The impact of electricity price on GDP: an IV approach with Brazilian data

Felipe Macedo Dias - 93651735

Victor Bejgel Epelbaum - 93972024

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Abstract: Energy prices constitute a major subject of political discourse and intervention. The cost of electricity impacts not only households but also heavily electricity-dependent industries. This paper seeks to assess the influence of electricity price fluctuations on the Gross Domestic Product (GDP). To achieve this, we analyze data from 2010 to 2019 for 5,566 counties in Brazil, a nation where over 60% of its electricity is generated from hydropower. To isolate the impact of political intervention and business cycles, we employ rainfall as an instrumental variable for electricity pricing. Our argument posits that rainfall indirectly affects manufacturing GDP exclusively through its influence on electricity costs. Our estimations reveal that a 1% increase in electricity prices corresponds to an average decrease of 0.25823% in manufacturing GDP per capita.

We would like to thank Jesse, Phil, Paul and Bruno for the amazing course and knowledge shared with us. Those were valuable times. Thank you.

1 Introduction

This paper is motivated by the stagnation observed in Brazil's economy during the 2010s, often referred to as the 'lost decade.' Figure 1 illustrates the GDP per capita, adjusted to 2022's real value. Notably, in 2019, the GDP per capita was 2.8% below the level of 2011, underscoring a period of negative growth, even after excluding the Covid-19 pandemic. This decline forms the backdrop against which we examine the impact of electricity pricing on economic performance.

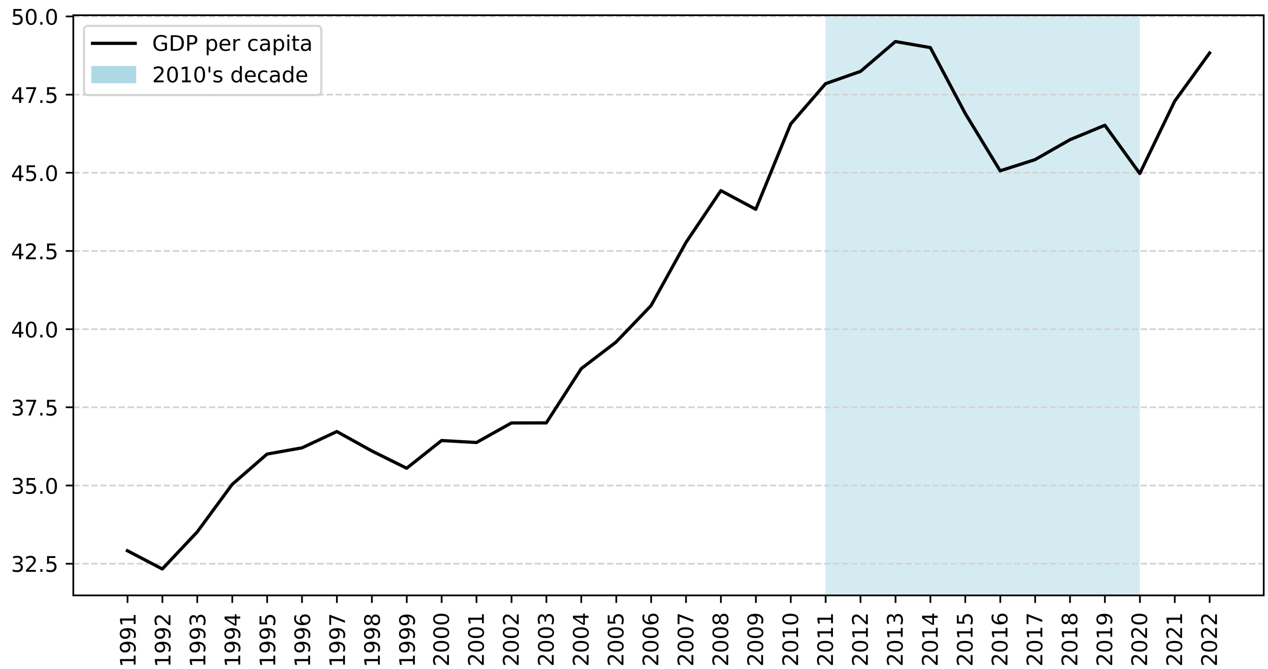

Figure 1. GDP per Capita (2022's Brazilian Reais) and the "Lost Decade"

