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Abstract

We examine the macroeconomic effects of the energy transition, focusing on the impact of oil prices on GDP, productivity and inflation. We find that energy dependence on fossil fuels increases vulnerability to oil price shocks, negatively affecting Total Factor Productivity (TFP). Using the Solow decomposition and including energy as part of the capital stock, we find two key effects: The Price and Scale Effect, in which higher energy prices increase production costs and reduce TFP; and The Recomposition Effect, in which greater use of domestic renewables boosts TFP by reducing reliance on non-renewable imports. Our findings for Chile between 2001 and 2019 the TFP adjustment for energy factors provides a complementary and enriched view of productivity, especially in periods or contexts with high volatility in energy consumption or prices. Finally, using a New-Keynesian DSGE model calibrated for Chile, we examine the macroeconomic consequences of the energy transition. A counterfactual scenario shows that, without diversification of the energy matrix, the economic impact of higher oil prices would have been more severe, with larger GDP declines, higher inflation, tighter monetary policy, and a steeper fall in TFP, highlighting the benefits of Chile's shift to a more renewable energy matrix.

Keywords: DSGE Model, Aggregate Production Function, Monetary Policy, Environment and Growth, Energy Shocks.
JEL codes: C54, E230, E52, O44, Q430.

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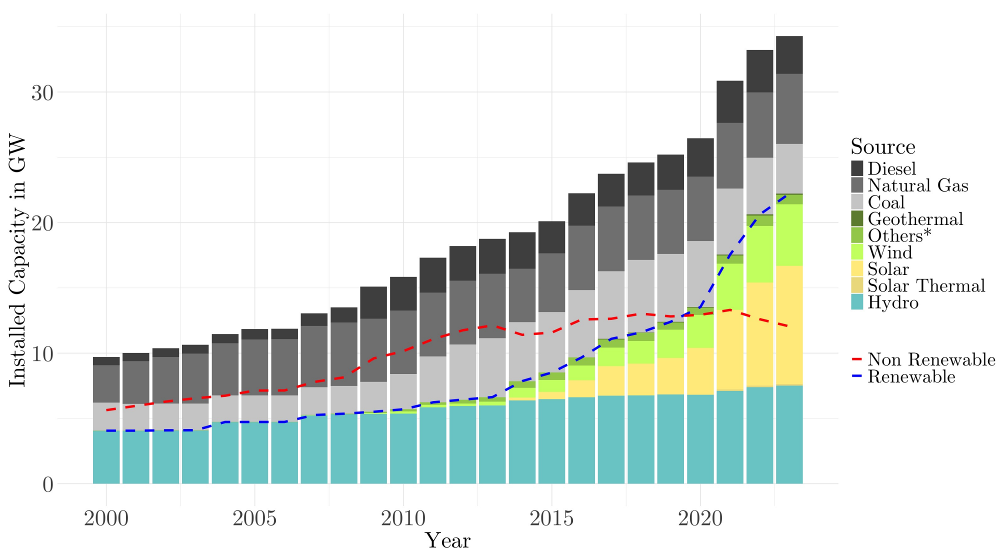
1 Introduction

Over the last decade, Chile has made significant strides towards renewable and non-polluting energy sources in pursuit of sustainability and environmental mitigation. The country has joined international agreements such as the Paris Agreement to achieve carbon neutrality. The transition to renewable energy offers significant benefits to both the planet and society. Chile's Ministry of Energy states in the Ministerio de Energía, Gobierno de Chile, 2022 plan that a national energy policy can help preserve biodiversity and the environment, improve air quality, promote equality, and encourage the development of renewable energy. This will lead to a more stable economy that will become less dependent on imported energy. According to Renewable Energy Policy Network for the 21st Century (REN21), 2015, the world experienced significant growth in renewable energy generation in 2014, with wind and solar energy leading the transition towards a more sustainable energy matrix. Chile also participated in this transition, with the government launching a tender in 2015 to supply electricity to regulated customers. Following Comisión Nacional de Energía, Gobierno de Chile, 2015, this process led to a reduction in pricing of almost 40% compared to the 2013 bid. Additionally, the participation of 38 new bidders and the introduction of non-conventional renewable energy (NCRE) into the Chilean energy market were significant achievements. This is an important milestone in the transition to a more sustainable and diversified energy system. See Figure 1.

Figure 1: Installed capacity by energy source (2000-2023)



Note: Own elaboration based on data from Histórico de Capacidad Instalada Total por Tecnología (2000), CEN.
The graph shows the installed capacity of energy sources in Chile from 2000-2023. Each bar represents cumulative gigawatt (GW) capacity for a specific source, as described in the legend. Dotted lines show time trends, with renewables in blue and non-renewables in red. The graph illustrates a steady increase in renewable energy capacity, indicating a shift toward cleaner, more sustainable energy sources. In contrast, non-renewable capacity generally declines over the same period.
Others* include fuel oil, biomass, biogas, cogeneration, petroleum coke, and the sum of SIC and SING capacity for years prior to 2017.

However, changing the supply of an energy matrix by investing in increased renewable energy production carries significant risks. According to Drudi et al., 2021, climate change poses significant physical risks, including extreme weather events such as heat waves, wildfires, floods, storms, droughts, and changing precipitation patterns. These disasters put financial institutions such as banks and investors at risk. On the other hand, there are transition risks, which involve the financial costs of shifting to a lower-carbon economy. These are the costs to businesses of adapting existing capital to production using new types of sustainable energy. This reallocation of productive resources is not instantaneous; it involves adjustment costs to replace equipment, train workers, and integrate new energy knowledge and production technologies. As noted in United Nations, 2015, these costs are estimated to exceed $830 billion per year worldwide.

World Bank, 2024 suggests that transitioning to sustainable energy sources may slow economic growth as countries reduce their reliance on fossil fuels. However, this shift can result in significant transition costs for economies, particularly in terms of infrastructure and technology. Fondo Monetario Internacional, 2022 predicts lower economic growth rates, especially in poorer regions that experience warmer climates. This could lead to higher costs for fossil fuel exporters and energy-intensive economies. Climate change may cause short-term fluctuations in output and inflation, which could lead to long-term macroeconomic volatility. This, in turn, could have lasting effects on relative prices and wages.

At the macroeconomic level, global warming poses ongoing challenges. Fondo Monetario Internacional, 2023 highlights the need to adjust monetary policy to keep inflation expectations anchored during the transition to cleaner electricity generation. Misaligned expectations could complicate the implementation of climate policies and create a dilemma between economic growth and inflation, both general and underlying. This could have significant macroeconomic implications, such as production losses and an increase in inflation. According to Banco Central de Chile (2020), the main objective of monetary policy is to guarantee price stability. When inflationary pressures align with economic activity, monetary policy becomes countercyclical, reducing the volatility of both inflation and gross domestic product (GDP). Thus, the loss of credibility in monetary policy could have significant costs, particularly in a high inflation context.

Given the pressing need to transition to an emission-free energy matrix, it is essential to evaluate the macroeconomic implications of the progress achieved so far. This study focuses on key questions: Do energy prices affect both GDP and productivity? Does the impact vary between domestically produced and imported energy? And what are the inflationary consequences of these changes? By addressing these questions, the analysis provides insights into the economic effects of the energy transition.

First, we review key trends in the global energy transition, focusing on investment in renewables and non-renewables between 2000 and 2021, and Chile's progress in solar, wind and hydro. The impact of Law 20.257 on Chile's non-conventional renewable energy (NCRE) generation is also highlighted, along with an assessment of non-renewable sources such as coal and natural gas. We then conduct an empirical analysis to explore the relationship between oil prices, TFP and the share of imported non-renewable energy. Using panel data regression, we assess how oil price fluctuations affect productivity globally and in Chile, showing that dependence on fossil fuels makes economies more vulnerable to external shocks.

Second, we analyze the impact of energy prices on productivity using the Solow decomposition, in which energy is treated both as part of the capital stock and as an intermediate input. Two effects emerge: the Price and Scale Effect, in which higher energy prices increase production costs and reduce TFP, and the Recomposition Effect, in which the use of more domestic renewable energy reduces reliance on non-renewable energy imports and boosts TFP. Our findings for Chile between 2001 and 2019 the TFP adjustment for energy factors provides a complementary and enriched view of productivity, especially in periods or contexts with high volatility in energy consumption or prices. This adjustment suggests that to fully understand the productive dynamics of an economy, it is relevant to consider the role of energy as an input in production. This highlights the role of energy transition policies in improving economic efficiency and resilience to energy shocks.

Finally, we develop a New-Keynesian DSGE model, calibrated for Chile to the year 2021, to assess the macroeconomic effects of the transition to a more renewable energy matrix. The results reveal that a 50% reduction in non-renewable energy imports mitigates inflation and economic contraction by reducing dependence on fossil fuels, leading to a faster recovery of the economy. In contrast, a counterfactual scenario based on Chile's energy mix in the early 2000s shows that maintaining a less diversified matrix would have had more severe macroeconomic repercussions. Specifically, the scenario predicts a steeper decline in GDP, higher inflation, tighter monetary policy, and a larger decline in TFP, underscoring the benefits of Chile's energy transition.

1.1 Related Literature

Several key studies address critical aspects of the green transition and renewable energy expansion. del Negro et al., 2023 challenges the notion that climate policies inevitably lead to higher inflation, emphasizing price flexibility in both "dirty" and "green" sectors, providing insights into potential trade-offs for euro area monetary policymakers. Additionally, De La Huerta and Luttini, 2017 quantifies Chile's economic growth sources, revealing potential misunderstandings in GDP calculations. Their findings show that mining adds 0.69% annually to value creation, while productivity and capital add 3.75%. Furthermore, Santos et al., 2018 develops a methodology linking production to capital, labor, and energy in Portugal, highlighting the importance of useful energy in economic growth. Their results suggest a causal relationship between energy and economic performance, indicating that useful energy contributes to economic growth without contradicting neoclassical assumptions.

By examining the impact of changes in energy prices on Chilean firms, Amann and Grover, 2023 analyzed the impact of changes in energy prices on Chilean firms. They found that increases in electricity prices reduce output and employment. On the other hand, increases in fossil fuel prices increase capital investment and output per worker. There were significant differences in the effects by firm size, ownership, and location. On the other hand, Gonzales et al., 2022 evaluated the expansion of renewable energy in Chile, highlighting positive results such as price convergence and the growth of renewable energy installations. Their study showed that market integration improved the efficiency of the electricity system, encouraged renewable generation, and reduced generating costs and emissions.

Several influential research studies have improved the understanding of key economic phenomena, such as the impact of environmental policies on macroeconomic stability and the relationship between energy prices and economic dynamics. In this area, Airaudo et al., 2022 examines the inflationary implications of the transition to a carbon-neutral economy and highlights the importance of strategic investments in renewable energy. With a DSGE model for Chile, they highlight short-term inflationary impacts and emphasize policies for sustainable energy transitions. Notably, rising conventional energy prices cause short-term inflation (8.6% in year two) and a 7.8% output recession in year three.

One of the most notable contributions of Aiyar and Dalgaard, 2004 is the introduction of a dual method for comparing TFP across countries, with particular attention to per capita income levels. Following Solow, 1957 and Barro, 1999, it finds that disparities in TFP are the main influence on income variations between countries, according to empirical results. Therefore, he shows that there is a notable difference between the dual and primary estimates of TFP using the Cobb-Douglas form. In this sense, Dhawan et al., 2010 examines the relationship between TFP, energy prices and the "great moderation". TFP volatility decreased due to lower impact of energy price changes after 1982, explaining 68% of output volatility reduction. However, the decline in energy share of GDP's contribution to the "Great Moderation" is minimal compared to the shift in the relationship between energy prices and TFP.

In a DSGE model for the US, Heutel, 2012 highlights the importance of adapting climate policies to business cycles. This can produce benefits similar to other environmental policies, but with different impacts on households and businesses. It finds that stricter policies can increase costs and reduce demand for carbon-intensive businesses. Finally, Annicchiarico and Di Dio, 2013 examines how different environmental policy approaches affect the economy, taking into account nominal and real uncertainty. It highlights the importance of mitigating a cap-and-trade system in the face of shocks, the role of nominal rigidities in volatility, the influence of price adjustment and monetary policy on the optimal response of environmental policy.

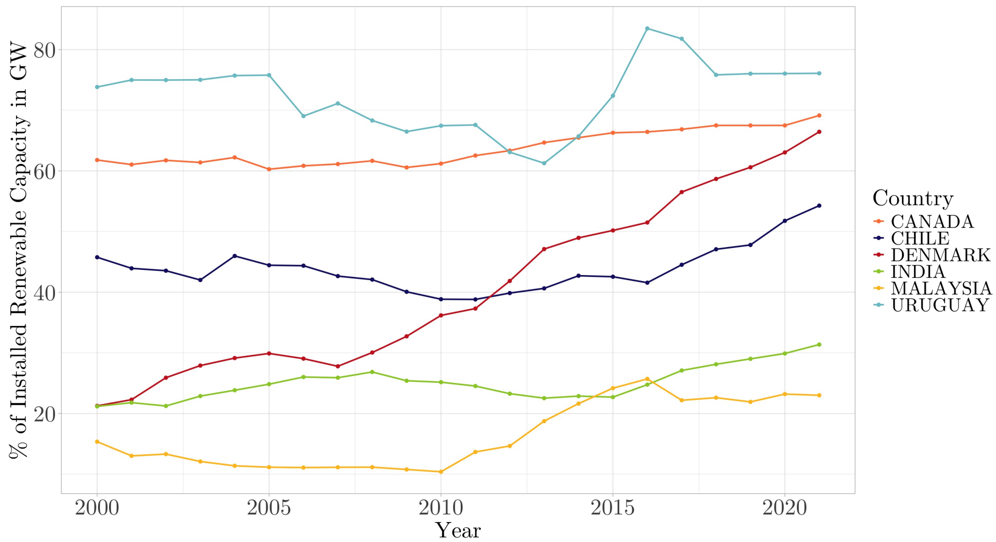
The paper is organized as follows. Section 2 outlines key aspects of Chile's energy transition. Section 3 examines how this transition impacts growth sources and reports estimated results. Section 4 details the Neo-Keynesian model. Section 5 discusses the calibration and model parameter estimation. Section 6 presents impulse response functions for counterfactual and current scenarios. Lastly, Section 7 concludes the paper.

