. (2020). According to Horridge (2012) and Chen (2019), investment allocation is defined by two basic rules:

$$G_i = \frac{I_{i,t}}{K_{i,t}} = F(E_i) \quad (3)$$

$$G_i = Q_i \cdot G_i^{Tend} \cdot \frac{(M_i)^{\xi_i}}{Q_i - 1 + (M_i)^{\xi_i}} \quad (4)$$

where in eq. (3), the investment/capital ratios or gross rate of capital growth in the next period are positively related to the expected rates of return (E_i); and in eq. (4), the expected rates of return converge to actual rates of return via a partial adjustment mechanism (Chen, 2019), with $M_i = E_i / R_i^{Normal}$, such that $R_{j,i}^{Normal}$ is the normal rate of return of capital for investor *i*; G_i^{Tend} is the growth trend of capital stocks, $Q_{j,i}$ is the (max/trend) investment/capital ratio; and ξ_i denotes the investment elasticity.

In our model, each household h maximizes utility subject to a budget constraint. The utility is derived from a Klein-Rubin function (Klein & Rubin, 1947), non-homothetic or quasi-homothetic, which separates a fixed portion of subsistence spending (Z_i^{Sub}) and a residual portion of "luxury spending" $(Z_i - Z_i^{Sub})$ rises (Betarelli Junior et al., 2020; Burfisher, 2021), that is:

$$U(Z_1, \dots, Z_c) = \sum_{i=1}^{c} S_i^{Lux} \, ln(Z_i - Z_i^{Sub}) \quad (5)$$

where Z_i is the total demand for the good i and S_i^{Lux} denotes the share of this residual allocated to each luxury good relative to total luxury expenditure. The demand for luxury goods depends on the household income and the relative prices of goods, which affect the scale of the consumer's utility function. In this specification, only the demand quantities for goods that exceed subsistence levels change by the same proportion as income. Budget shares of subsistence goods increase when income falls and decrease when income rises. In this special case, in the household consumption basket it is possible to identify some inferior good, if it is still subsistence. Households also choose rationally between domestic and imported goods (CES function) (Betarelli Junior et al., 2020; Burfisher, 2021).

These changes in household incomes can impact the demand for transport in a different and disproportionate way, as it depends on the endogenous effects controlled by the LES specification. We add to this theoretical structure the possibility of substitution via price (CES) between private and public transport, as developed in the study of Proque et al. (2022) inspired by the theoretical structure of Bruvoll and Larsen (2004), Steininger et al. (2007), Kalinowska and Steininger (2009) and Kalinowska (2009). This CES function for transportation demand (Z_t) is determined as:

$$Z_t = \left[\sum_{i=1}^{k} \delta_{k,t} D_{k,t}^{-\rho^T}\right]^{\frac{-1}{\rho^T}} \forall \quad k = (Private, Public) \quad (6)$$

where ρ^T denotes the CES-distribution parameter in transport compound between private and public transport demand for each household h; and $\sum_{i=1}^{k} \delta_{k,t} = 1$.

We also include a carbon emission module in the theoretical structure of the model. In accordance with Monash Multi-Regional Forecasting Model (MMRF) of Adams et al. (2010), fuel-burning emissions are modeled as being directly proportional to fuel usage (i.e. industries and household). Therefore, the ordinary variation in tons of CO2 emitted from fuel use $(\Delta G_{e,\mathrm{u}})$ is defined as:

$$\Delta G_{e,\mathrm{u}} = 0.01 * g_{e,\mathrm{u}} * G_{e,\mathrm{u}} \quad (7)$$

where $g_{e,\mathrm{u}}$ is the percentage change in the quantity demanded of each fuel (e) by each user (u) and $G_{e,\mathrm{u}}$ is the volume of tons of CO2 emitted by burning fuel. There are eight types of fuel (e), such as firewood taken from forestry; coal extraction; aviation fuel; gasoline; fossil oil; diesel; ethanol and biofuel; and other refining products. In turn, users (u) are divided between 67 industries and households (Magalhães, 2013).

3.1. Data

The model's database is derived from the National Accounts System (SNA) for the year 2015 (IBGE, 2023). This database includes 127 commodities and 67 economic sectors, utilizing three primary factors for production: land, capital, and labor. For this study, behavioral parameters were calibrated according to Betarelli Junior et al. (2020, 2021). For example, the Armington elasticities were calibrated following Tourinho et al. (2007), while the Frisch parameter was calibrated with a value of -1.94, as per Almeida (2008). Expenditure elasticities were sourced from Hoffmann et al. (2010). Additionally, for recursive mechanisms, Betarelli Junior et al. (2020) applied a value of 4.8 for investment elasticity, as indicated by Perobelli (2004), and 0.66 for wage elasticity, following Gonzaga; Corseuil (2001). Furthermore, a steady-state growth rate of 2% is assumed, with a ratio of physical investments to the physical capital stock of 8.5%, resulting in a depreciation rate of approximately 6%.