A variety of factors have been proposed by economists and political analysts to explain this stagnation, including poor federal policies, fiscal mismanagement, and the decline of the commodity cycle. While these explanations may concurrently hold validity, an additional, distinct factor emerges: the scarcity of rainfall. This unique perspective was first introduced by Borges (2021) in the FGV's policy discussion blog. Employing a Vector Autoregression with Exogenous Variables (VAR-X) approach, that paper analysis investigates the impact of precipitation (rainfalls) on GDP. The findings suggest that the drought between 2012 and 2019 reduced Brazil's annual GDP growth by approximately 1.6 percentage points - a significant effect. However, as this study is yet to be formally published, caution is warranted when interpreting these conclusions.

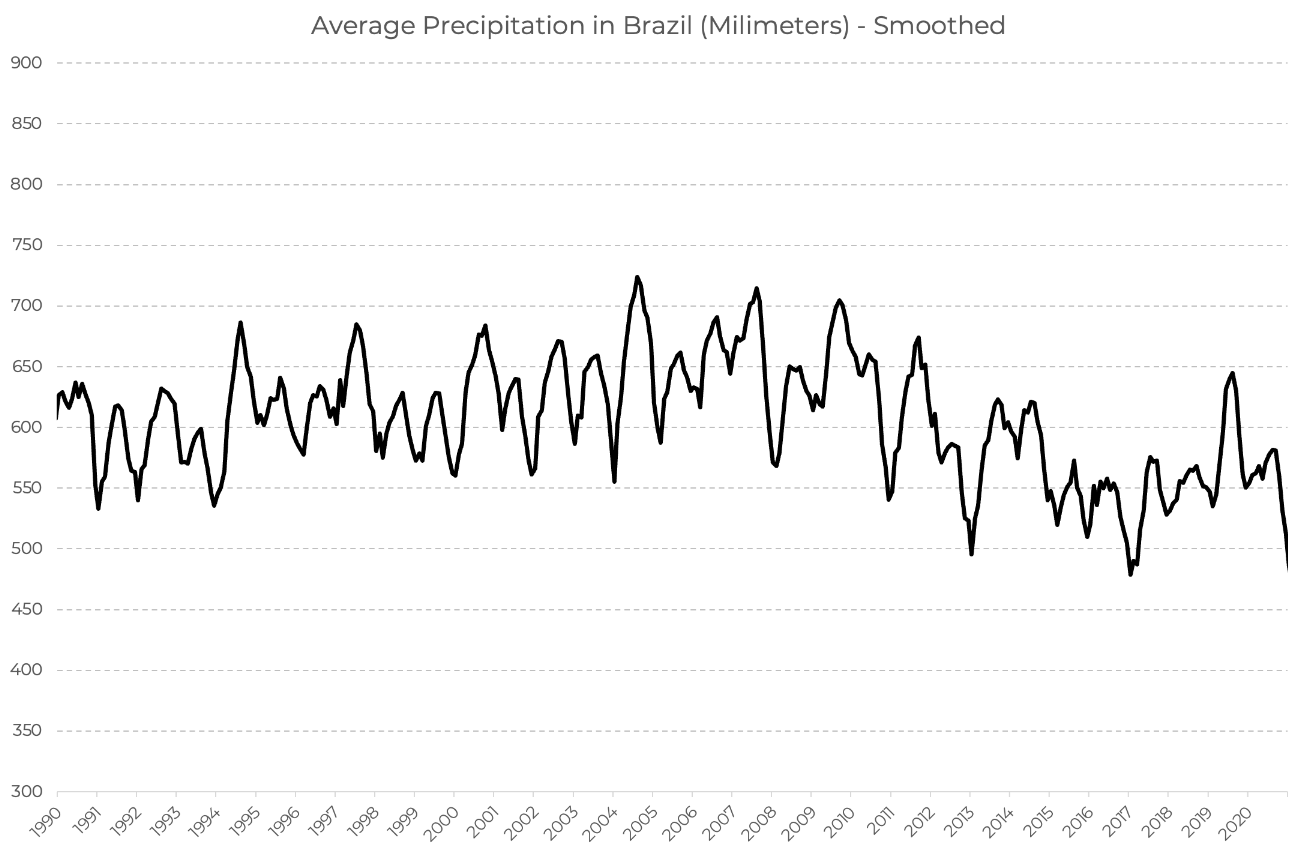

Figure 2. Average Precipitation in Brazil

The figure above shows the monthly average precipitation in Brazil, spanning from 1990 to 2020. It is critical to highlight that the data has undergone smoothing, employing a 12-month moving average to facilitate clearer analysis.