2 Stylized Facts about Energy Transition

Investment in Renewable and Non-Renewables Energy Generation in the world

Between 2000 and 2021, an in-depth analysis was conducted on the generation and installed capacity of renewable energy in six countries: Canada, Chile, Denmark, India, Malaysia, and Uruguay. The analysis focuses on these six countries due to their distinctive geographical, climatic, and socioeconomic characteristics that influence the generation and installed capacity of renewable energy. Canada, for instance, is notable for its significant natural resources industry and potential for hydroelectric generation. Chile has a great potential for solar energy due to the geographical location and sunny climate. Denmark known for its leadership in renewable technology, is a pioneer in wind energy. India, with its vast land and growing energy needs, is focusing on diverse energy sources. Malaysia offers insights into renewable energy development in tropical regions, and Uruguay is notable for its comprehensive and successful renewable energy strategy, these countries represent important case studies for understanding how innovation and technology drive renewable energy adoption.

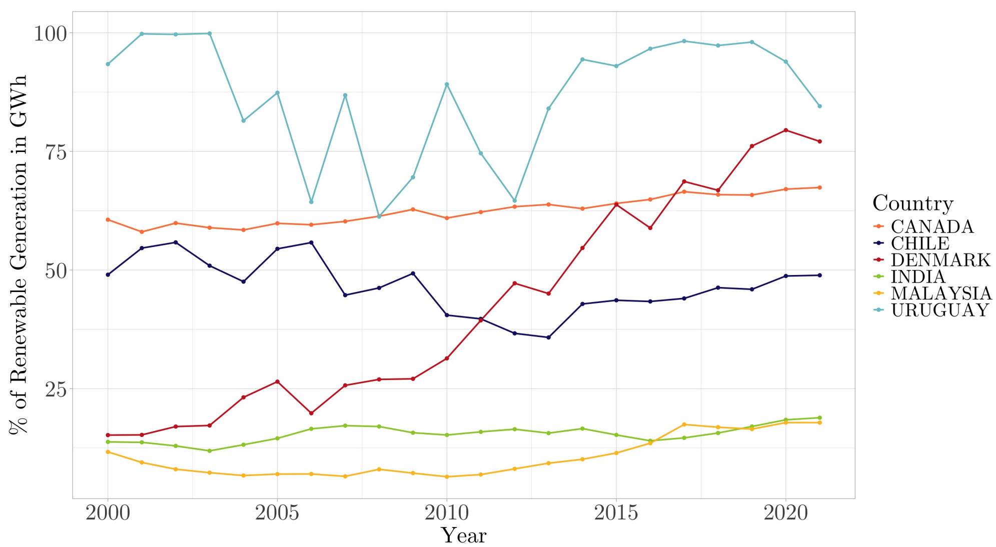
Figure 2: Installed Capacity of Renewable Energy in GW (2000-2021)



Note: Own elaboration based on data from IRENA (2023), Renewable Capacity Statistics 2023 and IRENA (2023), Renewable Energy Statistics 2023, The International Renewable Energy Agency, Abu Dhabi.
Installed capacity and Renewable Generation are in GigaWatt hour (GWh).

Figure 2 shows distinct trends and variations in the installed capacity of renewable energy as a percentage of total energy capacity across these six countries. Canada consistently shows a high percentage, maintaining a slow but consistent growth in the past years, reflecting its heavy reliance on hydroelectric power, with almost 70% in the 2021. The case of Denmark is outstanding, it started with a 15% in 2000, and finished with almost 70% in 2021, mainly driven by wind energy. Uruguay is also an interesting case, since early years it had over 70% of installed capacity, with some fluctuations but ending at a similar fraction. Chile has seen a significant growth in the past decade, nearing 55% by 2021, highlighting successful renewable energy policies and investments, like the ones already mentioned. India has seen different trends, with an increasing trend from 2015 onwards, indicative of its ongoing efforts to expand renewable energy infrastructure amidst rapid industrial growth. Malaysia, on the other hand, has relatively lower but increasing percentages, which suggests either slower adoption of renewable technologies or greater reliance on non-renewable sources. Overall, the plot shows that most countries have seen a recent increase in their percentage of renewable energy installation, driven by each country's unique characteristics and policy frameworks.

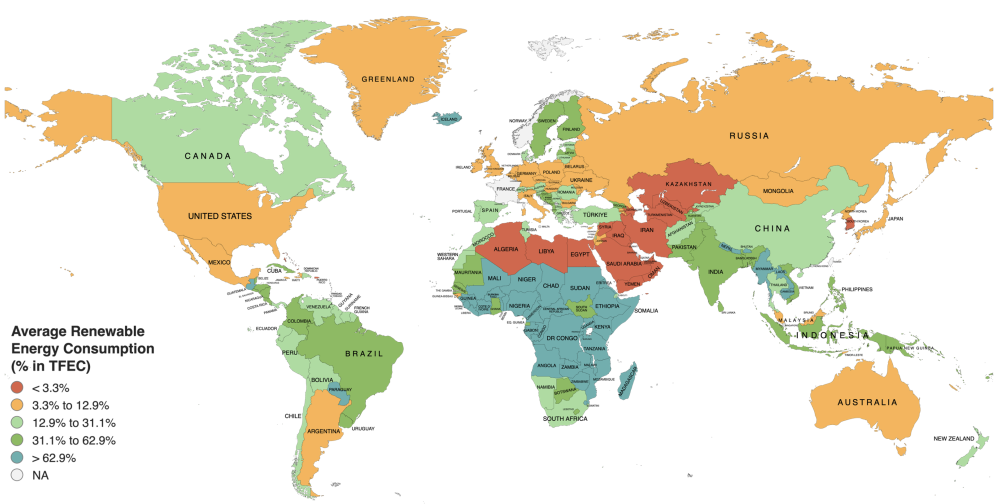
Figure 3: Generated Capacity of Renewable Energy in GWh (2000-2021)



Note: Own elaboration based on data from IRENA (2023), Renewable Capacity Statistics 2023 and IRENA (2023), Renewable Energy Statistics 2023, The International Renewable Energy Agency, Abu Dhabi.
Installed capacity and Renewable Generation are in GigaWatt hour (GWh).

In contrast, Figure 3 shows the Generated Capacity of Renewable Energy in GW per hour, which is a flow variable. Installed Capacity is a stock variable, in GW. If a country has more installed capacity than generated capacity, it is less efficient in producing renewable energies. It can be observed that Uruguay tends to have a higher generated capacity than installed, meaning that it is more efficient in producing renewable energy. On the other hand, Chile, India and Malaysia also have less generated than installed capacity in the past few years, indicating that they are less efficient in producing renewable energies. Denmark and Canada have relatively similar values of installed and generated capacity.

Figure 4: Average Renewable Energy Consumption as a Percentage of Total Final Energy Consumption (1996-2019)



Note: Own elaboration based on data from World Bank.

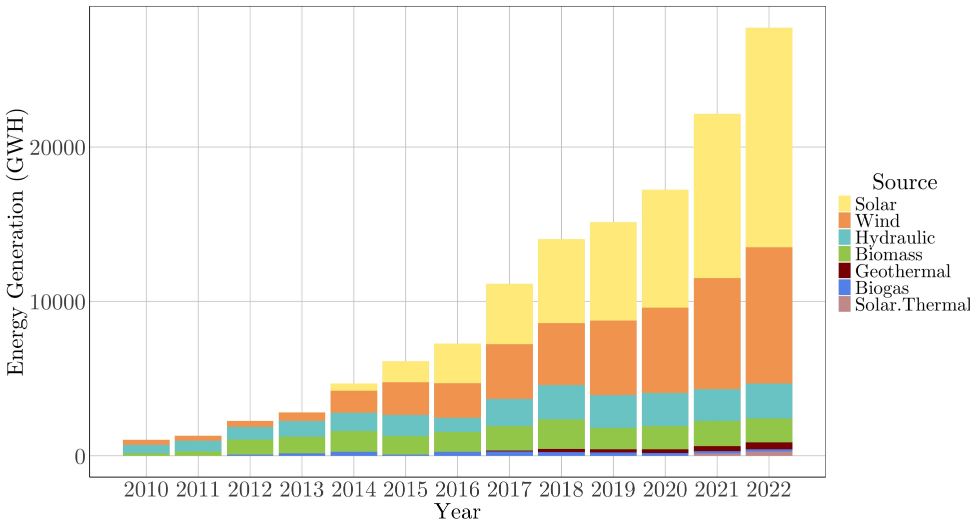
Figure 4 shows the change in renewable energy consumption as a percentage of total energy consumption between 1996 and 2019 globally. This percentage is calculated by dividing renewable energy consumption by total energy consumption (Renewable Energy Consumption/Total Energy Consumption) and then calculating its average from 1996 to 2019. Instead, Figure 2 illustrates the percentage of installed capacity dedicated to renewable energy in various countries during the same period. Although many countries are increasing their percentage of installed renewable energy capacity, as seen in Figure 2, the low average growth values of renewable energy consumption observed in Figure 4 can be attributed to several factors. Specifically, some countries may be increasing their total consumption of energy from other sources (the denominator of the ratio) at a faster rate than their consumption of renewable energy (the numerator). This can lead to a situation where, despite an increase in renewable energy generation and installation, the proportion of renewable energy within the total energy mix already decreases. This highlights the complexity of energy transitions, where increases in renewable energy capacity do not always directly translate into higher shares of renewable energy consumption.

Renewable Energy in Chile: Solar, Wind and Hydraulic

Since the enactment of Law 20.257 (República de Chile, 2008), Chile has experienced a significant boost in the incorporation of non-conventional renewable energies (NCRE) to its energy matrix. This legislation obliges electric companies to guarantee that a certain percentage of the energy marketed comes from renewable sources. The result has been a significant acceleration in the adoption of NCRE as an integral part of Chile's national energy policy, where greater competitiveness and an increase in economic exchanges between companies operating in the energy market are promoted. Subsequently, this legislation was adapted and, through Law 20.698 (República de Chile, 2013), the expansion of the energy matrix through NCRE was encouraged. The objective was to produce electricity from renewable resources. In this sense, producers are required to certify that a certain percentage of the energy consumed by their final customers corresponds to NCRE, establishing fines in case of non-compliance.

According to Comisión Nacional de Energía, Gobierno de Chile, 2015, after six years of implementing NCRE requirements, there is evidence of consistent compliance and significant contributions from plants. Some months in 2015 even saw requirements double or triple. This phenomenon highlights the rapid adoption and impact of non-conventional renewable energies in the Chilean energy sector, as shown in figure 5.

Figure 5: Generation of NCRE according to Law 20.257 (2010-2022)



Note: Own elaboration based on data from CEN-Generación Histórica de Energía por Tecnología, Coordinador.
Generation are in GigaWatt hour (GWh).
ERNC generation according to law 20.257.

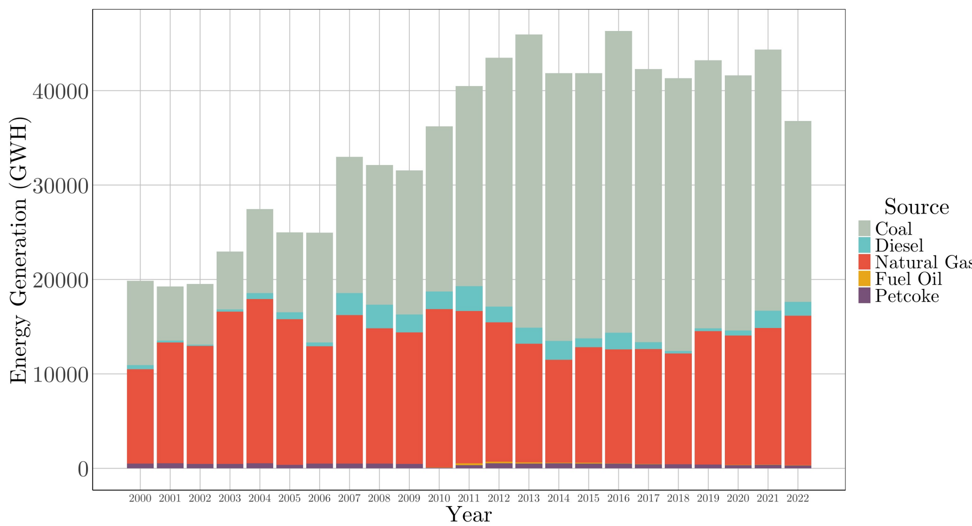
Solar energy is a significant non-conventional energy source in Chile, with a notable increase in generation since 2013. Between 2011 and 2022, there was a percentage increase, making it the primary contributor to the national energy matrix during this period. Its clean and sustainable nature makes it a relevant option to diversify the country's energy matrix, aligning with the objectives of supply security and environmental sustainability. Similarly, there was a notable increase in the production of wind energy and hydraulic energy during the same period. These results indicate a shift towards greater diversification and adoption of renewable energy sources in Chile, supported by policies and regulations aimed at promoting the transition to a more sustainable and resilient energy system.

There are significant changes in the composition of the energy matrix when analyzing the shares of hydro, wind and solar generation in Chile in 2011 and 2022. In 2011, the share of hydraulic generation in the total NCRE generation was about 53.77%, followed by wind energy with about 24.42%, while solar energy had no contribution to the energy landscape at that time. On the other hand, the distribution of NCRE generation will undergo a remarkable change by 2022. Hydraulic generation will experience a significant decrease in its share, representing only about 8.14% of the total, while wind energy will increase to about 31.84%. The most notable change is in solar energy generation, which becomes the main energy source in 2022, representing about 51.29% of total NCRE generation. These results show a significant shift towards renewable energy sources in Chile, with particular emphasis on wind and solar energy.