The sectoral emissions data utilized in our study originates from the Greenhouse Gas Emissions Estimates System (SEEG, 2022). A comprehensive assessment of all emission sources is conducted, including Agriculture, Energy, Land Use Change, Industrial Processes, and Waste, mirroring the detailed approach found in emissions inventories. All emission sources are evaluated – Agriculture, Energy, Land-Use Change, Industrial Processes, and Waste – with the same level of detail found in emission inventories. The data also include Bunker emissions (international maritime and air transport). In 2015, the transport sector alone accounted for 10% of all emissions recorded in Brazil, while the energy sector contributed 21.59% of GHG emissions. This comprehensive dataset allows for disaggregation, enabling a more precise allocation of sectoral emissions by fuel use (Agriculture, Industry, and Waste).

4. Policy scenario settings

4.1. Business-as-usual (BAU) scenario

Our model is a dynamic recursive version and projects an economic scenario for Brazil until 2040 without any exogenous policy shock. This scenario is known as Business-as-usual" (BAU) or baseline. Between 2016 and 2021, exogenous projections in this scenario are derived from annual variations in macroeconomic indicators and population growth, as shown in SNA (IBGE, 2023). On the other hand, between 2023 and 2024, the Brazilian GDP growth rate will follow the steady state rate (2.2%), accompanied by an average annual population growth of 0.8%. This prospective information (2022 - 2040) is based on the forecast of the Brazilian government (Brasil, 2020) and the International Monetary Fund (IMF, 2023).

Moreover, the underlying premise is based on macroeconomic stability, ensured by the balance of trade relative to GDP and the influence of income on household expenditures. The scenario considers the end of the spending ceiling and the implementation of Complementary Law Proposal (CLP) 93/2023, known as the New Fiscal Framework, which manages the primary surplus with a margin of 0.25 percentage points. Article 9 of CLP establishes that from 2024 to 2027, real expenditure growth is limited to 70% of the real revenue variation, with expenditure increases ranging from 0.6% to 2.5% per year, even if revenue increases by 4% or more. Simulating changes in fuel prices is also expected to affect government revenue. To address this issue, we adopt the balanced budget hypothesis. The adoption of this hypothesis implies that government demand is determined by tax revenue. Additionally, we use the exchange rate as our numeraire.

4.2. Policy scenario

Within the recursive dynamic model, we simulated the change in the market price of diesel and domestic gasoline with the extinction of International Price Parity (IPP) in 2023. To accommodate this policy change by Petrobras, the market prices of these two fossil fuels were determined exogenously, while the powers of tax rate are adjusted according to the new market price (i.e. price-oriented model). When we make this swap of exogenous variable in the policy closure (i.e. tax power for market price), tax revenue will decrease in accordance with the cut in the tax base caused by the reduction in the market price of fuels directly involved with Petrobrás' policy change. The end of the IPP represented a reduction of 12.8% in the average selling price of diesel (BRL 0.44 per liter) and 12.6% in gasoline (BRL 0.40 per liter) in 2023.

This policy change is significant for a few reasons. First, the volume of gasoline and diesel are the most produced and consumed fuels in the Brazilian economy. According to Brazil's National Agency for Petroleum, Natural Gas and Biofuels (ANP, 2024), from 2015 to 2024, the proportion of gasoline production in Brazil ranged from 20.13% to 24.83% of the total fuel output. In the same period, diesel production varied between 38.04% and 41.75%. Together, they account for more than 60% of the crude oil refined in the country. Second, Petrobras refineries are responsible for more than 92% of domestic production in the country. Third, in relation to the total supply of these two types of fuels, around 58.28% are demanded as inputs in the production process of economic sectors, 28.52% are consumed by families, and none are exported. and 13.2% are exported (IBGE, 2023).

The Brazilian fuel market is characterized by a diverse range of fuels, including gasoline, ethanol, natural gas, and diesel. In response to the oil crises of the 1970s and 1980s, Brazil initiated efforts to reduce reliance on fossil fuels and promote biofuels, notably through Proalcool, establishing the country as the second largest global producer of biofuels (Khanna et al., 2016; OECD & FAO, 2022). Despite these advancements, Brazil remains dependent on fossil fuels, with gasoline and diesel comprising approximately 60% of total fuel sales volume, while ethanol reached a peak of 16% between 2015 and 2023 (ANP, 2024). Although oil production has increased by 140% since 2000 (ANP, 2024), this expansion has not been sufficient for Brazil to achieve fuel self-sufficiency, resulting in a rising reliance on imports. Brazil's fuel import levels have exhibited annual fluctuations, with gasoline imports fluctuating from 9.60% in 2015 to 8.89% in 2024, peaking at 12.56% in 2017 and 13.95% in 2020. Concurrently, diesel imports increased from 26.98% in 2015 to 37.96% in 2024, showing consistent growth except for a slight decline in 2021 (ANP, 2024).