The data distinctly illustrates that the first decade of the 21st century experienced, on average, higher levels of precipitation compared to the subsequent decade. The latter period is characterized by reduced rainfall across Brazil, significantly impacting economic and other activities within the country. The next figure displays precipitation in terms of the Standard Normal Distribution (Z-Score), further substantiating the trend of diminished rainfall, particularly from 2012 to 2020, where negative values indicate below-average precipitation. It is important to note that this analysis encompasses a broader timeframe (1990 to 2020), facilitating a more comprehensive comparison against longer-term data and averages.

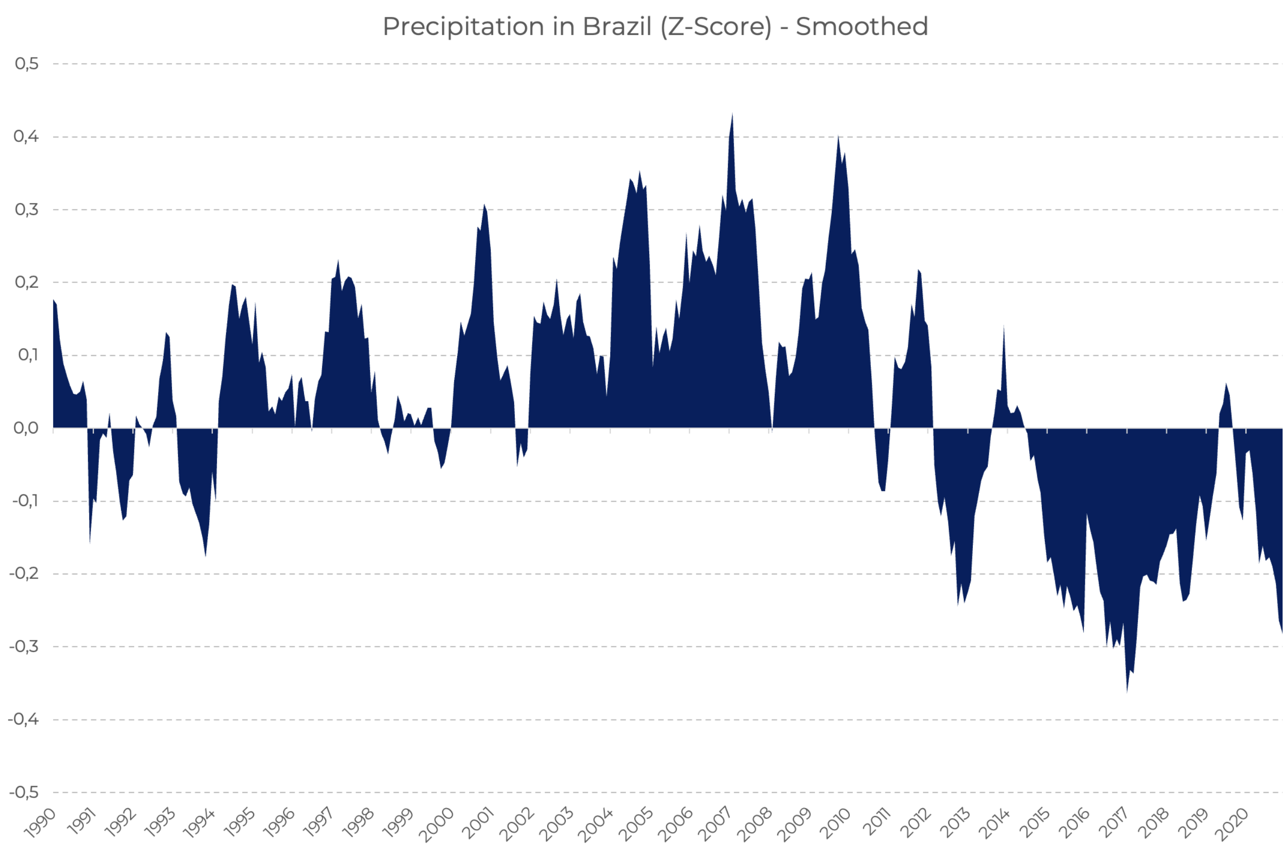

Figure 3. Precipitation in Z-Score

Additionally, a disaggregated analysis of each Brazilian region reveals distinct climatic characteristics and features. The Northern region, encompassing the Amazon rainforest, typically experiences the highest levels of precipitation in the country. This is a critical factor, considering the Amazon's vast ecological and climatic influence. In contrast, the Northeast region is characterized by the Caatinga biome, known for its arid conditions and lower rainfall levels. This disparity in precipitation patterns across regions is significant for various ecological and economic reasons.