Non-Renewable Energy in Chile: Coal, Diesel and Natural Gas

Non-renewable energy sources have also played a significant role in Chile's energy landscape. These sources comprise fossil fuels, such as coal, diesel, and natural gas. Although they have historically provided a substantial portion of the country's energy needs, there has been a growing awareness of the environmental and sustainability issues associated with their use. Non-renewable energy sources continue to be a crucial part of Chile's energy mix, especially in meeting the demand for baseload electricity and maintaining grid stability. As is evident from the Figure 6.

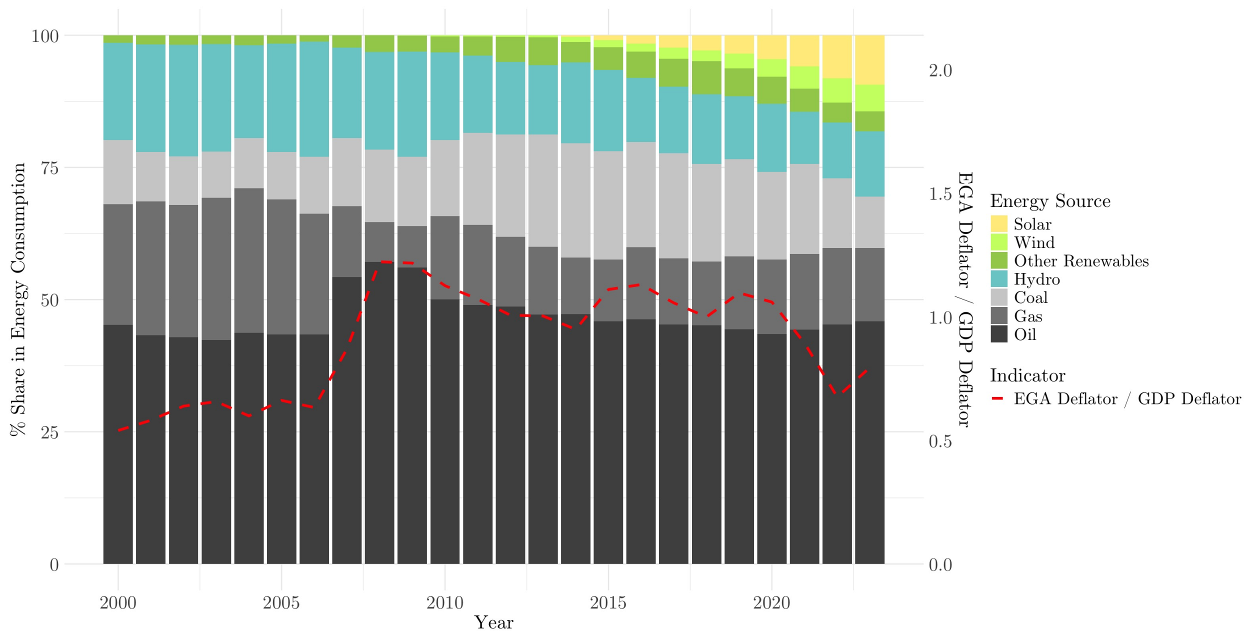
Figure 6: Generation by type of Non-Renewable technology in Chile's energy matrix (2000-2022)



Note: Own elaboration based on data from CEN-Generación Histórica de Energía por Tecnología, Coordinador.
Generation are in GigaWatt hour (GWh).
Annual gross energy generation.

Between 2000-2022, there was a increase in generation from Coal. The continued growth of Coal generation could have a negative impact on greenhouse gas emissions and air quality, leading to increased costs associated with pollution control. However, this trend shows signs of slowing down, as non-renewable energy generation decrease 31% in 2022 compared to 2021. Natural Gas has consistently accounted for an average of 43% of non-renewable energy generation from 2000 to 2022. In contrast, Diesel has had a relatively stable and low contribution, around 7%, throughout the period. Coal and natural gas play an important role in Chile's energy supply, and the country's energy matrix is complex.

Figure 7: Consumption Chile's energy matrix (2000-2023)



Note: Own elaboration based on data from Balance Nacional Energético.
Consumption are in TeraWatt hour (TWh).

Figure 7 illustrates the evolution of Chile's energy consumption matrix between 2000 and 2023, demonstrating a notable shift in the proportion of energy sources. Since 2010, there has been an increase in the utilisation of renewable energy sources, including solar, wind and others, which has occurred at the expense of fossil fuels such as coal, gas and oil. This reflects Chile's endeavours to diversify its energy matrix and reduce its reliance on non-renewable sources, in alignment with global energy transition policies. The EGA Deflator/GDP Deflator indicator (red dashed line) is used to illustrate the ratio between energy prices and the general price level. From 2007 onwards, the ratio increases, indicating an increase in energy costs due to fossil fuels. However, since 2010, with the growth of renewables, the indicator tends to stabilise or decline, suggesting a reduction in relative energy costs. This highlights the positive impact of the energy transition on economic competitiveness.

3 Empirical Analysis: Initial Insights on Macroeconomic Variables and TFP

A comprehensive analysis of the relationship between macroeconomic variables and total factor productivity (TFP) requires an initial description of the data employed in this study. The following section presents an overview of the data set, including sources, description of variables, and the time period covered.

Data

We use the World Development Indicators from World Bank, 2023, which provide a comprehensive time series of economic variables for 33 countries (excluding OPEP countries) from 1990 to 2019. Specifically, we use GDP in current U.S. dollars and the official exchange rate (LCU per US$, period average). Total factor productivity (TFP) is calculated using GDP growth rates, capital stock, labor input, and labor compensation's share in GDP, allowing for a comparative analysis of productivity trends across countries over the same period Feenstra et al., 2015. Additionally, we incorporate domestic oil end-user prices, expressed in constant 2015 USD and adjusted for purchasing power parity (PPP). This variable is derived from the average household prices of unleaded premium 95, premium 98, and regular gasoline, adjusted for inflation using the Consumer Price Index (CPI). The data is then converted to gigawatt-hours per U.S. dollar and further adjusted into local currencies via exchange rates, covering 35 countries from 1990 to 2019 IEA World Energy Prices database, 2023.

Exploring the Relationship Between TFP, and Energy Prices in Global Contexts

The energy transition, defined as the change from an energy matrix based on fossil fuels to one based on renewable energies, is a complex process with many economic implications. To better understand its implications, in this section, we examine the influence of oil prices and share of import energy on TFP. This initial analysis, conducted using panel data regression, allows us to elucidate how this external factor affect productivity at the global and Chilean reality. The joint consideration of this variable is crucial, as the oil price acts as a supply shock.

$$\textit{Log TFP}_{i,t} = \beta_0 + \beta_1 \textit{Log Oil Price}_{i,t} + \beta_2 \textit{Non-Renewable/Total Energy Ratio}_{i,t} + \alpha_i + \eta_t + \epsilon_{i,t} \quad (1)$$

Where $\textit{Log TFP}_{i,t}$ represents the logarithm of total factor productivity (TFP) for country i in year t. TFP is calculated as the logarithm of inflation-adjusted productivity relative to its level in 2017. $\textit{Log Oil Price}_{i,t}$ is the logarithm of the oil price for country i in year t. $\textit{Non-Renewable/Total Energy Ratio}_{i,t}$ represents the ratio of energy consumption from non-renewable sources to the total energy consumption for country i in year t, captures the proportion of energy derived from fossil fuels (such as coal, oil, and natural gas) relative to the total energy consumption, including both renewable and non-renewable sources. Finaly, α_i and η_t represent country and year fixed effects, respectively, and $\epsilon_{i,t}$ is the error term.

	Dependent variable: Log TFP					
	OLS		Panel Linear			
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.233***	-0.011				
	(0.065)	(0.198)				
Log Oil Price	-0.041**	-0.047***	-0.018	-0.025	-0.060***	-0.053***
	(0.015)	(0.015)	(0.020)	(0.015)	(0.022)	(0.020)
Non-Renewable/Total Energy Ratio		0.341		-1.171***		-0.896***
		(0.259)		(0.348)		(0.234)
Observations	25	25	543	543	543	543
R^2	0.258	0.310	0.011	0.203	0.138	0.253
Adjusted R^2	0.226	0.248	-0.054	0.149	0.027	0.154
Year FE	-	-	-	-	✓	✓
Country FE	-	-	✓	✓	✓	✓
Sample	Chile	Chile	All	All	All	All

*Note: Standard errors in parentheses are robust to heteroscedasticity. Statistical significance are *p<0.1; **p<0.05; ***p<0.01.*

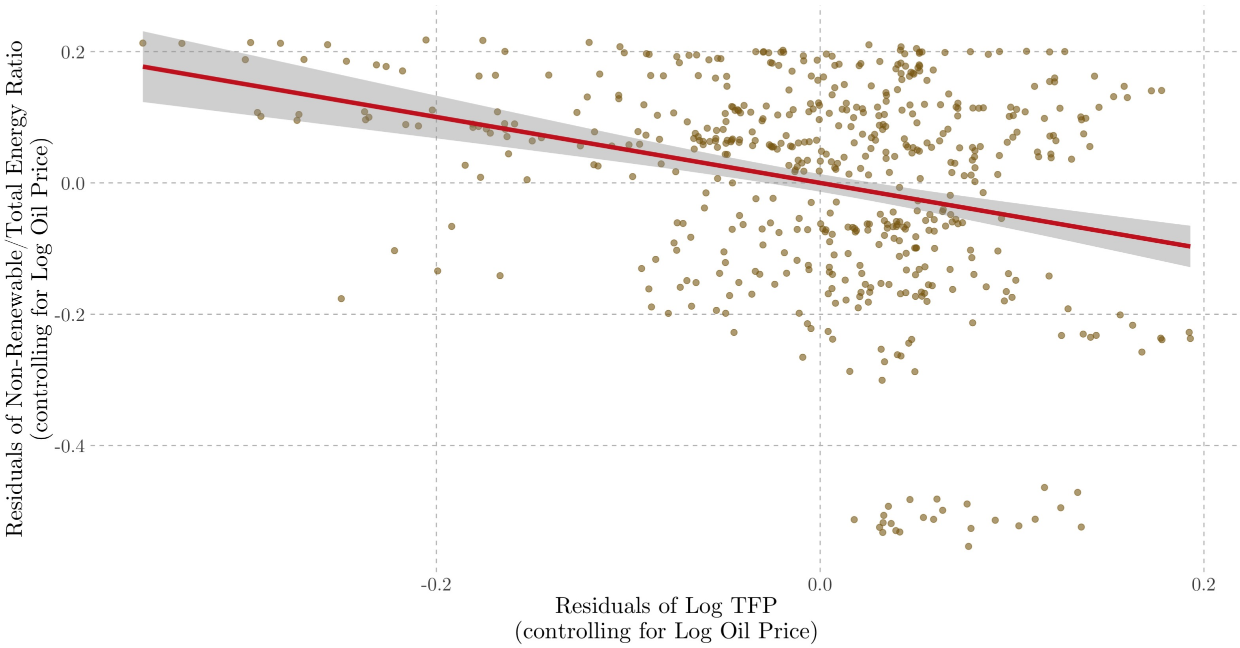
Consistent with the findings of higher energy costs reducing economic activity, as noted by Bertinatto et al. (2015), the results in the table show a negative and significant relationship between oil prices and Total Factor Productivity (TFP). Specifically, in column (2), a 1% increase in oil prices is associated with a 0.047% decrease in TFP, which is statistically significant at the 1% level. This suggests that higher oil prices increase production costs, reduce firms' efficiency, and ultimately lead to a decline in TFP.

In column (4), which includes country fixed effects, the coefficient for Non-Renewable/Total Energy Ratio shows a strongly negative and significant relationship with TFP. A 1-unit increase in the Non-Renewable/Total Energy Ratio is associated with a 1.171% decrease in TFP, significant at the 1% level. This suggests that economies that rely more heavily on non-renewable energy sources experience lower productivity, potentially due to the inefficiencies and environmental costs associated with such energy sources.

In column (6), which also controls for both country and year fixed effects, the coefficient for oil prices is again negative (-0.053) and statistically significant at the 1% level, confirming the robust negative impact of higher oil prices on TFP across different countries and time periods. Similarly, the Non-Renewable/Total Energy Ratio retains its negative relationship with TFP, with a 1-unit increase in the ratio leading to a 0.896% decrease in TFP, significant at the 1% level. This reinforces the conclusion that greater reliance on non-renewable energy sources is detrimental to productivity.

These results emphasize the significant influence of both oil prices and the Non-Renewable/Total Energy Ratio on TFP. Controlling for both country and year effects is essential to accurately capture the full extent of this relationship. The findings suggest that policies aimed at reducing reliance on non-renewable energy and stabilizing energy costs could have a considerable positive effect on productivity and economic efficiency.

Figure 8: Partial Correlation: Log TFP vs Non-Renewable/Total Energy Ratio



Note: The brown points represent the residuals of the regression between Log TFP and Non-Renewable/Total Energy Ratio, both controlled for Log Oil Price.
The red line represents the linear trend, indicating the negative relationship between the residuals, with a significant negative slope.
This suggests that as the Non-Renewable/Total Energy Ratio increases, the Log TFP tends to decrease, controlling for oil price effects.

The negative slope observed in Figure 8 indicates that an increase in total productivity (Log TFP) is associated with a decrease in non-renewable energy use (Non-Renewable/Total Energy Ratio), once the influence of oil prices is controlled for. In other words, an increase in the dependence of economies on non-renewable energy is associated with a decline in total factor productivity (Log TFP). This reflects an inverse relationship: higher non-renewable energy use is correlated with lower productivity, after controlling for the impact of oil prices (Log Oil Price). The graph demonstrates that a one-unit increase in the Non-Renewable/Total Energy Ratio is associated with a 0.5018-unit decrease in total productivity (Log TFP), after controlling for the price of oil.