These recent statistics denote that any change in Petrobras' pricing policy that results in cheaper gasoline and diesel tends to generate significant and widespread effects in several markets in the Brazilian economy. Sectors that are more intensive in the use of these fossil fuels would tend to grow relatively more with lower prices, wealthier families would use private transport more, but economic growth would occur at a cost to the environment, that is, the volume of carbon emissions. would increase. In the next section we will explore the effects of this policy in relation to the Business-as-usual" (BAU) scenario.

5. Results

Our study analyzes the impact of ending the IPP policy on the Brazilian economy. The results are in terms of the accumulated deviations (%) caused by the policy of reducing gasoline and diesel prices on aggregate macroeconomic variables. This direct reduction in consumption costs and final demand in the economy would lead to a decrease in fuel costs, spreading systematically through economic channels and promoting a generalized reduction in internal costs and prices, known as the price effect. The overall price reduction would boost demand in various markets, increasing real income for household and the competitiveness of domestic products, both domestically and internationally. This would result in higher production, raising remuneration for primary factors and generating additional revenue for the public budget. Which could offset part of the decline in tax revenue, reducing the need for government spending adjustments to maintain budget balance.

According to Table 2, the implicit GDP deflator, which reflects internal costs and prices, would decrease compared to the baseline scenario of the Brazilian economy by 2040 (business-as-usual). However, in the year the policy ends, 2023, the market price drop was consistent with shock values in the simulation. This resulted in a more intense transmission of fuel price reduction in economic transactions, amplifying the activity effect with increased production and remuneration for primary factors. If the activity effect outweighs the price effect, the GDP deflator will have a positive deviation from the baseline scenario. In the short term, we observe this effect; however, in the long term, the deflator would show a negative trend, suggesting an increase in competitiveness of domestic products.

The policy would promote a gradual increase in GDP, with an accumulated addition of about 0.64% by 2040 compared to the baseline scenario. As observed in Graph 1, the GDP growth would be driven primarily by capital, followed by labor from an income perspective. In the short term, the impact of capital would be limited but would increase after 2030 due to rising investments between 2023 and 2025. From the expenditure perspective, changes in GDP would be primarily driven by household consumption and investment, while initially, negative variations are related to a trade deficit. Thus, it is noted that the outcome on household consumption would be positive for all years of the policy. By 2040, household consumption would show a positive variation of 0.84% compared to the baseline scenario.

The reduction in domestic fuel prices would boost Brazilian exports due to increased competitiveness in the global market. This would result in a surplus in the trade balance by 2040, with a 1.17% increase compared to the counterfactual scenario. Furthermore, the activity effect could be observed in the labor market, where policies would stimulate employment above the trend level. This is because, as the capital stock lags behind current investments by one-year, economic activity expansion primarily occurs through additional hiring in the year of policy implementation. Demand expansion induces increases in nominal wages in the economy, leading to higher production costs.

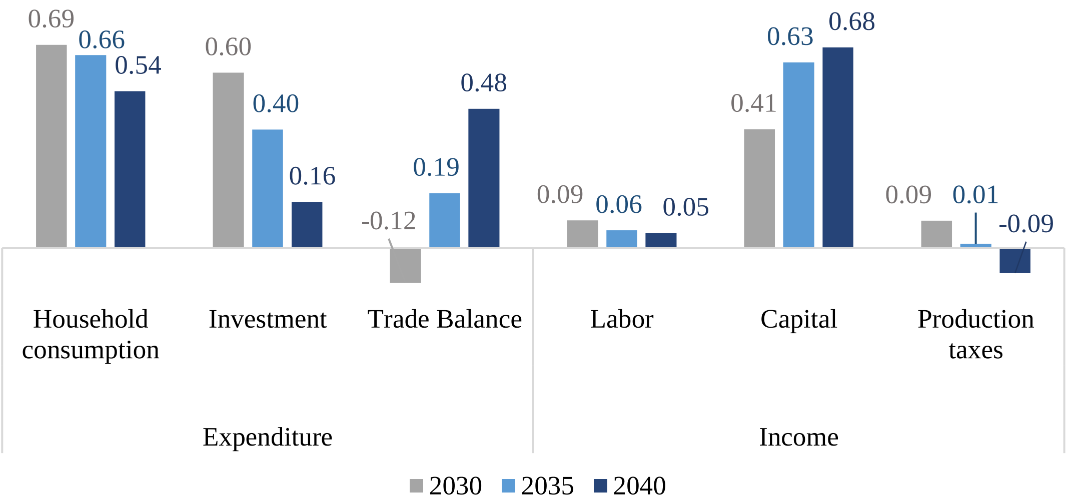
Table 2 – Effects of policy on the main macroeconomic variables (BAU = 2023)

Variables	Unit	2030	2035	2040
GDP	Var.%	0,55	0,67	0,64
Investment	Var.%	2,83	1,88	0,53
Household consumption	Var.%	1,14	1,07	0,84
Household utility	Var.%	2,31	2,11	1,64
Aggregate employment	Var.%	0,13	-0,01	-0,08
Real wages	Var.%	1,24	1,38	1,18
Capital stock	Var.%	0,77	1,25	1,34
Total government income	Var.%	-0,12	-1,59	-2,41
Total government expenditure	Var.%	-0,50	-1,92	-0,76
Government tax revenue	Var.%	-1,37	-2,71	-3,46
GDP deflator	Var.%	0,33	-1,32	-2,12
Terms of trade	Var.%	0,14	-0,90	-1,44
Exports	Var.%	-0,17	0,95	1,56
Imports	Var.%	1,25	0,75	0,40
Balance of trade	Var.%	-1,42	0,20	1,17
Total taxes	Var. BRL Bi.	-15,23	-25,77	-28,81

Source: Research results.
Note: *accumulated % deviation from the base scenario.