Furthermore, it's important to note the geographical distribution of hydroelectric plants, which are predominantly located in the Southeast region. This area, encompassing Brazil's most densely populated states, such as São Paulo and Rio de Janeiro, plays a pivotal role in the country's energy production and consumption dynamics. The variability in precipitation across these regions not only affects local ecosystems and agriculture but also has profound implications for energy generation, particularly given Brazil's reliance on hydroelectric power.

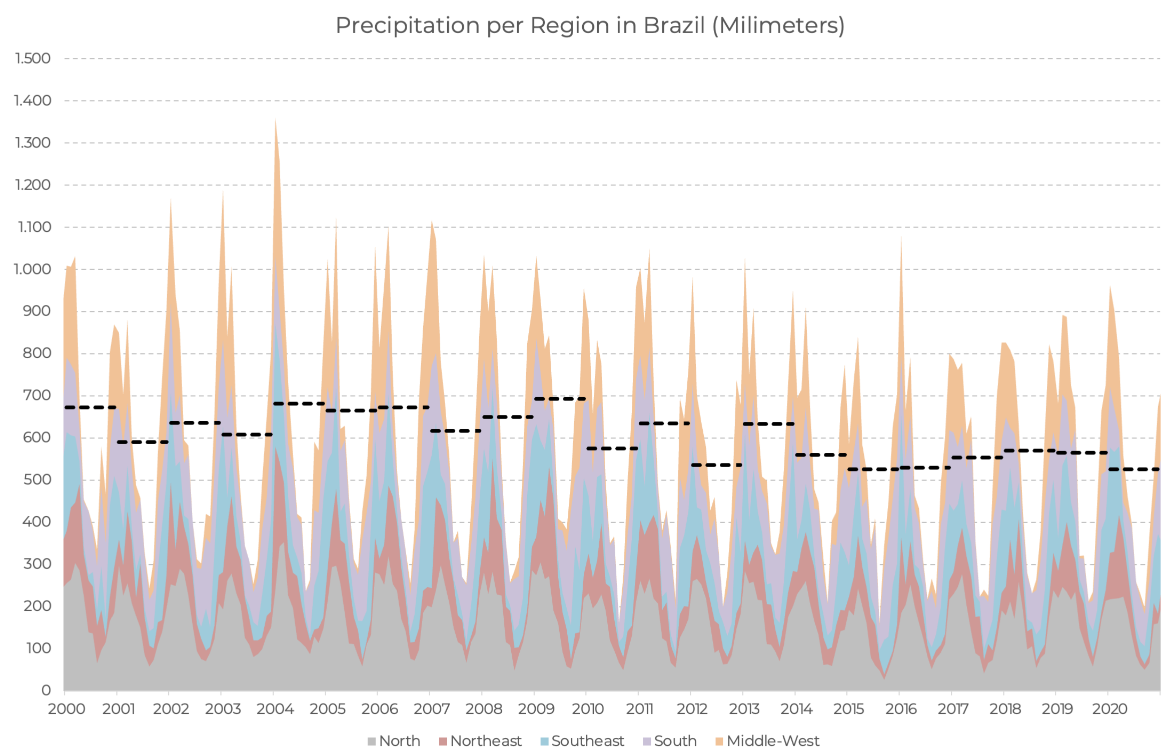

Figure 4. Precipitation per Region in Brazil

Brazil's power matrix is diverse and predominantly reliant on renewable energy sources.

1. **Hydropower:** Brazil is one of the world's leaders in hydropower, forming the backbone of its electricity supply. Large hydroelectric plants, like Itaipu Dam (Foz do Iguaçu - South) and Belo Monte Dam (Belo Monte - North), are crucial. This reliance is due to Brazil's abundant river systems, especially in the Amazon and Paraná basins. However, it also makes the energy sector vulnerable to climatic variations in rainfall - what we going to look in more detail.