Economic Growth and Energy Transition: The Role of Energy as an Intermediate Input

This section analyzes the impact of energy prices on economic productivity using the Solow decomposition. Energy is considered both as part of the capital stock and a direct input to productivity. We compare the efficiency of renewable (domestic) and non-renewable (import) energy sources, highlighting the implications of transitioning to cleaner energy.

In the context of the energy transition, it is crucial to understand how technological advancements and changes in energy usage impact economic production and wealth distribution. Energy plays a pivotal role not only as a final output but also as an intermediate input in production processes. As economies shift towards cleaner energy sources, understanding the non-linear interactions between energy and other production factors becomes essential for evaluating the broader economic effects of energy policies. Following the approach outlined by Finn (2000), we introduce a non-linear function $f(E_t)$ that affects the utilization of capital. This non-linearity captures the critical role energy plays as an intermediate input in production, emphasizing how energy efficiency and technological improvements can enhance productivity. The gross value of production is formulated as:

$$VB_t = F[A_t, (L_t)^\beta, (K_t^* \cdot f(E_t))^\alpha] \tag{2}$$

This equation represents the total production at a given time, where VB_t is the gross value of production, A_t is the available technology, K_t represents the aggregation of capital, L_t represents the labor input and E_t denotes the total energy input used.

We introduce VB_t as the gross value of production, modeled by a Cobb-Douglas production function that incorporates capital-labor with increasing returns to scale and the utilization of capital with energy with increasing returns to scale.

$$VB_t = A_{VB,t}(K_t^\alpha L_t^\beta E_t^\gamma), \quad \text{with} \quad \alpha + \beta + \gamma > 1 \quad \text{and} \quad A_{VB}, \alpha, \beta, \gamma > 0. \tag{3}$$

Here, $A_{VB,t}$ is the efficiency parameter that shifts the production function. α, β and γ characterize the relative weights of capital, labor and energy, respectively.

Maximization problem

The objective is to maximize the profits, defined as:

$$\max_{K_t, L_t, E_t} \pi : PVB_t \cdot VB_t - P_{K,t} \cdot K_t - P_{L,t} \cdot L_t - P_{E,t} \cdot E_t$$

Replacing equation 3,

$$\max_{K_t, L_t, E_t} : PVB_t \left(A_{VB,t} \cdot K_t^\alpha \cdot L_t^\beta \cdot E_t^\gamma \right) - P_{K,t} \cdot K_t - P_{L,t} \cdot L_t - P_{E,t} \cdot E_t$$

The first-order conditions are:

$$\frac{\partial \pi}{\partial K_t} : P_{VB,t} \cdot \alpha \cdot A_{VB,t} \cdot K_t^{\alpha-1} \cdot L_t^\beta \cdot E_t^\gamma - P_{K,t} = 0$$

$$\frac{\partial \pi}{\partial L_t} : P_{VB,t} \cdot \beta \cdot A_{VB,t} \cdot K_t^{\alpha} \cdot L_t^{\beta-1} \cdot E_t^\gamma - P_{L,t} = 0$$

$$\frac{\partial \pi}{\partial E_t} : P_{VB,t} \cdot \gamma \cdot A_{VB,t} \cdot K_t^{\alpha} \cdot L_t^\beta \cdot E_t^{\gamma-1} - P_{E,t} = 0$$

The gross value of production VB_t is defined as:

$$VB_t = A_{VB,t} \cdot K_t^\alpha \cdot L_t^\beta \cdot E_t^\gamma$$

Replacing the first order condition of energy E_t, we get:

$$VB_t = A_{VB,t} \cdot K_t^{\alpha} \cdot L_t^{\beta} \cdot \left(\frac{P_{VB,t} \cdot \gamma \cdot VB_t}{P_{E,t}} \right)^{\gamma} \tag{4}$$

In addition, the expression can be rearranged and simplified:

$$VB_t = A_{VB,t}^{\frac{1}{1-\gamma}} \cdot K_t^{\frac{\alpha}{1-\gamma}} \cdot L_t^{\frac{\beta}{1-\gamma}} \cdot \left(\gamma \cdot \frac{P_{VB,t}}{P_{E,t}} \right)^{\frac{\gamma}{1-\gamma}} \tag{5}$$

This equation provides a transformed perspective on VB_t, showing its composition in terms of productivity, factor inputs, and relative price dynamics that influence value added over time.

National accounts

If we assume that energy is imported, the formulation of real value added presents the following relationship:

$$VA_t = P_{VB,t} \cdot VB_t - P_{E,t} \cdot E_t \tag{6}$$

Where $(P_{A,t})$ represents the price of value added, (VA_t) denotes the nominal value added, $(P_{K,t})$ is the price of capital considered as numeraire, and $(P_{E,t})$ indicates the price of energy (E_t).

If we take as a reference the value added in a base year, and consider that the imported non-renewable energy component of the intermediate input constitutes only a fraction of what is used domestically in the country, denoted as $(1 - D_{e,t})$:

$$VA_t = P_{VB,0} \cdot VB_t - P_{E,0} \cdot E_t(1 - D_{e,t}) \tag{7}$$

Substituting the gross value from equation 5 and the first order condition of energy E_t, we get

$$VA_t = A_{VB,t}{}^{\frac{1}{1-\gamma}} \cdot K_t{}^{\frac{\alpha}{1-\gamma}} \cdot L_t{}^{\frac{\beta}{1-\gamma}} \cdot \left(\gamma \frac{P_{VB,t}}{P_{E,t}} \right)^{\frac{\gamma}{1-\gamma}} \cdot [P_{VB,0} - P_{E,0} \cdot (\gamma \frac{P_{VB,t}}{P_{E,t}})(1 - D_{e,t})] \tag{8}$$

Solow decomposition

To linearize and temporally derive the equation, we apply the natural logarithm to both sides and then differentiate with respect to time (t), where $\dot{x} = \frac{d \ln X}{dt}$. This notation denotes the derivative with respect to time t, representing the rate of change of variable x over time. Additionally, we define $\tilde{P_{e,t}} = \frac{P_{e,t}}{P_{vb,t}}$.

Thus, the log-linearization of equation 8 is:

$$\dot{va}_t = \frac{1}{1-\gamma} \dot{a_{vb,t}} + \frac{\alpha}{1-\gamma} \dot{k}_t + \frac{\beta}{1-\gamma} \dot{l}_t - \frac{\gamma}{1-\gamma} \left(\gamma \dot{\tilde{p_{e,t}}} \right) + \frac{\gamma \left[\frac{P_{e,0}}{\tilde{P_{e,t}}} \right] \left[\dot{d_{e,t}} + \frac{\dot{\tilde{p_{e,t}}}}{\tilde{P_{e,t}}} (1 - D_{e,t}) \right]}{\left[P_{vb,0} - \gamma \frac{P_{e,0}}{\tilde{P_{e,t}}} (1 - D_{e,t}) \right]} \tag{9}$$

This allows us to find the residual of total factor productivity is

$$\dot{a}_{vb,t} = (1-\gamma)\dot{va}_t - \alpha\dot{k}_t - \beta\dot{l}_t + \gamma\left(\gamma\dot{\tilde{p}}_{e,t}\right) - (1-\gamma)\frac{\gamma\left[\frac{P_{e,0}}{\tilde{P_{e,t}}}\right]\left[\dot{d_{e,t}} + \frac{\dot{p_{\tilde{e},t}}}{\tilde{P_{e,t}}}(1-D_{e,t})\right]}{\left[P_{vb,0} - \gamma\frac{P_{e,0}}{\tilde{P_{e,t}}}(1-D_{e,t})\right]} \tag{10}$$

The "narrow" total productivity residual is instead calculated as

$$\dot{a_{vb_\eta,t}} = \dot{va}_t - \alpha\dot{k}_t - \beta\dot{l}_t \tag{11}$$

Finally, the bias in the total factor productivity is the difference between the two measures:

$$\dot{a_{vb_\eta,t}} - \dot{a_{vb,t}} = \gamma\left(\dot{va}_t - \gamma\dot{\tilde{p}}_{e,t} + (1-\gamma)\frac{\left[\frac{\dot{p_{\tilde{e},t}}}{\tilde{P_{e,t}}}(1-D_{e,t}) + \dot{d_{e,t}}\right]}{\left[P_{vb,0}\left(\frac{P_{e,0}}{\tilde{P_{e,t}}}\right) - \gamma(1-D_{e,t})\right]}\right) \tag{12}$$

We identify two key effects related to energy prices and their impact on Total Factor Productivity (TFP). First, the price and scale effect: higher energy prices increase production costs, which directly reduces TFP. However, these higher prices can also reduce (non-renewable) energy imports, potentially boosting value added in the domestic economy, thus creating an apparent gain in TFP - although these forces act in opposite directions. Second, the Recomposition Effect: expanding the use of domestic (renewable) energy reduces dependence on imported (non-renewable) energy, contributing to an overall increase in TFP by promoting a more efficient and sustainable energy mix. This is consistent with the idea that excluding energy from GDP calculations may understate value added. Including energy as a factor has a direct impact on production costs and TFP, as demonstrated by Beltrán et al., 2024.

We calculate γ, which represents the relative weight of energy as an intermediate input for each year. This is measured by the electricity balance, defined as the sum of domestic electricity consumption and imported electricity, expressed in millions of Chilean pesos. This value is then divided by the nominal GDP, also in millions of Chilean pesos, for each year over the period from 2000 to 2019, as shown in Table 1.

$$\gamma_t = \frac{Electricity\ Balance_t}{Nominal\ GDP_t}$$

where t denotes each year in the period from 2000 to 2019. This calculation provides the annual proportion of energy as an intermediate input relative to the nominal GDP.

Table 1: Calibration of γ

Year	*Electricity Balance$_t$*	*Nominal GDP$_t$*	γ_t
2000	2,524,666	42,215,030	0.060
2001	2,834,430	45,409,055	0.062
2002	3,054,409	48,428,963	0.063
2003	3,319,895	52,897,339	0.063
2004	3,666,943	60,391,763	0.061
2005	4,389,803	68,467,940	0.064
2006	4,846,269	81,577,533	0.059

Year	*Electricity Balance*$_t$	*Nominal GDP*$_t$	γ_t
2007	7,515,818	90,159,479	0.083
2008	5,420,369	93,867,121	0.058
2009	4,600,644	96,138,477	0.048
2010	4,857,218	110,777,867	0.044
2011	5,345,422	121,509,299	0.044
2012	5,184,742	129,973,394	0.040
2013	3,781,843	137,309,192	0.028
2014	4,156,022	147,951,290	0.028
2015	4,860,744	158,622,903	0.031
2016	5,171,358	168,764,688	0.031
2017	5,260,923	179,314,910	0.029
2018	5,024,964	189,434,867	0.027
2019	5,413,847	195,531,722	0.028

Table 2 presents the calibration of the parameters used in the Solow decomposition model for Chile during the period 2001-2019. These parameters include variables related to energy prices, energy use intensity, and other factors influencing Total Factor Productivity (TFP). Key parameters include γ (elasticity of GDP with respect to total energy consumption), $\tilde{P}_{e,t}$ (change in energy price), and $\dot{d}_{e,t}$ (change in domestic (renewable) energy consumption). The calibrated values provide the basis for analyzing the evolution of productivity in Chile.

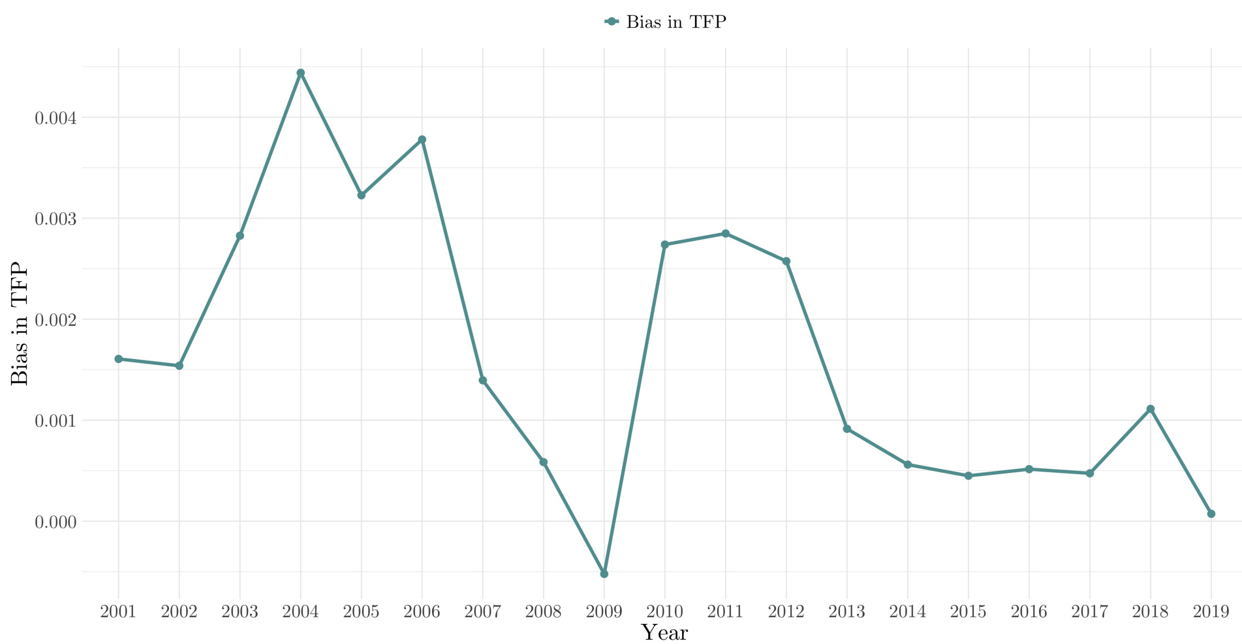
Table 2: Parameter Calibration

Year	γ	$\tilde{P_{e,t}}$	$\dot{\tilde{p}}_{e,t}$	$P_{e,0}$	$P_{vb,0}$	$D_{e,t}$	$\dot{d_{e,t}}$	$\dot{va_t}$	$\dot{a_{vb_\eta,t}} - \dot{a_{vb,t}}$
2001	0.062	0.582	0.076	100	100	69,084	0.136	0.032	0.00160
2002	0.063	0.639	0.099	100	100	73,385	0.062	0.032	0.00153
2003	0.063	0.657	0.029	100	100	70,983	-0.033	0.047	0.00282
2004	0.061	0.599	-0.088	100	100	66,924	-0.057	0.067	0.00443
2005	0.064	0.662	0.105	100	100	78,967	0.180	0.058	0.00322
2006	0.059	0.633	-0.043	100	100	84,871	0.075	0.060	0.00377
2007	0.083	0.871	0.376	100	100	71,792	-0.154	0.052	0.00139
2008	0.058	1.223	0.404	100	100	79,751	0.111	0.038	0.00058
2009	0.048	1.218	-0.004	100	100	81,366	0.020	-0.011	-0.00052
2010	0.044	1.126	-0.075	100	100	72,191	-0.113	0.059	0.00273
2011	0.044	1.072	-0.048	100	100	71,284	-0.013	0.062	0.00284
2012	0.040	1.007	-0.061	100	100	75,503	0.059	0.062	0.00257
2013	0.028	1.004	-0.003	100	100	77,773	0.030	0.033	0.00091
2014	0.028	0.950	-0.054	100	100	83,512	0.074	0.018	0.00056
2015	0.031	1.111	0.170	100	100	90,738	0.087	0.022	0.00044
2016	0.031	1.131	0.018	100	100	87,562	-0.035	0.018	0.00051
2017	0.029	1.057	-0.066	100	100	100,510	0.148	0.014	0.00047
2018	0.027	1.000	-0.054	100	100	113,950	0.134	0.040	0.00111