However, the increase in employment in the initial period influences wages at a later stage. In the trajectories of real wages, expansions indicate an increase in labor costs per unit produced, discouraging demand for labor in subsequent years. Nonetheless, negative deviations in real wages would again stimulate employment. In the long term, the activity effect is partially offset by increases in real wages. This is because workers have more bargaining power when labor demand is high. The rise in real wages, in turn, increases production costs, which can lead to reduced labor demand. Thus, there is an explicit lagged adjustment mechanism in the labor market, where there is a negative relationship between employment and real wages, resulting in the convergence of current national employment to the trend (Proque, 2019). We can observe that the policy instrument would have a positive impact on real wages with a variation of 1.18% compared to the reference wage, while employment would decrease by 0.08% in 2040.

Graph 1 – Effects of policy on the composition of GDP from two sides (BAU = 2023)



Source: Research results.
Note: *accumulated % deviation from the base scenario.

Investments, on the other hand, would experience a higher growth rate in the short term (2.83% by 2030) due to increased capital supply, while capital stock growth would only be observed in the long term. However, government tax revenue would decrease by 2040 due to reduced fuel prices and consequently, the tax base. By 2030, there would be a reduction of BRL 15.23 billion in total revenue, while by 2040, this loss would widen to BRL 28.81 billion. This reduction in revenue would lead to a decrease in public spending, affecting long-term economic activity.

Moreover, the end of the IPP policy would bring about changes in economic sectors. Table 3 shows how production and employment are impacted in eight major sectors, with details for the fifteen products with the largest production variations. The simulation suggests a positive impact on the agricultural sector, as the reduction in fuel prices would lower production costs, making agricultural products more competitive in the international market. This could boost exports of agricultural products, which represent about 15% of Brazilian exports. Production in the food sector would increase by 1.08% by 2040, while the extractive industry, especially in oil and natural gas, would see growth of 2.20% compared to the reference scenario. The capital goods sector, including extraction machines, would also experience growth, notably with a 1.74% increase by 2040.

Table 3 – Sectoral effects of the policy instrument (BAU = 2023)

Sectors	2030	2035	2040
Production			
Agriculture	0,36	0,97	1,31
Extractive industry	0,84	1,54	1,98
Oil, natural gas and support services	1,98	2,22	2,20
Mineral coal	1,08	1,65	1,80
Iron ore	0,71	1,40	1,73
Foodstuffs	0,56	0,93	1,08
Consumer goods	0,54	0,70	0,65
Durable consumer goods	1,48	1,13	0,59
Intermediate goods	1,19	1,54	1,61
Gasoline[5]	5,52	5,55	5,34
Other oil refining products	1,99	2,30	2,26
Aviation fuels	1,42	1,97	2,07
Diesel	1,22	1,46	1,50
Ethanol and other biofuels	1,44	1,55	1,49
Capital goods	1,10	1,37	1,33
Extraction machinery	2,09	2,13	1,74
Services	0,47	0,51	0,39
Water transport	0,84	1,62	2,08
Metro rail	2,06	2,20	2,16
Collective road transport	2,09	2,22	2,17
Munic. and metropolitan passenger road transport	1,96	2,08	2,02
Pipeline transportation	1,23	1,55	1,69
Road freight transportation	0,96	1,16	1,16
Employment			
Agriculture	0,55	1,04	1,35
Extractive industry	0,94	1,43	1,49
Foodstuffs	0,60	0,79	0,89
Consumer goods	0,59	0,54	0,44
Durable consumer goods	1,52	1,05	0,51
Intermediate goods	1,18	1,15	1,07
Capital goods	1,23	1,38	1,23
Services	-0,09	-0,30	-0,40