2. **Wind Power:** Wind energy in Brazil has grown significantly, particularly in the Northeast region, known for its constant winds. This growth is part of Brazil's effort to diversify its energy matrix and reduce reliance on hydropower, especially during droughts.

3. **Solar Power:** Solar energy, though a smaller fraction of Brazil's energy mix, is growing due to high solar irradiation levels across the country. Increasing investments and declining costs of solar technology are driving this expansion.

4. **Biomass and Biofuels:** Brazil is a global leader in biomass and biofuels, especially ethanol from sugarcane. Biomass energy, from agricultural residues and forestry products, significantly contributes to the renewable energy portfolio.

5. **Fossil Fuels:** Fossil fuels, mainly natural gas and oil, still play a role in Brazil's energy matrix. Offshore oil reserves are key for energy independence but contrast with the renewable energy focus. The discovery of the pre-salt layer off Brazil's coast, rich in oil reserves, has significantly bolstered Brazil's position in the global fossil fuel market. This deep-sea oil reserve, challenging to extract due to its depth and geological complexity, promises substantial economic benefits but also brings environmental and technological challenges, making it a pivotal aspect of Brazil's energy strategy.

6. **Nuclear Energy:** Nuclear energy, primarily from the Angra Nuclear Power Plant, is a minor but present part of Brazil's energy mix. The construction of nuclear facilities in Brazil has historically experienced delays, and currently, nuclear energy contributes only a minor share to the country's energy matrix. However, there are indications that its role may expand in the future.

Brazil's energy policy emphasizes expanding renewable sources, enhancing energy security, and reducing greenhouse gas emissions. Managing this diversity, especially the interplay between renewables and climate variability, remains a challenge.

1.1 Energy Price Formation

The energy tariff corresponds to the amount required to cover the technical operations and investments made by agents in the electricity sector's production chain, as well as the necessary infrastructure to facilitate the production and delivery to the end consumer. Thus, the tariff represents the sum of components related to the generation, transmission, and distribution of energy. At the end of the bill, charges and taxes are added to enable public policies.

The energy tariff comprises costs for energy acquisition, costs related to the transmission system, distribution, electrical losses, and charges/taxes. The sectorial charges and taxes are not created by ANEEL (Brazilian National Electric Energy Agency), but are established by laws. They can be levied on the cost of distribution or be included in the costs of generation and transmission.

Regarding taxes, the Federal, State, and Municipal Governments charge on the electricity bill the Social Integration Program (PIS), Contribution to Social Security Financing (COFINS) at the federal level, Tax on Circulation of Goods and Services (ICMS) at the state level, and the Contribution for Public Lighting (COSIP) at the municipal level.

Finally, it is necessary to pay attention to the tariff flags, created in 2015 by ANEEL with the aim of solving the energy crisis in the country. There are four official flags: green, yellow, red level 1, and red level 2, in increasing order of value. In 2021, an exceptional flag was also created due to the water crisis scenario the country experienced at the time.

The green flag indicates favorable generation conditions, meaning there will be no additional charge on the energy bill. The yellow flag signals a warning and includes an additional charge per MW/h on the energy bill. The red flags indicate more critical generation conditions, necessitating a higher additional charge per MW/h on the energy bill, depending on the level of flag activation, with level 2 having the higher value.

The values of the energy tariff are determined by ANEEL, with a specific value for each Distributor (our data has prices by each distributor). These values are defined in tariff reviews that occur on average every four years and are also annually adjusted by ANEEL until the next review. They can be calculated for both a distributor or a transmission concessionaire.