Year	γ	$\tilde{P_{e,t}}$	$\dot{\tilde{p}}_{e,t}$	$P_{e,0}$	$P_{vb,0}$	$D_{e,t}$	$\dot{d_{e,t}}$	$\dot{va}_t$	$\dot{a_{vb_\eta,t}} - \dot{a_{vb,t}}$
2019	0.028	1.097	0.097	100	100	111,212	-0.024	0.006	0.00007

Figure 9 shows the evolution of the TFP bias in Chile from 2001 to 2019, calculated using the parameters presented in Table 1 The figure highlights how changes in these parameters, especially those related to the energy balance and energy prices, have influenced TFP over time. Notable fluctuations are apparent, with peaks in 2004 and 2006, followed by a sharp decline in 2009. After 2013, the TFP bias shows some stability, with minor variations persisting throughout the following years. The results presented in Figure 9 offer insights into how changes in energy-related factors and other calibrated parameters have affected Chile's total productivity. Years with positive bias indicate higher-than-expected productivity, while years with negative bias suggest productivity below model projections, offering valuable information for evaluating the impact of energy policies on economic efficiency.

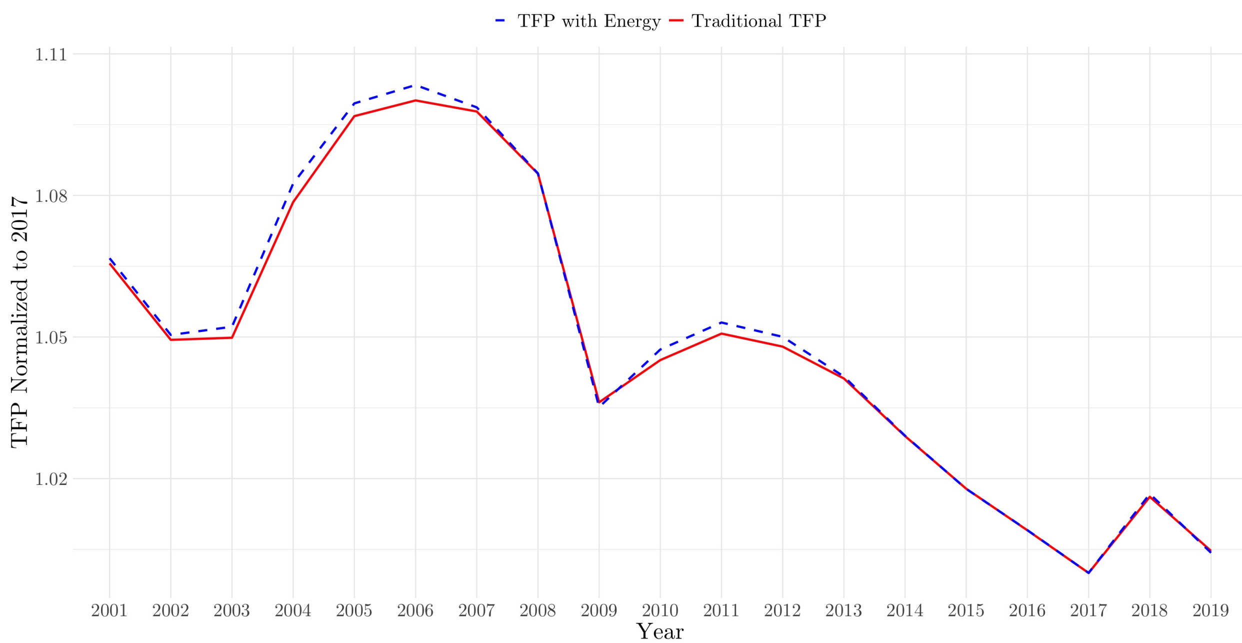
Figure 9: Evolution of TFP Bias in Chile (2001-2019)



Note: Own elaboration based on Solow decomposition model results.

Figure 10 compares the traditional TFP measure (red line) with the energy-adjusted TFP (blue dashed line) for the period 2001 to 2019, normalized to 2017. The energy-adjusted TFP incorporates fluctuations in energy consumption and prices, which the traditional TFP does not capture, leading to subtle but noticeable differences in certain periods. This adjustment accounts for the role of energy as an intermediate input, making the energy-adjusted TFP slightly more responsive to changes in energy demand and prices. While both lines generally follow similar trends, the energy-adjusted TFP occasionally shows higher peaks or deeper troughs, particularly in years with significant shifts in energy consumption relative to GDP. This additional sensitivity highlights the impact of energy dynamics on productivity, offering a more comprehensive perspective on economic efficiency, especially in energy-intensive contexts.

Figure 10: Comparison of Traditional TFP and TFP with Energy (2001-2019) normalized to 2017

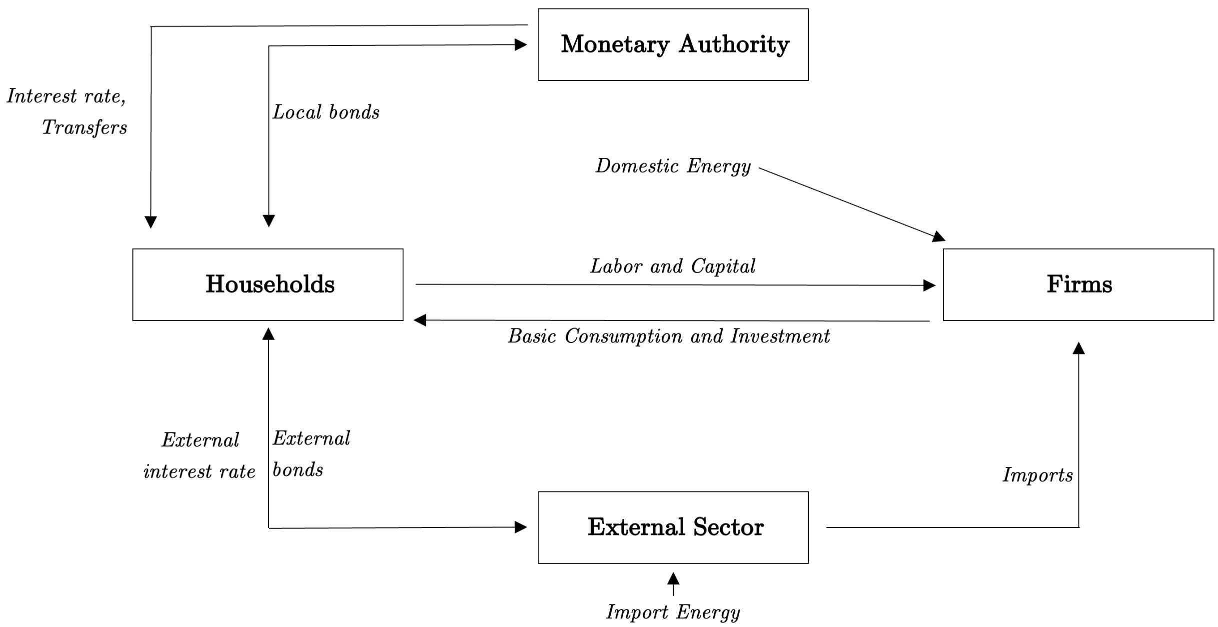


Note: Own elaboration based on Solow decomposition model results.
TFP with Energy are Traditional TFP + Bias in TFP.

4 The Model

We build a New-Keynesian DSGE model for a small open economy, following the framework of Airaudo et al., 2022, calibrated for Chile. The model incorporates energy as a productive input, the renewable energy ratio and fluctuations in natural resource prices to assess the energy transition in a comprehensive manner. The diagram in Figure 11 provides a simplified illustration of the model's structure, where households supply labor and capital to firms, engage in basic consumption and investment, and hold both local and external bonds, influenced by domestic and foreign interest rates. Firms, in turn, utilize labor, capital, and domestic energy in production, while also depending on imported energy. The monetary authority influences household decisions by setting interest rates and providing transfers, whereas the external sector supplies imported energy and external bonds, also affected by external interest rates. This configuration allows us to explicitly model the interactions between economic growth, total factor productivity, energy as an intermediate input, and household preferences, enabling an analysis of the potential macroeconomic consequences of transitioning to a more renewable energy matrix. Furthermore, this framework facilitates the evaluation of alternative policy scenarios, providing a robust foundation for designing strategies that promote energy sustainability while minimizing potential economic disruptions.

Figure 11: General diagram of The Model



4.1 Households

The preferences of households are represented by consumption C_t and labor effort h_t. The utility function is given by:

$$U_t = \mathbb{E}t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \psi_h \frac{h_t^{1+\sigma_h}}{1+\sigma_h} \right] \tag{13}$$

where C_t is consumption, h_t denotes the household's labor effort, σ is the coefficient of risk aversion, σ_h is the elasticity of labor disutility, β is the intertemporal discount factor, and ψ_h is the parameter for labor disutility.

The consumption bundle Z_t is given by a constant elasticity of substitution (CES) function, which consists of goods produced domestically (national goods) $Z_{H,t}$ and imported goods (foreign goods) $Z_{F,t}$:

$$Z_t = \left[\omega^{\frac{1}{\eta}} (Z_{H,t})^{\frac{\eta-1}{\eta}} + (1-\omega)^{\frac{1}{\eta}} (Z_{F,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{14}$$

where ω defines the proportion of national goods in the consumption bundle, and η is the elasticity of substitution between national and imported goods. In adittion, local consumption (Z_t) and investment (INV_t) are aggregated in C_t.

In each period, the household purchases a combination of domestic and imported goods with the objective of reducing the overall cost of the consumption basket. The household's cost minimization problem is:

$$\min_{Z_{H,t},Z_{F,t}} P_{H,t}Z_{H,t} + P_{F,t}Z_{F,t} \quad \text{subject to} \quad Z_t = \left[\omega^{\frac{1}{\eta}} (Z_{H,t})^{\frac{\eta-1}{\eta}} + (1-\omega)^{\frac{1}{\eta}} (Z_{F,t})^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{15}$$

where $P_{H,t}$ and $P_{F,t}$ are the prices of goods produced domestically and imported from foreign countries, respectively.

The first-order conditions with respect to $Z_{H,t}$ and $Z_{F,t}$ from the Lagrangian for this problem are written, respectively, as:

$$Z_{H,t} = \omega \left(\frac{\lambda_t}{P_{H,t}}\right)^{\eta} Z_t \tag{16}$$

$$Z_{F,t} = (1-\omega) \left(\frac{\lambda_t}{P_{F,t}}\right)^{\eta} Z_t \tag{17}$$

Substituting the first-order conditions into $P_t Z_t = P_{H,t}Z_{H,t} + P_{F,t}Z_{F,t}$ and solving for the Lagrange multiplier λ_t, we obtain:

$$\begin{aligned}
P_t Z_t &= P_{H,t}\omega \left(\frac{\lambda_t}{P_{H,t}}\right)^{\eta} Z_t + P_{F,t}(1-\omega)\left(\frac{\lambda_t}{P_{F,t}}\right)^{\eta} Z_t \\
P_t Z_t &= Z_t \lambda_t^{\eta} \left[\omega P_{H,t}^{1-\eta} + (1-\omega) P_{F,t}^{1-\eta}\right] \\
P_t &= \lambda_t^{\eta} \left[P_t\right]^{1-\eta} \\
P_t^{\eta} &= \lambda_t{}^{\eta} \\
P_t &= \lambda_t
\end{aligned}$$

Substituting for λ_t, we obtain the demand function for home and foreign goods, which the households use to allocate aggregate expenditure:

$$Z_{H,t} = \omega \left(\frac{P_{H,t}}{P_t}\right)^{-\eta} Z_t \tag{18}$$

$$Z_{F,t} = (1-\omega) \left(\frac{P_{F,t}}{P_t}\right)^{-\eta} Z_t \tag{19}$$

The capital accumulation equation for the households' physical capital stock is given by:

$$K_t = (1-\delta)K_{t-1} + \Phi\left(\frac{INV_t}{K_{t-1}}\right) K_{t-1} \tag{20}$$

where δ is the depreciation rate.