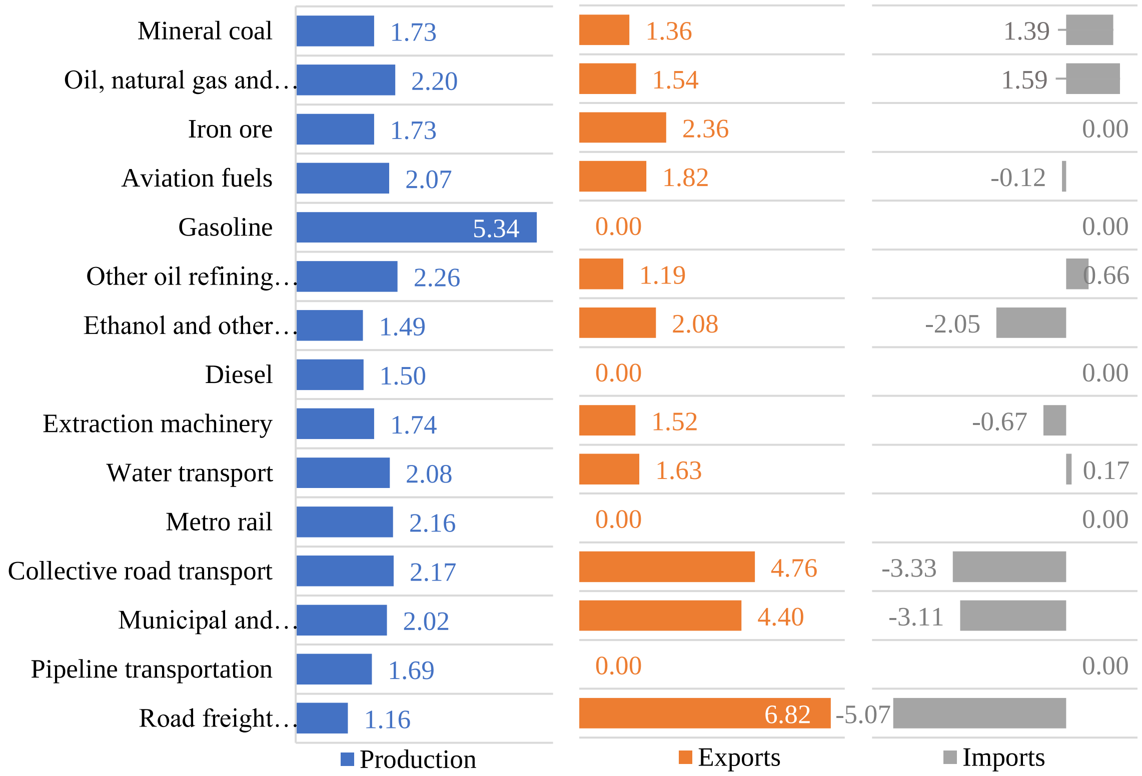
Source: Research results.

[5] Gasoline refers to the standardized blend of pure gasoline and anhydrous ethanol, according to the regulatory standards established in Brazil to meet vehicle performance and environmental requirements.

On the other hand, the reduction in fuel prices would directly impact the intermediate goods sector, resulting in increased production of these goods. By 2040, gasoline would show a variation of 5.34%, while diesel would increase by 1.50%. However, the services sector would have lower production growth, with a variation of just 0.39%, being the only one with a negative impact on employment. Additionally, transport sectors would be positively impacted, with three long-term favored sectors: collective road transport (positive variation of 2.17%), metro-rail transport (2.16%), and pipeline transport (1.69%).

Graph 2 presents the cumulative variations of the policy on production, export, and import. Overall, we can conclude that the policy of reducing fuel demand prices has contributed to the industrialization process of the Brazilian economy, diversifying the export agenda by increasing the share of manufactured goods and mitigating the trend towards primary production and specialization in the short term, a concern that has been recurrent in the debate on the country's productive structure in the last 10 years. For instance, this diagnosis had already been made by the Greater Brazil Plan 2011-2014 (GBP), which foresaw the implementation of export tax breaks to counteract the increase in imports and the decline in competitiveness of the industrial sector, whose context indicated deindustrialization of the economy. The industrial sector in the country is strategic for several reasons. Firstly, its higher capital intensity allows for greater potential for production gains due to the absorption of technology incorporated into new machinery and equipment. Secondly, industrial activities are seen as a key source of innovations for the productivity of other sectors, despite the growth of certain services as sources of innovation. Finally, this type of sector is traditionally perceived as a source of higher-quality jobs with lower turnover, which enables the development of specific human capital with a positive impact on productivity (Messa, 2015).