The tariff calculated for distributors are the distribution tariffs, a value that represents the price charged from the consuming unit for energy consumption and for the use of the network. [1]

[1] Acessed and based in: https://cpflsolucoes.com.br/o-que-e-tarifa-de-energia-e-como-ela-e-calculada-na-conta-de-luz

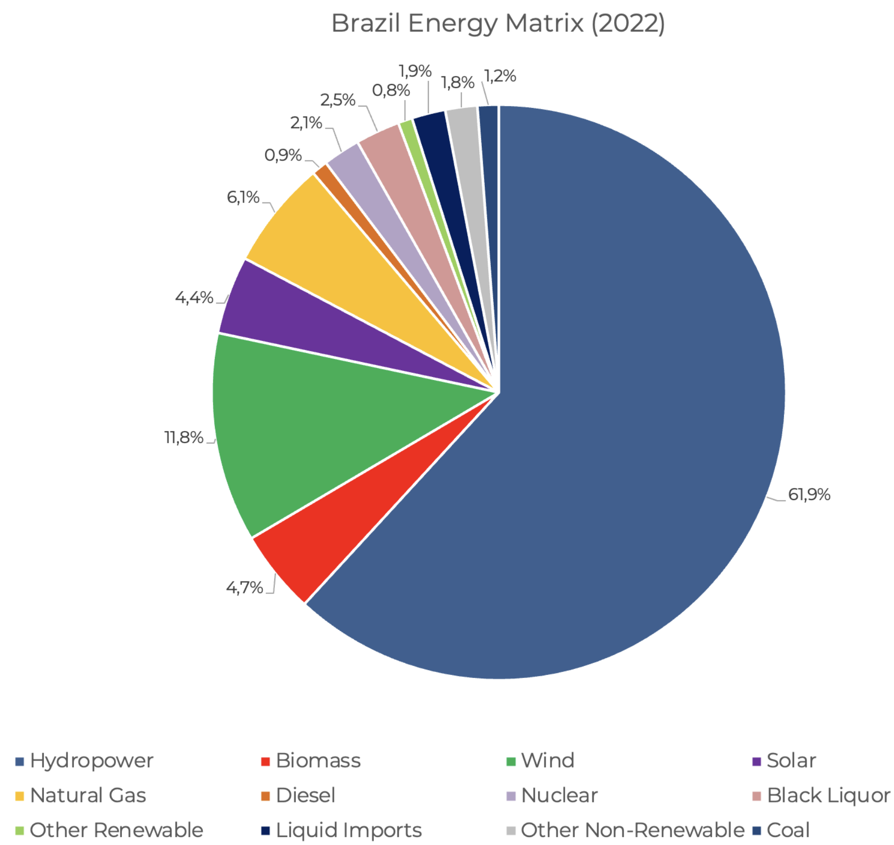

Figure 5. Brazil's Energy Matrix

2 Literature Review

In Kotz et al. (2022), the authors show that that economic growth rates are reduced by increases in the number of wet days and in extreme daily rainfall, in addition to responding nonlinearly to the total annual and to the standardized monthly deviations of rainfall. Not only, but richer nations and services and manufacturing sectors are most strongly affected by measures of rainfall.

In the Brazilian scenario, Borges (2021) argues that the several droughts have reduced the Gross Domestic Product (GDP) by a consistent and relevant magnitude. Furthermore, the end of commodities cycle might have boosted this effect on economic activity.

Card (1993) and Card (2000) are in the references because of the empirical method employed - it's the same as we are using here: IV's. In the first one especifically, the distance from the university is used as an instrument to determine schooling.

Landon-Lane et al. (2009) analyze the relationships between the weather, agricultural markets, and financial markets, that have long been of interest to economic historians. The authors use modern drought indexes, which are available in detail over a wide area and for long periods of time to perform a battery of tests on the relationship between these indexes and sensitive indicators of financial stress.

Also, Rosenzweig and Udry (2014) study the effects of rainfall forecasts and realized rainfall on equilibrium agricultural wages over the course of the agricultural production cycle. They conclude that a forecast of good weather can lower wages in the planting stage, by lowering ex ante out-migration, and can exacerbate the negative impact of adverse weather on harvest-stage wages.

There are other references (which have been annexed to the references section), but the most relevant are those above.

3 Empirical Strategy

3.1 Identification

As demonstrated, hydropower plants are the most important source of electrical energy in Brazil. However, this energy source is heavily influenced by precipitation levels during rain periods. The exogenous variability in rainfall has a direct impact on energy prices: abundant rain tends to lower electricity prices, while periods of drought lead to heightened prices due to reduced electricity production.

In our study, we propose employing rainfall as an instrumental variable that energy prices withou directly affecting the manufacturing GDP per capita, our outcome variable. Specifically, we focus our study in this segment of the GDP because the full GDP contains the agricultural sector, which is directly impacted by rainfall. The choice of utilizing an instrumental variable is justified by the fact that the definition of energy prices is influenced by some variables which also effect GDP but are difficult to measure, such as political (both at the federal and local levels) and business cycles.