Households also face a budget constraint that covers consumption C_t, investment INV_t, domestic bonds B_t, and foreign bonds $\varepsilon_t D_{t-1} R^*_{t-1}$, where ε_t is the nominal exchange rate and R^*_{t-1} is the foreign interest rate. A quadratic adjustment cost $\frac{\Phi_D}{2}(D_t - \bar{d})^2$ penalizes deviations from a target level of external debt

$\bar{d}$. Household income includes wage income $w_t h_t$, returns on capital $R_t^k K_{t-1}$, where R_t^k is the rental rate of capital, foreign bond returns $\varepsilon_t D_t$, and payments on domestic bonds $R_{t-1}B_{t-1}$. Finally, T_t are transfers made by the government and Ω_t encompasses all profits of the firms in all sectors.

The household budget constraint is:

$$P_t C_t + P_t INV_t + B_t + \varepsilon_t D_{t-1} R^*_{t-1} + \varepsilon_t \frac{\Phi_D}{2}(D_t - \bar{d})^2 = W_t h_t + R_{t-1}B_{t-1} + \varepsilon_t D_t + +R_t^k K_{t-1} + T_t + \Omega_t \tag{21}$$

The optimality conditions that are generated from maximizing equation 13 subject to equation 20 and equation 21 are as follows

$$\lambda_t = C_t^{-\sigma} \tag{22}$$

$$\lambda_t = \frac{\psi_h {h_t}^{\sigma_h} P_t}{W_t} \tag{23}$$

$$1 = q_t \Phi' \left(\frac{INV_t}{K_{t-1}}\right) \tag{24}$$

$$\lambda_t q_t = \beta \mathbb{E}_t \left\{ \lambda_{t+1} \left(\frac{R_{t+1}^k}{P_{t+1}} + q_{t+1} \left((1-\delta) + \Phi\left(\frac{INV_{t+1}}{K_t}\right) - \Phi'\left(\frac{INV_{t+1}}{K_t}\right)\frac{INV_{t+1}}{K_t} \right) \right) \right\} \tag{25}$$

$$\lambda_t \left[1 - \Phi_D \left(D_t - \bar{d}\right)\right] \varepsilon_t = \beta \mathbb{E}_t \left[\lambda_{t+1} \varepsilon_{t+1} \frac{P_t}{P_{t+1}} R_t^*\right] \tag{26}$$

$$\lambda_t = \beta \mathbb{E}_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}} R_t\right] \tag{27}$$

4.2 Firms

There are two different types of firms in this economy. The final goods producers (in a perfectly competitive market), the intermediate goods producers (intermediate goods producers face Calvo's staggered pricing and operate in a monopolistically competitive market) and importing firms (in a perfectly competitive market with linear production function).

Final Goods Producers

The final goods producers supply both domestic and foreign markets, producing $Z_{H,t} + Y^*_{H,t}$ units of goods. These goods are produced by aggregating domestically produced intermediate varieties, as represented by the following CES production function:

$$Z_{H,t} + Y^*_{H,t} = \left(\int_0^1 Y_{H,t}(i)^{\frac{\epsilon_H - 1}{\epsilon_H}} \, di\right)^{\frac{\epsilon_H}{\epsilon_H - 1}} \tag{28}$$

where $Y_{H,t}(i)$ denotes the quantity of intermediate variety i, and ϵ_H is the elasticity of substitution between intermediate varieties.

The final goods producer operates in a perfectly competitive market, maximizing profits by solving the following problem:

$$\max_{Y_{H,t}(i)} P_{H,t}(Z_{H,t} + Y^*_{H,t}) - \int_0^1 P_{H,t}(i)Y_{H,t}(i)\, di \quad \text{subject to} \quad Z_{H,t} + Y^*_{H,t} = \left(\int_0^1 Y_{H,t}(i)^{\frac{\epsilon_H - 1}{\epsilon_H}}\, di\right)^{\frac{\epsilon_H}{\epsilon_H - 1}} \tag{29}$$

where $P_{H,t}(i)$ is the price of variety i. The producer takes the prices of intermediate goods $P_{H,t}(i)$ and the final good price $P_{H,t}$ as given.

The first-order condition is:

$$P_{H,t}\left(\int_0^1 Y_{H,t}(i)^{\frac{\epsilon_H - 1}{\epsilon_H}}\, di\right)^{\frac{\epsilon_H - 1}{\epsilon_H}} Y_{H,t}(i)^{-\frac{1}{\epsilon_H}} = P_{H,t}(i) \tag{30}$$

Solving for $Y_{H,t}(i)$ while using equation 28, results in the domestic demand function:

$$P_{H,t}\left(Z_{H,t} + Y^*_{H,t}\right) Y_{H,t}(i)^{-\frac{1}{\epsilon_H}} = P_{H,t}(i) \tag{31}$$

$$\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon_H}\left(Z_{H,t} + Y^*_{H,t}\right) = Y_{H,t}(i) \tag{32}$$

Intermediate Goods Producers

Intermediate goods producers are indexed by i along a continuum. Each producer has access to a production technology described by the following production function:

$$Y_{H,t}(i) = \left[A_t\left[(K_{t-1}(i))^{1-\alpha}(h_t(i))^{\alpha}\right]^{\frac{\epsilon-1}{\epsilon}} + A_{e,t}\left(e_t(i)\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \tag{33}$$

where $K_{t-1}(i)$, $h_t(i)$, and $e_t(i)$ represent the firm's rented inputs of physical capital, labor, and energy, respectively. The parameters A_t and $A_{e,t}$ capture the productivity of the capital-labor composite and energy inputs. Finally, ϵ denotes the elasticity of substitution between these composite inputs.

The production of energy is given by the following CES function:

$$e_t(i) = \left[(1-\xi)^{\frac{1}{\nu}}\left(e_{G,t}\right)^{\frac{\nu-1}{\nu}} + \xi^{\frac{1}{\nu}}\left(e_{B,t}\right)^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}, \tag{34}$$

where total energy production $e_t(i)$ is a combination of domestic energy (renewable) $e_{G,t}$ and import energy (non-renewable) $e_{B,t}$, with shares $1-\xi$ and ξ, respectively. In this expression, ξ is the share of import energy, and ν represents the elasticity of substitution between domestic and import energy.

The demand for domestic energy $e_{G,t}$ and import energy $e_{B,t}$ are:

$$\frac{P_{e_t}}{(1-\xi)}\left(\frac{e_t}{e_{G,t}}\right)^{1/v} = Pe_{G,t} \tag{35}$$

$$\frac{P_{e_t}}{\xi}\left(\frac{e_t}{e_{B,t}}\right)^{1/v} = Pe_{B,t} \tag{36}$$

This equation shows the relationship between total energy e_t, import energy $e_{B,t}$, domestic energy $e_{G,t}$ and their respective prices Pe_t, $Pe_{B,t}$ and $Pe_{G,t}$.

The aggregate energy price Pe_t, follows Calvo prices, and is determined as follows:

$$Pe_t = \left[\xi\left(Pe_{B,t}\right)^{1-v} + (1-\xi)\left(Pe_{G,t}\right)^{1-v}\right]^{1/(1-v)} \tag{37}$$

Firms face a two-stage optimization problem. In the first stage, taking input prices W_t and R_t^K as given, they rent $h_t(i)$ and $K_{t-1}(i)$ in perfectly competitive factor markets to minimize their real costs. The cost minimization problem can be expressed as:

$$\begin{aligned} \min_{h_t(i),K_{t-1}(i),e_t(i)} \quad & W_t h_t(i) + R_t^K K_{t-1}(i) + P_{e,t} e_t(i) \\ \text{subject to} \quad & Y_{H,t}(i) = \left[A_t\left((K_{t-1}(i))^{1-\alpha}(h_t(i))^{\alpha}\right)^{\frac{\epsilon-1}{\epsilon}} + A_{e,t}\left(e_t(i)\right)^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon}{\epsilon-1}} \end{aligned} \tag{38}$$

The first order conditions for this problem are:

$$W_t = MC_{H,t}A_t\left[\frac{Y_{H,t}(i)}{(K_{t-1}(i))^{1-\alpha}(h_t(i)^{\alpha}}\right]^{1/\epsilon}\alpha\left(\frac{K_{t-1}(i)}{h_t(i)}\right)^{1-\alpha} \tag{39}$$

$$R_t^K = MC_{H,t}A_t\left[\frac{Y_{H,t}(i)}{(K_{t-1}(i))^{1-\alpha}(h_t(i))^{\alpha}}\right]^{1/\epsilon}(1-\alpha)\left(\frac{h_{t(i)}}{K_{t-1}(i)}\right)^{\alpha} \tag{40}$$

$$Pe_t = MC_{H,t}A_{e,t}\left[\frac{Y_{H,t}(i)}{e_t(i)}\right]^{1/\epsilon} \tag{41}$$

In the second stage, intermediate goods producers set prices to maximise their discounted real profits. When adjusting prices, firms set export prices in domestic currency, allowing the foreign currency price of their goods to fluctuate with the exchange rate. They follow the same pricing scheme as households. In each period, a random fraction $1-\theta_H$ of firms are allowed to change their prices, while the remaining firms adjust their prices based on a geometric average of past CPI inflation and a fixed inflation target set by the monetary authority. The indexation weights are determined by the parameter $\chi_H \in [0,1]$.

Firms allowed to reset their prices in period t maximise the discounted sum of expected real profits net of fixed costs, which can be expressed as:

$$
\begin{aligned}
\max_{P_{H,t}(i)} \quad & \mathbb{E}_t \left[\sum_{t=0}^{\infty} \frac{\lambda_{t+\tau}}{\lambda_t} (\beta\theta_H)^{\tau} \left(\frac{\Gamma^{\tau}_{H,t} P_{H,t+\tau}(i) P_{H,t+\tau}}{P_{H,t+\tau} P_{t+\tau}} - \frac{MC_{H,t+\tau}}{P_{t+\tau}} \right) Y_{H,t+\tau}(i) \right] \\
\text{subject to} \quad & Y_{H,t+\tau}(i) = \left[\frac{\Gamma^{\tau}_{H,t} P_{H,t}(i)}{P_{H,t+\tau}} \right]^{-\epsilon_H} \left(Z_{H,t+\tau} + Y^*_{H,t+\tau} \right) \\
& \Gamma^{\tau}_{H,t} = \prod_{i=1}^{\tau} (\Pi_{H,t+i-1})^{\chi_H} (\bar{\Pi})^{1-\chi_H}
\end{aligned} \tag{42}
$$

where $\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$.

The optimality conditions of the firm's problem are as follows:

$$
g^1_{H,t} = \frac{\epsilon_H - 1}{\epsilon_H} g^2_{H,t} \tag{43}
$$

$$
g^1_{H,t} = \lambda_t \frac{MC_{H,t}}{P_t} \left(Z_{H,t} + Y^*_{H,t} \right) + \beta\theta_H \mathbb{E}_t \left(\frac{\Gamma^1_{H,t}}{\Pi_{H,t+1}} \right)^{-\epsilon_H} g^1_{H,t+1} \tag{44}
$$

$$
g^2_{H,t} = \lambda_t \widehat{\Pi_{H,t}} \frac{P_{H,t}}{P_t} \left(Z_{H,t} + Y^*_{H,t} \right) + \beta\theta_H \mathbb{E}_t \left(\frac{\Gamma^1{}_{H,t}}{\Pi_{H,t+1}} \right)^{1-\epsilon_H} \frac{\widehat{\Pi_{H,t}}}{\widehat{\Pi_{H,t+1}}} g^2_{H,t+1} \tag{45}
$$

Given Calvo's pricing, the price index evolves:

$$
1 = \theta_H \left(\frac{\Gamma^1{}_{H,t}}{\Pi_{H,t+1}} \right)^{1-\epsilon_H} + (1-\theta_H) \left(\widehat{\Pi_{H,t}} \right)^{1-\epsilon_H} \tag{46}
$$

Importing Goods

The importing sector in the home economy is perfectly competitive with a linear production function, hence, price $P_{F,t}$ equals marginal cost, $\epsilon_t P^*_{F,t}$:

$$
P_{F,t} = \epsilon_t P^*_{F,t}. \tag{47}
$$

The Real Exchange Rate

The real exchange rate is defined as the relative price of a foreign price level and the price of a consumption basket in the domestic economy:

$$
RER_t = \frac{\epsilon_t P^*_{F,t}}{P_t}. \tag{48}
$$

Following Calvo, 1983, the consumption price index (CPI), denoted by P_t, is related to the real exchange rate through the consumption price deflator, which can be expressed as:

$$
P_t = \left[\omega P^{1-\eta}_{H,t} + (1-\omega) P^{1-\eta}_{F,t} \right]^{\frac{1}{1-\eta}} \tag{49}
$$

Dividing by $P_{F,t}$ results in:

$$\left(\frac{P_t}{P_{F,t}}\right)^{1-\eta} = \omega\left(\frac{P_{H,t}}{P_{F,t}}\right)^{1-\eta} + (1-\omega) \tag{50}$$

The Government

The government sets the nominal interest rates according to the Taylor rule:

$$\frac{R_t}{R} = \left[\left(\frac{R_{t-1}}{R}\right)^{\phi_R}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi_\pi}\left(\frac{GDP_t}{GDP_{t-4}}\right)^{\phi_{GDP}}\right]^{1-\phi_R}\exp(ms_t) \quad \text{with} \quad ms_t = \sigma_R\epsilon_R \tag{51}$$

through open market operations which are financed by T_t transfers.

To smooth the interest rate path, we incorporate R_{t-1} into the Taylor rule. The term ϵ_R represents a monetary policy shock, assumed to follow $\mathcal{N}(0,1)$. Transfers T_t ensure a balanced government budget. The government's total net position evolves as:

$$R_t^{-1}B_t = T_t + B_{t-1} \tag{52}$$

4.3 Market Clearing

The clearing conditions for the goods and import markets needs to hold in equilibrium as well as the aggregate resource constraint.