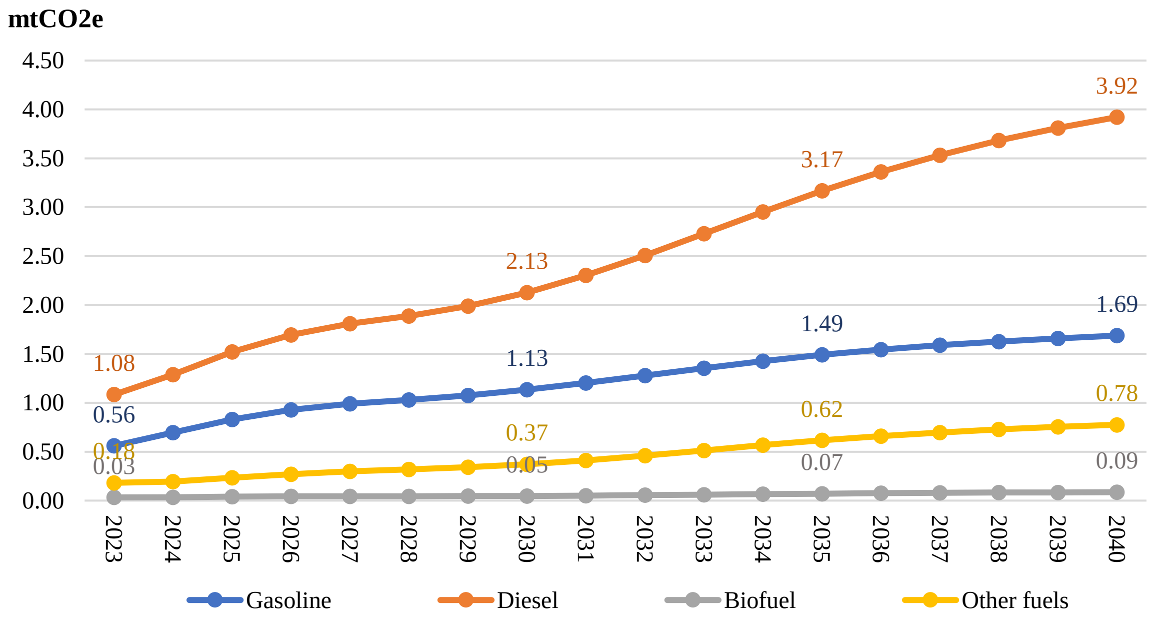
Graph 2 – Cumulative impacts on sector indicators in 2040 (BAU = 2023)



Source: Research results.
Note: *accumulated % deviation from the base scenario.

On the other hand, the increase in production and demand for fossil fuels, given the end of the IPP policy, would result in significant increases in emissions of the three main fuels: other fuels – aviation fuel and fuel oil – (2.461%), biofuel (1.701%) and diesel (1.501%). The incentive to fossil fuels led to higher emissions, with diesel being responsible for 3.92 Million Tonnes of CO2 Equivalent (mtCO2e), followed by gasoline (1.69 mtCO2e) and other fuels[6] (0.78 mtCO2). Therefore, the policy would not be able to reduce emissions, mainly due to the increase in demand for gasoline and diesel. It is important to note that the emissions analyzed in this section are only from use, i.e., the burning of fuels by demand. However, in summary, the incentive to fuels resulted in an increase in Greenhouse Gas Emissions (GGE) due to increased demand.

Graph 3 – Variations in GGE emissions by type of fuel burned (BAU = 2023)



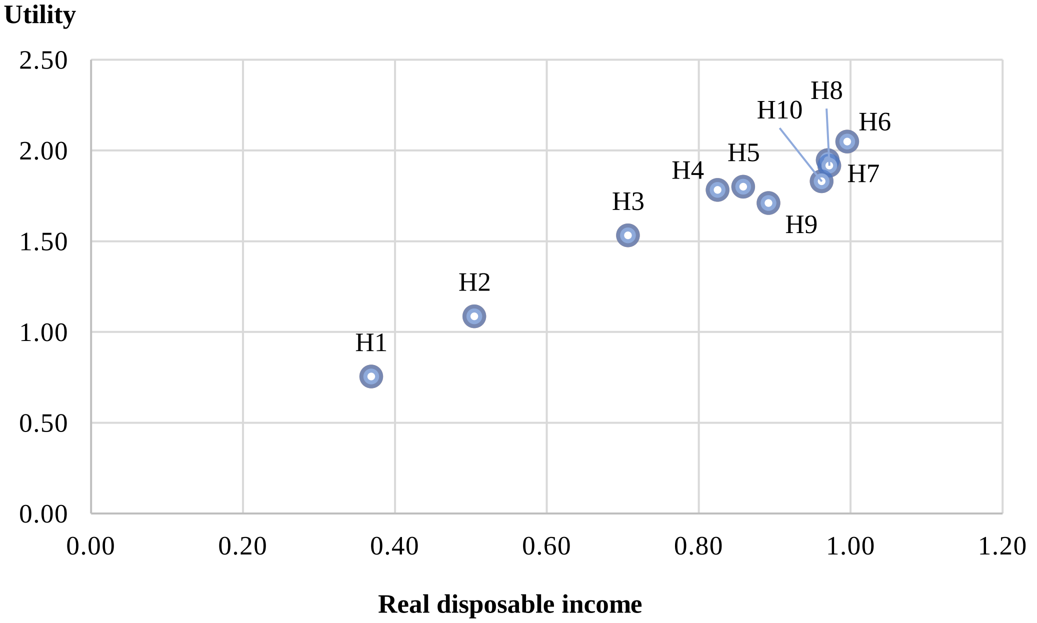
Source: Research results.