The relationship among these variables is depicted in the Directed Acyclic Graph (DAG) illustrated in Figure 7.

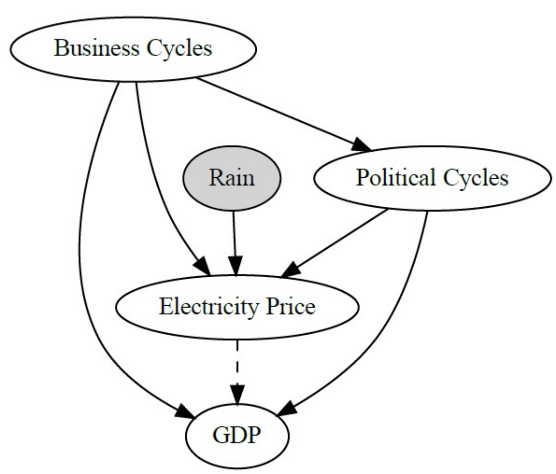

Figure 6. DAG of study variables

3.2 Data

For our analysis, we employ precipitation raster data sourced from Xavier et al. (2022), which offers comprehensive daily weather records spanning from 1961 to 2020 across Brazil. This dataset is meticulously aggregated on an annual basis for each county, providing a detailed basis for our estimations.

Our study utilizes electricity price data provided by the National Agency of Electric Energy (ANEEL), encompassing the rates charged by each electrical distribution company in Brazil from 2010 to 2022 [2]. It also provides a dataset that shows which county each company is responsible for providing electricity [3], and the distribution companies operating in each county [4]. To extract this data, embedded within the agency's website, we developed a web scraping script using Python's Selenium library. One downside of this data is that this information is only available for the present time. So we have to assume that those companies were serving the same counties since 2010.

We calculate the price of the electricity of each county as the weighted average price of each company that works at that county weighted by the amount of consuming units of each firm. We then aggregate the price into years, as the GDP data is annual.

Apart from those data sources, population and GDP data come from the Brazilian Institute of Geography and Statistics (IBGE), ranging from 2010 to 2021. For the analysis, we select observations within the years of 2010 to 2019, as the Covid-19 pandemic would affect our results. Table 1 displays descriptive statistics of our data.

The map on Figure 7 shows the variability on the companies across municipalities, where each color represents one firm. Is is possible to see that the interior/small counties of each state are generally supplied by the same company, but the capitals and large cities tend to have a company that works only at that county.

[2]With more time, we could also get data from prices before 2010, but they are in (not well formatted) PDFs for each company for each year and would take too much time for analysing.

[3]Available at: http://www2.aneel.gov.br/relatoriosrig/(S(uz40escnmxlmkg3kjmrz031u))/relatorio.aspx?folder=sfe&report=MunicipiosdecadaDistribuidora

[4]Available at: http://www2.aneel.gov.br/relatoriosrig/(S(2fvq0gw5m22mefgpjhzkivqp))/relatorio.aspx?

Table 1. Descriptive Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Area	55,660	1,526.524	5,606.860	3.565	159,533.300
Electricity_Price	51,989	185.699	61.328	0.000	337.350
Precipitation	55,660	1,329.310	561.455	0.000	4,714.753
Precipitation_per_km2	55,660	5.178	9.976	0.000	524.840
GDP	55,620	1,032,241.000	10,432,485.000	7,218	763,597,808
Share_Agriculture	55,620	20.043	15.548	0.000	90.770
Share_Industry	55,620	13.796	14.222	0.000	100.000
Share_Services	55,620	66.161	16.613	0.000	99.710
Population	55,620	36,265.200	213,464.100	781	12,252,023
GDP_pc	55,620	18.953	20.962	2.262	815.698
Precipitation_per_km2_lag	50,094	5.202	10.046	0.000	524.840
Precipitation_per_km2_sqrt	55,660	1.905	1.244	0.000	22.909
Precipitation_per_km2_sqrt_lag	50,094	1.909	1.248	0.000	22.909
GDP_Industry_pc	55,620	420.643	1,307.506	0.000	67,384.790
GDP_Agriculture_pc	55,620	387.255	596.857	0.000	12,416.330
ln_Precipitation_per_km2	55,660	1.400	0.859	0.000	6.265
ln_Precipitation_per_km2_lag	50,094	1.402	0.861	0.000	6.265
ln_GDP_Industry_pc	55,620	4.878	1.407	0.000	11.118
ln_GDP_Agriculture_pc	55,620	5.169	1.371	0.000	9.427
ln_Electricity_Price	51,989	5.168	0.371	0.000	5.824