Domestic Intermediate Goods

Each domestic intermediate goods producer sets prices in both domestic and foreign monopolistically competitive markets. In equilibrium, the supply of differentiated intermediate goods produced domestically must match the combined domestic and foreign demand. The market clearing condition for home-produced goods is expressed as follows:

$$\int_0^1 Y_{H,t}(i)di = \left(Z_{H,t} + Y^*_{H,t}\right)\int_0^1\left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\epsilon_H} di \tag{53}$$

$$\int_0^1 Y_{H,t}(i)di = \left(Z_{H,t} + Y^*_{H,t}\right)v_{H,t} \tag{54}$$

where $v_{H,t}$ represents the degree of price dispersion among domestically produced differentiated goods sold in both domestic and foreign markets.

Under the Calvo pricing model with indexation, $v_{H,t}$ evolves according to the following expression:

$$v_{H,t} = (1-\theta_H)\left(\Pi_{H,t}\right)^{-\epsilon_H} + \theta_H\left(\frac{\Pi_{H,t-1}^{\chi_H}\bar{\Pi}^{1-\chi_H}}{\Pi_{H,t}}\right)^{-\epsilon_H} v_{H,t-1} \tag{55}$$

Goods Market

Furthermore, it holds:

$$Z_{H,t} = Z_t + INV_t \tag{56}$$

Profits

Per period, nominal profits for domestic and exporting intermediate goods producers are:

$$\Omega_t = \int_0^1 \Omega_t(i)di \tag{57}$$

$$\Omega_t = \int_0^1 (P_{H,t}(i) - MC_{H,t})\, Y_{H,t}(i)dI - MC_{H,t} \tag{58}$$

$$\Omega_t = \left[P_{H,t}^{\epsilon_H}\left(\int_0^1 P_{H,t}^{1-\epsilon_H}(i)di\right) - MC_{H,t}\right]\left(Z_{H,t} + Y^*_{H,t}\right) - MC_{H,t} \tag{59}$$

where we use that:

$$P_{H,t}^{1-\epsilon_H} = \int_0^1 P_{H,t}^{1-\epsilon_H}(i)di \tag{60}$$

Finally, all profits in this economy are:

$$\Omega_t = P_{H,t}\left(Z_{H,t} + Y^*_{H,t}\right) - MC_{H,t}\left[v_{H,t}\left(Z_{H,t} + Y^*_{H,t}\right)\right] \tag{61}$$

Final Goods Markets

The final goods markets in this economy are fully competitive. By aggregating over all households, we obtain the aggregated resource constraint:

$$P_tC_t + P_tINV_t + B_t + \varepsilon_t D_{t-1}R^*_{t-1} + \varepsilon_t\frac{\Phi_D}{2}(D_t - \bar{d})^2 = W_th_t + R_{t-1}B_{t-1} + \varepsilon_t D_t + +R^k_t K_{t-1} + T_t + \Omega_t \tag{62}$$

Applying the budget constraint of the government (equation 52), we obtain:

$$P_tC_t + P_tINV_t + \varepsilon_t D_{t-1}R^*_{t-1} + \varepsilon_t\frac{\Phi_D}{2}(D_t - \bar{d})^2 = W_th_t + \varepsilon_t D_t + +R^k_t K_{t-1} + \Omega_t \tag{63}$$

From the cost minimization problem of domestic intermediaries (38), applying (39), (40) and (41) will result in:

$$C_t + INV_t + \frac{\varepsilon_t}{P_t}D_{t-1}R^*_{t-1} + \frac{\varepsilon_t}{P_t}\frac{\Phi}{2}\left(D_{t-1} - \bar{d}\right)^2 = \frac{P_{H,t}}{P_t}\left(Z_{H,t} + Y^*_{H,t}\right)v_{H,t} - \frac{Pe_{B,t}}{P_t}e_{B,t} + \frac{\varepsilon_t}{P_t}D_t \tag{64}$$

Let us also define GDP to be:

$$GDP_t = \frac{P_{H,t}}{P_t}\left(Z_{H,t} + Y^*_{H,t}\right) v_{H,t} - \frac{Pe_{B,t}}{P_t} \cdot e_{B,t}$$

And inferred TFP is:

$$TFP_t = \frac{GDP_t}{{K_{t-1}}^{1-\alpha} {h_t}^{\alpha}} \tag{65}$$

Domestic Bonds

The domestic government issues government bonds to finance its deficit. However, since we assume that the budget is closed by taxes every period, the outstanding debt in equilibrium is zero:

$$B_t = 0 \tag{66}$$

4.4 Exogenous Shocks

The exogenous shocks processes in this economy are:

$$A_t = (1 - \rho_A) \log A_{SS} + \rho_A A_{t-1} + \epsilon_t^A \tag{67}$$

where A_t represents productivity at time t, A_{SS} is the steady-state productivity, ρ_A is the autoregressive coefficient, A_{t-1} is the lagged productivity, and ϵ_t^A is the productivity shock.

$$A_{e,t} = (1 - \rho_{A_e}) \log A_{e,SS} + \rho_{A_e} A_{e,t-1} + \epsilon_t^{A_e} \tag{68}$$

where $A_{e,t}$ represents energy efficiency at time t, $A_{e,SS}$ is the steady-state energy efficiency, ρ_{A_e} is the autoregressive coefficient, $A_{e,t-1}$ is the lagged energy efficiency, and $\epsilon_t^{A_e}$ is the energy efficiency shock.

$$P_{B,t} = (1 - \rho_{P_B}) \log P_{B,SS} + \rho_{P_B} P_{B,t-1} + \epsilon_t^{P_B} \tag{69}$$

where $P_{B,t}$ represents the price of import energy at time t, ρ_{P_B} is the autoregressive coefficient, $P_{B,SS}$ is the steady-state price of import energy, $P_{B,t-1}$ is the lagged price of import energy, and $\epsilon_t^{P_B}$ is the import energy price shock.

$$\frac{e_{G,t}}{e_t} = (1 - \rho_{e_G}) \log\left(\frac{e_{G,t}}{e_t}\right) + \rho_{e_G} \frac{e_{G,t-1}}{e_{t-1}} + \epsilon_t^{e_G} \tag{70}$$

where $\frac{e_{G,t}}{e_t}$ represents the ratio of domestic energy to total energy at time t, ρ_{e_G} is the autoregressive coefficient, $\frac{e_{G,t-1}}{e_{t-1}}$ is the lagged ratio of domestic energy to total energy at time $t-1$, and $\epsilon_t^{e_G}$ is the shock to the share of domestic energy at time t.

$$R^*_t = (1 - \rho_{R^*}) \log R^*_{SS} + \rho_{R^*} R^*_{t-1} + \epsilon_t^{R^*} \tag{71}$$

where R_t^* represents the foreign interest rate at time t, ρ_{R^*} is the autoregressive coefficient, R_{SS}^* is the steady-state foreign interest rate, R_{t-1}^* is the lagged foreign interest rate, and $\epsilon_t^{R^*}$ is the foreign interest rate shock.

5 Parametrization

Table 3 illustrates the calibration of the parameters utilized in the base model to assess the influence of energy prices on the Chilean economy. These parameters reflect essential characteristics of the Chilean economy in 2021, including the contribution of capital and labor to production, the elasticity of substitution between energy sources, and monetary policy. Furthermore, specific parameters have been included to capture the dynamics related to share of import energy (ξ), domestic (renewable) energy price ($Pe_{G_{SS}}$) and the ratio of import energy to GDP ($e_{B_{GDP_{SS}}}$), thus enabling the simulation of the effects of the energy transition on output, inflation, employment, and total factor productivity. The calibration is based on previous studies and academic standards, thereby ensuring consistency with similar models used in macroeconomic analysis.

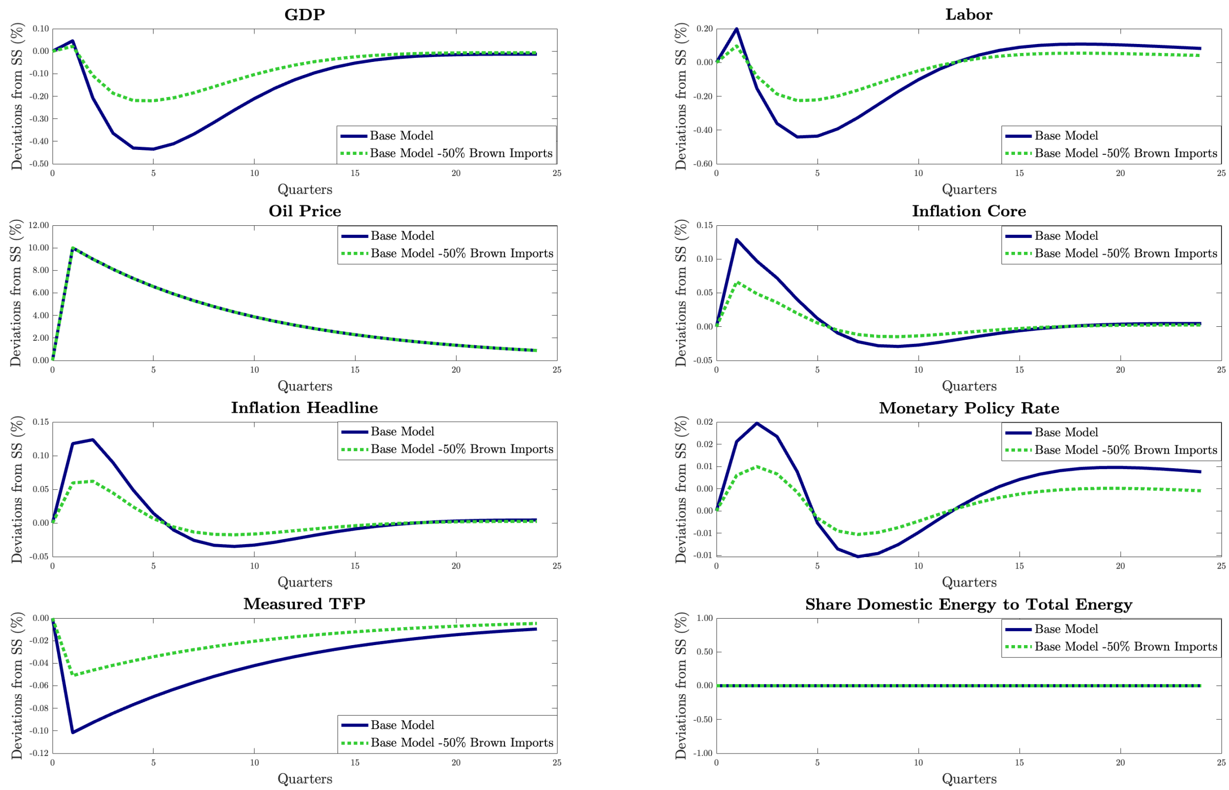
Table 3: Parameter Calibration to Base Model

Parameter	Explanation	Value	Source
β	Discount factor	0.987	Airaudo et al., 2022
σ	Relative risk aversion	1	Standard
σ_h	Elasticity of labor supply	2	Standard
α	Capital share in production	0.74	Airaudo et al., 2022
ϵ	Elasticity of substitution	0.4834	Airaudo et al., 2022
ξ	Share of import energy	0.756	BNE 2021
ν	Elasticity of energy substitution	0.67	Papageorgiou et al., 2017
ω	Weight on utility from labor	0.76	Justiniano and Preston, 2010
η	Inverse Frisch elasticity	0.86	Justiniano and Preston, 2010
η^*	Elasticity of substitution in labor	0.85	Airaudo et al., 2022
ϕ_D	Cost of debt adjustment	0.01	Standard
μ	Markup	2.50	Standard
δ	Depreciation rate	0.02	Standard
θ_H	Calvo parameter for prices	0.75	Standard
χ_H	Habits in consumption	0.50	Standard
θ_w	Calvo parameter for wages	0.95	Airaudo et al., 2022
ϕ_R	Interest rate smoothing	0.90	Airaudo et al., 2022
ϕ_π	Inflation coefficient	1.12	Martínez et al., 2020
$\phi_{D_{GDP}}$	Debt to GDP ratio	0.25	Airaudo et al., 2022
ρ_A	Autoregressive coefficient for A	0.90	Standard
ρ_{A_e}	Autoregressive coefficient for A_e	0.90	Standard
ρ_{P_B}	Autoregressive coefficient for P_B	0.90	Standard
ρ_{P_G}	Autoregressive coefficient for P_G	0.90	Standard
ρ_{R^*}	Autoregressive coefficient for R^*	0.90	Standard
σ_A	Standard deviation of A shock	0.005	Standard
σ_{A_e}	Standard deviation of A_e shock	0.005	Standard
σ_{P_B}	Standard deviation of P_B shock	0.10	Standard
σ_{P_G}	Standard deviation of P_G shock	0.10	Standard
σ_{R^*}	Standard deviation of R^* shock	0.0025	Standard
σ_R	Standard deviation of R shock	0.0025	Standard
$e_{B_{GDP_{SS}}}$	Ratio of import energy imports to GDP	0.0360	BCCH 2021
$Pe_{G_{SS}}$	Domestic energy price	1	Normalization

6 Results and Analysis

6.1 Impulse Response Functions

Figure 12: Positive Oil Price Shock: Mitigated Effect on GDP and TFP due to Reduction in Import Energy



In Figure 12 we see that an increase in energy prices increases firms' marginal costs, which in turn leads to an increase in core inflation. This results in a sudden reduction in output by firms, which in turn affects employment by reducing the demand for labor. As a consequence of the reallocation of resources towards production, total factor productivity (TFP) declines significantly, thereby impairing the capacity of firms to generate income and resulting in a pronounced decline in GDP. The diminished capacity of firms to provide elevated wages, coupled with wage rigidity, results in a gradual diminution of real wages. This, in conjunction with rising energy prices, constrains consumers' purchasing power, curbing their consumption. To mitigate inflationary pressures, the monetary authority implements a contractionary policy, raising interest rates, which discourages consumption and investment.