Finally, the end of the International Price Parity (IPP) policy would have effects on typical household in the Brazilian economy. Graph 4 illustrates the aggregate effects on real income for household, revealing real gains across all income range and the utility of household. It is expected that wealthier household would tend to use more fuel for private transport, while poorer ones rely more on public transportation, which primarily consumes diesel and biofuels. However, a decrease in diesel prices also raises the cost of food as the machinery used for production, as well as the transport of these inputs, is directly dependent on diesel. Thus, when there is an increase in fuel prices, this cost is passed on to the population. However, the policy instrument would lead to an increase of 2.73% in the real income of less privileged household by the year 2030, and 1.58% by 2040. On the other hand, household representing the middle and upper classes (H4-H10) would benefit the most from the IPP. This can be explained by the fact that they are the main owners of cars and trucks, which typically consume more gasoline and diesel for private transportation. In 2030, middle-income household would see a real income increase of 4.96%, and 3.65% by 2040. Higher-income household, on the other hand, would experience a 3.51% increase in real income by 2030 and 2.83% by 2040. From this perspective, it can be inferred that the policy in question will not lead to an improvement in

[6] Other fuels represent the sum of emissions from aviation fuels and fuel oil.

income deconcentration, as it is mainly middle-class household that receive the greatest benefits.

Graph 4 – Cumulative impacts on real household income and utility (2040)



Source: Research results.
Note: *accumulated % deviation from the base scenario.

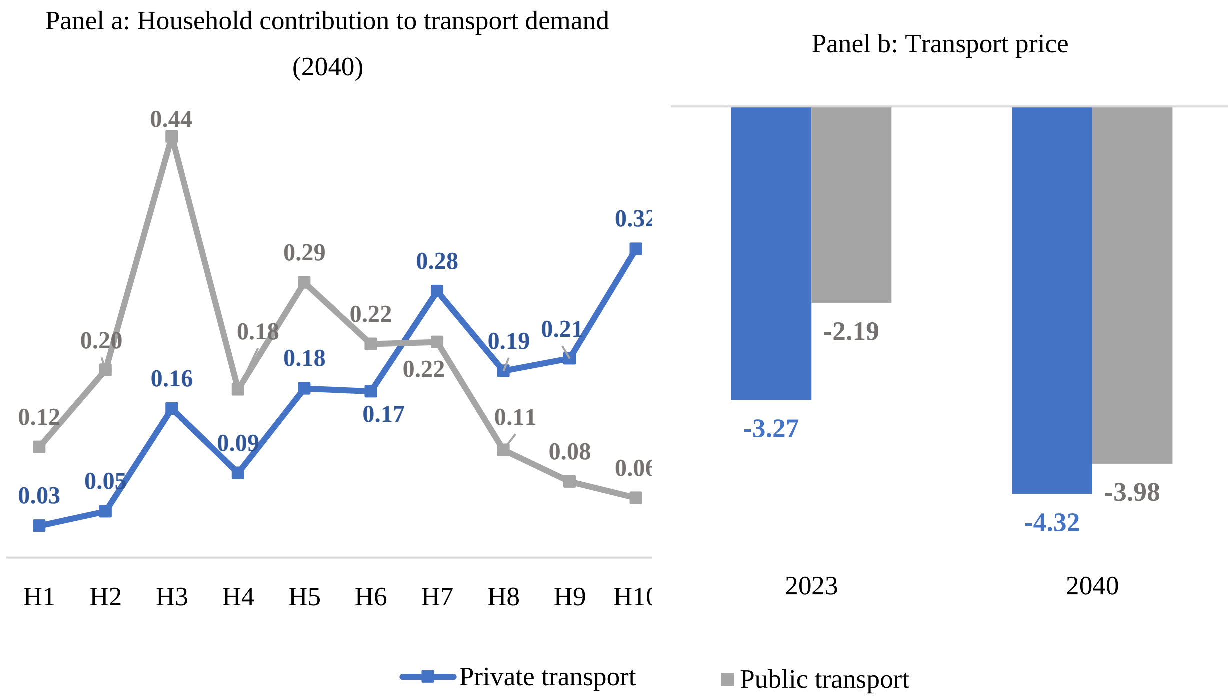
According to the Linear Expenditure System (LES) specification, expanding the consumption set increases the level of utility[7] for household, so changes in fuel prices associated with the policy would enhance the well-being of all household groups. Utility would be higher in 2030 with a variation of 2.31% compared to the reference scenario and would remain positive until 2040 (1.64%). In other words, the policy of reducing gasoline and diesel prices would produce a gain in well-being for the Brazilian economy. It is noted that household with incomes from H6 to H10 would have significant gains in utility and real disposable income, with an average increase of about 2% by 2040. Conversely, lower-income household (H1-H3) would experience the smallest increase in well-being.

These changes in household incomes can disproportionately affect transportation demand, especially due to endogenous effects controlled by the LES specification. We can observe that the demand for both public and private transportation per household would increase compared to the reference scenario due to the end of the IPP, which directly influences gasoline and diesel prices. However, even with the increased demand for private transportation, low and middle-income household show a relative increase in demand for public transportation. Panel a of Figure 1 shows that middle-low-income household (H3, H5, H7, H4) contributed more to the

[7] Traditionally, there are two ways to analyze welfare in CGE models: equivalent variation or changes in household utility. Equivalent variation is calculated based on changes in nominal variables in monetary terms, which depends on the price and quantity trajectories. This poses a problem in a recursive dynamic CGE model like ours. Operationally, we would have to construct a comparative static exercise within a dynamic model. To avoid errors in calculating the welfare effect, we chose to use the utility variable as a reference for welfare effects on households (Betarelli et al., 2021).

growth in demand for public transportation, while wealthier household (H10, H7, H9, H8) were primarily responsible for the increase in demand for private transportation.

Figure 1 – Effect of policy on private and public transport



Source: Research results.
Note: *accumulated % deviation from the base scenario.

The Figure 1b demonstrates the projections of average prices reduction in both public and private transportation due to the analyzed policy. The simulation indicates a significant decrease in public transportation prices, with a negative variation of 4% by 2040. Between 2023 and 2040, there would be a decreasing trend in public transportation prices. Making public transportation even more attractive in the long run. However, the policy would result in a more pronounced and persistent reduction in private transportation prices compared to public transportation. In summary, the end of the policy would stimulate demand for both modes of transportation due to the decrease in prices in the household consumption set.

6. Conclusion and policy implications

Our study aims to provide insights into the short-, medium-, and long-term effects of specific fuel price change policies on the Brazilian economy. There is limited emphasis in the ongoing debate and scant academic exploration on how these policies impact the economy considering the transmission of effects through established production and demand channels within the productive system, as well as the interactions among a country's economic institutions. Price adjustment policy instruments for fuels impact relative price structures, production operations (especially in fuel-intensive sectors), typical household consumption sets across income strata, and the income and payment flows among economic institutions (i.e., companies, households, and the public sector). However, beyond altering production scale, demand, income, and payments, fuel price changes affect carbon dioxide (CO_2) emissions volume, derived both directly and indirectly from fuel combustion and sectoral activity levels. Certain fuel price change policies in Brazil are expected to favor economic growth and international trade but may also negatively impact public budget revenues, generate redistributive and income concentration effects, while increasing CO_2 emissions into the atmosphere. The benefits of such policies must be weighed against their costs.

Projections of these economic effects can aid in discussions of current and future fuel price change policies, whether stemming from tax rate adjustments or indirect changes in the tax base. This study, unique in its approach, aims to fill this critical gap in fuel price policy discussions by projecting economic effects up to 2040. To address this research focus, we evaluated the International Price Parity (IPP) policy, which ended in 2023 and directly impacted gasoline and diesel prices. Recent policies in the country have reduced market prices for certain fuels. Our analysis of the fuel sector underscores Brazil's economic dependence on these resources. Thus, our article stands out by addressing recent debates on fuel policies, which continue to have repercussions in the economy, while also examining changes in CO_2 emissions resulting from these measures, contributing to the understanding of sectoral policies' interactions and economic ramifications.

To answer the research question, we employed a Dynamic Recursive Computable General Equilibrium (DRE) model, which incorporates a tax module derived from a Social Accounting Matrix (SAM) and a CO_2 emissions module into its theoretical framework. This approach facilitates the analysis of current taxes and future projections, offering a robust and comprehensive methodological framework for analyzing the economic and sectoral impacts of fuel policies. The findings reveal significant effects of the policy's end on various macroeconomic variables. Firstly, the direct decrease in fuel prices would lead to a reduction in consumption costs and final demand in the economy, spreading systematically through economic channels and promoting a generalized reduction in internal costs and prices. This would positively impact demand in several markets, boosting production, primary factor remuneration, and the competitiveness of domestic products in both domestic and external markets. Additionally, the policy would have positive impacts on the industrial sector, driving production in various segments such as agriculture, food, extractive industries, and capital goods. The service sector would show distinct variations in production and employment. In the short and long term, an increase in real income and utility of households could be observed, especially for those in the middle and upper classes who own most cars and pickups, consuming more gasoline and diesel for private transportation. However, it is safe to say that the end of the policy would not result in income deconcentration in the country. Furthermore, the increase in production and demand for fossil fuels would lead to an increase in greenhouse gas emissions, posing a challenge to environmental and sustainability policies.

The policy implications of these results are straightforward. The link between fuel prices, production costs, aggregate demand, and product competitiveness offers insights for discussing policies aimed at boosting specific sectors of the economy and fostering sustainable growth. However, these policies must align not only with economic goals but also with environmental and climate concerns. The rise in fuel demand due to lower prices can harm the environment, necessitating a cautious and balanced approach that prioritizes sustainability. Moreover, targeted industrial policies like tax incentives, research and development investments, and improved access to global markets are pivotal in bolstering key economic sectors. These dynamics also prompt pertinent discussions on fairness and income distribution, influencing the shaping of social policies such as benefit programs and public service access. Therefore, it is crucial to evaluate not only immediate impacts but also consider the long-term effects on economic sectors and the welfare of Brazilian households. A comprehensive analysis forms the basis for making informed political and strategic decisions that foster sustainable and equitable economic development.

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