In contrast, a reduction in non-renewable energy imports by 50% allows firms to rely less on more expensive and volatile energy sources, thereby mitigating the impact on their marginal costs. This results in a diminished decline in GDP and TFP, thereby facilitating a more expeditious recovery. In consequence of the diminished inflationary pressures, both core and headline inflation remain more contained, thereby reducing the necessity for severe monetary policy tightening. Consequently, there is less of an impact on labor demand and real wages, which preserves the purchasing power of workers and limits the contraction in consumption. This stabilizes the economy more efficiently than in the baseline scenario.

Consequently, the 50% reduction in non-renewable energy imports serves to mitigate the negative impact of a positive oil price shock on GDP and total factor productivity (TFP) to a considerable extent. By reducing reliance on more expensive energy sources, inflation is contained and a more severe economic contraction is avoided, thereby facilitating a faster recovery. Furthermore, this results in a reduction in the necessity for contractionary monetary policy, which in turn stabilises consumption and employment to a greater extent than in the baseline scenario.

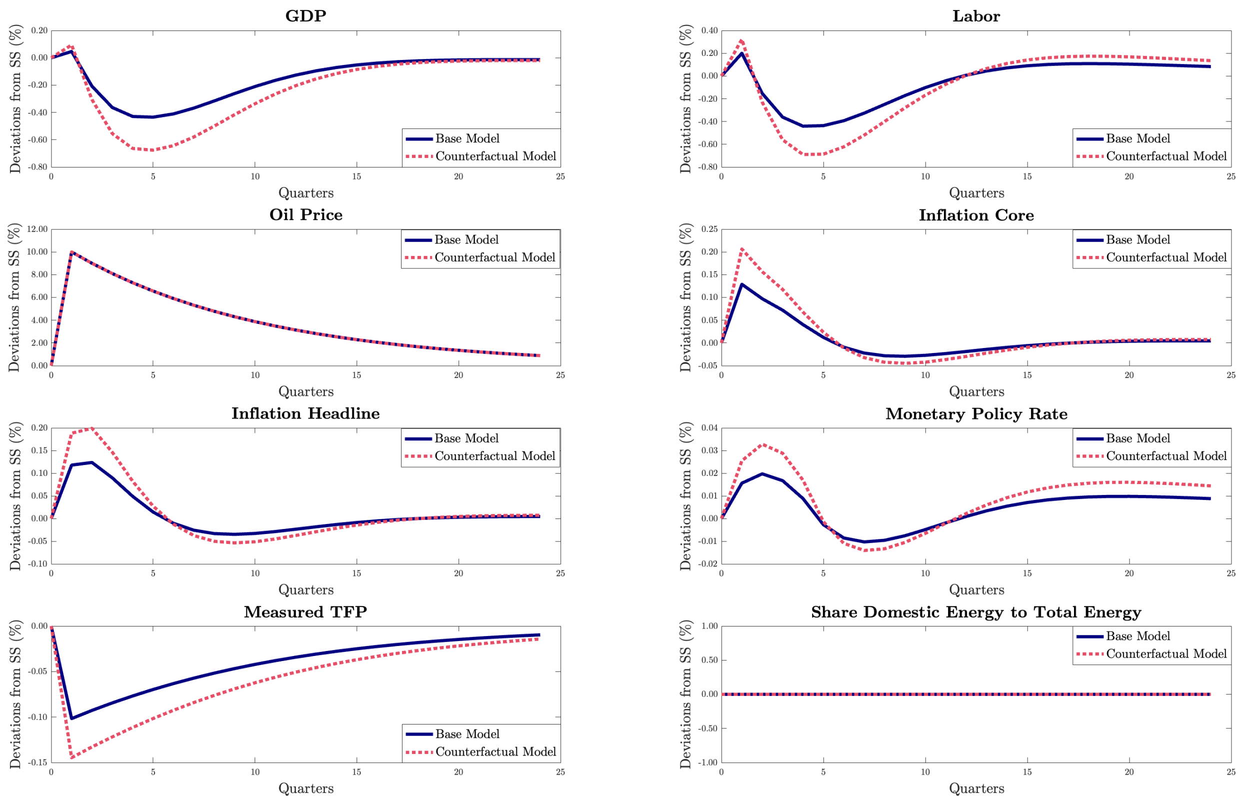
6.2 Counterfactual

Table 4: Parameter Calibration for Counterfactual Model

Parameter	**Explanation**	**Value**	**Source**
ξ	Share of import energy	0.8020	BNE 2000
$e_{B_{GDP_{SS}}}$	Ratio of import energy imports to GDP	0.0620	BCCH 2000
$Pe_{G_{SS}}$	Domestic energy price	0.9486	Regression

Table 4 presents the calibration of the parameters utilized in the counterfactual model, which simulates the Chilean economy in the year 2000. In this model, three key parameters merit particular attention: the share of non-renewable energy (ξ), the ratio of non-renewable energy imports to GDP ($e_{B_{GDP_{SS}}}$), and the price of domestic (renewable) energy ($Pe_{G_{SS}}$). These parameters permit an evaluation of the impact of an increased dependence on non-renewable energy in the context of a shock in oil prices, contrasting this scenario with the base model, in which the Chilean economy has already progressed towards a more diversified energy matrix.

Figure 13: Positive Oil Price Shock



In accordance with the baseline model, the analysis of the counterfactual scenario, Figure 13 demonstrates that had Chile not transitioned towards a more diversified energy matrix and relied more heavily on non-renewable energy sources, as was the case in the 2000s, it would have experienced a more pronounced impact from an increase in energy prices. In particular, the inflationary impact would have been more pronounced, as the economy would have been more vulnerable to fossil fuel price volatility, which would have significantly increased firms' marginal costs. This higher price pressure would have resulted in a more pronounced decline in GDP, as firms would be compelled to further reduce output and employment in response to elevated energy costs.

In this context, employment would have undergone a more pronounced contraction, resulting in a greater number of job losses due to the reduction in demand for labor in energy-intensive sectors. Consequently, the decline in total factor productivity (TFP) would have been more pronounced, as organizations contend with elevated expenses and diminished capacity to generate income, intensifying the economic deceleration. Furthermore, a more stringent monetary policy would have been required to contain the acceleration of inflation, entailing the implementation of higher interest rate hikes. Such a policy would, however, have resulted in a vicious circle whereby consumption and investment in the economy would have been discouraged, thereby deepening the economic contraction.

A comparison with the baseline scenario demonstrates that diversification of the energy matrix has served to mitigate the negative effects, limiting both inflation and the decline in GDP and employment, and facilitating a faster economic recovery that is less dependent on fluctuations in the international energy market.

Figure 14: Counterfactual-Base Model Difference under a Positive Oil Price Shock

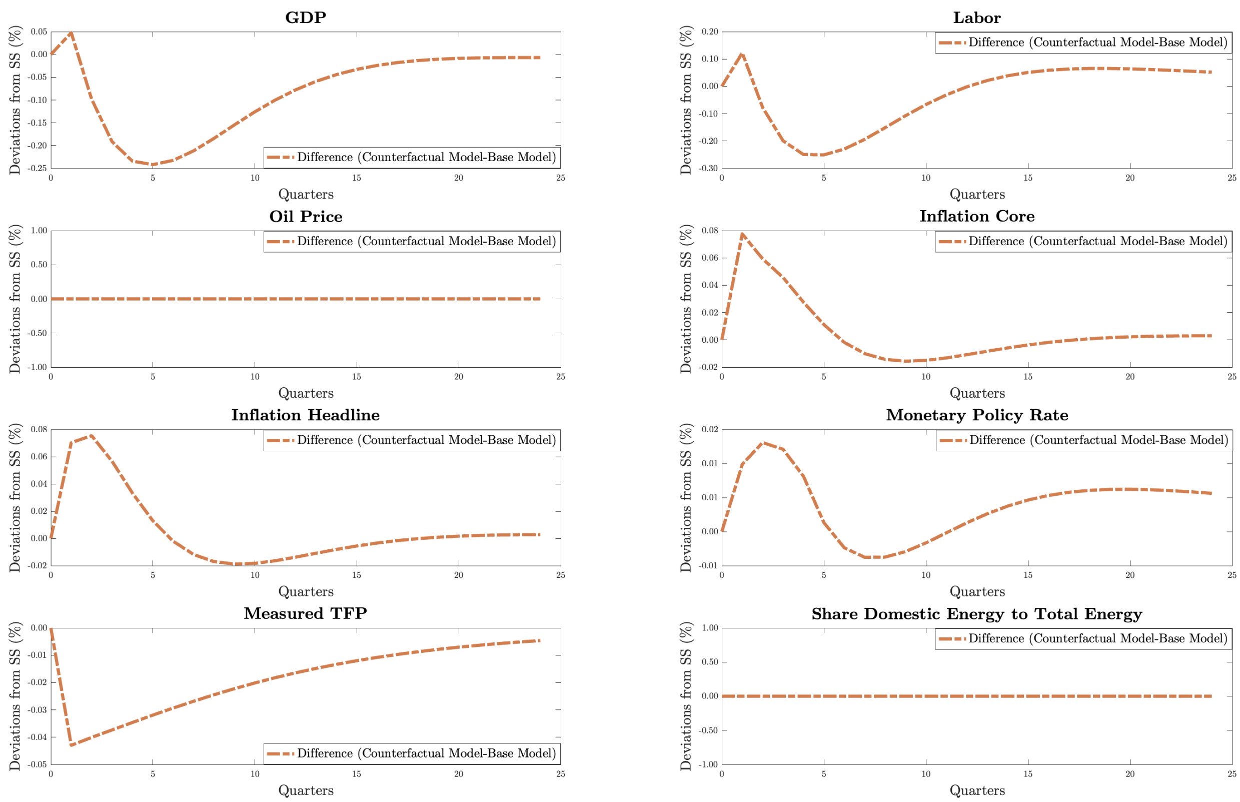


Figure 14 presents a quantitative comparison between the counterfactual model (calibrated to the year 2000 for Chile) and the base model (calibrated to the year 2021 for Chile) in the event of a positive oil price shock. The objective of this illustration is to demonstrate the potential impact that the Chilean economy might have experienced had it not diversified its energy matrix.

With respect to GDP, the discrepancy reaches as high as -0.25% in the initial quarters, indicating a more pronounced economic contraction in the absence of a diversification of the energy matrix. This illustrates how elevated non-renewable energy costs would have augmented production costs, exerting a detrimental impact on both output and income. Similarly, employment would have undergone a more pronounced contraction, with a discrepancy reaching up to -0.2%, suggesting a greater reduction in labour demand in sectors reliant on fossil energy.

With respect to inflation, the counterfactual scenario indicates a more pronounced increase. Headline inflation would have been 0.07% higher in the first quarter due to the higher dependence on fossil fuels and the consequent increases in marginal costs. Consequently, core inflation would have been approximately 0.08% higher in the counterfactual scenario, reflecting the impact of fossil fuel price volatility on production costs and consumer purchasing power.

In the counterfactual scenario, monetary policy would have been more restrictive in response to the steeper inflationary increase, with a difference of up to 0.015% in the interest rate compared to the baseline model. This indicates that the central bank would have been compelled to implement more pronounced interest rate increases to regulate inflation, which would have intensified the contraction in consumption and investment. Furthermore, total factor productivity (TFP) would have experienced a more pronounced decline, with a difference of up to -0.04%, due to elevated production costs and the diminished capacity of firms to generate income.

7 Conclusions

We demonstrated the profound macroeconomic implications of energy prices and the energy transition, focusing on the relationship between energy prices, GDP, and productivity. The analysis revealed several key findings that contribute to the understanding of how energy costs, particularly oil prices and the use of non-renewable energy, impact economic efficiency and inflationary dynamics.

First, results confirm that higher oil prices significantly reduce Total Factor Productivity (TFP). A 1% increase in oil prices leads to an appreciable fall in productivity, highlighting the vulnerability of fossil fuel-dependent economies. Moreover, economies with a higher ratio of import energy to total energy - indicating a greater reliance on non-renewable energy - experience steeper declines in TFP, reflecting the inefficiencies and environmental costs of non-renewable energy sources.

Second, we shows the different impacts of domestically produced versus imported energy. Two effects in particular; the Price and Scale Effect and the Recomposition Effect, illustrate how the energy transition influences productivity. The Price and Scale Effect shows that higher energy prices increase costs and reduce productivity. However, a shift towards more domestic and renewable energy mitigates this impact, as demonstrated by the Recomposition Effect, which shows that greater use of domestic renewable energy reduces dependence on volatile and costly imports, leading to improvements in TFP and economic efficiency.

Finally, in terms of inflationary consequences, the analysis shows that energy price increases raise production costs. Firms face higher marginal costs, resulting in reduced output, lower employment and lower productivity. Tight monetary policy, in the form of higher interest rates, becomes necessary to control inflation, but at the cost of lower consumption and investment. The results further show that reducing dependence on non-renewable energy imports by 50% can alleviate these negative effects, containing inflation and mitigating the economic contraction associated with oil price increases. The analysis of the counterfactual scenario underlines the benefits of Chile's energy transition. Had Chile maintained its energy matrix of the early 2000s, the economy would have faced more severe macroeconomic consequences. The absence of diversification would have resulted in a more precipitous decline in GDP, heightened inflationary pressures, a more stringent monetary policy response in conjunction with a more substantial decline in TFP.

In conclusion, the transition to a cleaner and more diversified energy mix has had considerable positive effects on Chile's economic stability and productivity. The results suggest that policies that promote the adoption of renewable energy and reduce reliance on non-renewable energy not only help with the environment and the drive towards carbon neutrality, but are also crucial for long-term economic resilience and efficiency.

In the future, we would like to focus on incorporating sector-specific data and assess the long-term effects of energy transition policies in different industries. The inclusion of behavioural economics in household decision-making processes could provide further insights into the dynamics of energy consumption. In addition, examining the role of fiscal policies alongside monetary measures could provide a deeper understanding of how to stabilise economies during energy transitions, while assessing the distributional effects of these policies would help address concerns related to inequality in the transition process.

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