The map presented in Figure 7 delineates the variability among companies across counties, with each distinct color symbolizing a specific firm. It becomes evident that interior and smaller counties within each state are predominantly served by a singular company. In contrast, capitals and larger cities exhibit a tendency for exclusive service provision by a company specific to that particular county."

Figure 7. Distribution companies and counties

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4 Results

Table 2 displays the results from various specifications of our instrument. We conducted tests on different transformations of our precipitation per km^2 variable, employing the Wald statistic (referred to as the "Kleibergen-Paap rk Wald F statistic" for Stata users) to identify the optimal instrument. A large Wald statistic value rejects null hypothesis that the instrument is weak. The coefficients exhibited negative values, consistent with our earlier assumption, indicating that increased rainfall indeed leads to a reduction in electricity prices.

We acknowledge criticisms regarding the selection of strong instruments. Andrews et al. (2019) provide insights into the utilization of weak instruments and recommend employing the effective F-statistic proposed by Olea and Pflueger (2013) when dealing with a single endogenous regressor. To compute this statistic, we utilized the Stata package WEAKIVTEST (Pflueger and Wang (2015)). However, due to taking more than 24 hours for the estimation to run, we could only calculate it for the natural log specification. The obtained value of 88.989 rejects the null hypothesis of weak instruments under heteroscedasticity and serial correlation.[5] Given these metrics, we opted for the natural log of 1 + precipitation as our instrument.[6]

The outcomes of the second stage of the instrumental variable (IV) regression, along with the ordinary least squares (OLS) estimator and a fixed-effects model, are presented in Table 3. In our IV specification, a statistically significant negative effect of the electricity price on manufacturing GDP is observed at the 10% significance level. More specifically, we find that a 1% increase in the electricity value is associated with an average reduction of -0.25823% in manufacturing GDP per capita.

[5] This test has a 5% critical value of the "worst-case" bias of 37.418.

[6] As our dataset includes observations with zero precipitation, we employed the 'log(1+x)' transformation to address this issue and prevent missing values.

Table 2. Impact of precipitation on Price of Electricity, 2010 to 2019

Dependent Variable:	ln(Electricity Price)			
	(1)	(2)	(3)	(4)
Precipitation_per_km2	-0.00390***			0.00152***
	(0.00128)			(0.00043)
Precipitation_per_km2_sqrt		-0.05786***		-0.06910***
		(0.00644)		(0.00751)
ln_Precipitation_per_km2			-0.08517***	
			(0.00903)	
Controls				
City	X	X	X	X
Year	X	X	X	X
Fit statistics				
Standard-Errors	City			
Observations	51,949	51,949	51,949	51,949
R^2	0.7469	0.7475	0.7474	0.7475
F-test (1st stage)	91.0997	212.7812	193.1556	109.2979
Wald (1st stage)	9.2734	80.7386	89.0198	43.9504
Montiel-Pflueger Effective F			88.989	
Dependent variable mean	5.1681	5.1681	5.1681	5.1681

Notes: All regressions use a panel of 5566 counties per month from 2010 to 2019. Precipitation per km2 refers to total monthly rainfall in millimeters divided by the county area. All regressions include year and county fixed effects. Column 1, 2, 3 and 4 denotes the results of the regression of the log of electricity price on precipitation, precipitation squared, the 1 + natural log of precipitation, and precipitation and precipitation squared, respectively. Standard errors are clustered by County. P-Values: ***: 0.01, **: 0.05, *: 0.1

Table 3. Impact of the price of electricity on Manufacturing GDP per capita, 2010 to 2019

Dependent Variable:	ln(Manufacturing GDP per capita)		
	OLS	FE	IV
	(1)	(2)	(3)
Constant	2.00626***		
	(0.14597)		
ln(Electricity Price)	0.54833***	-0.00553	-0.25823*
	(0.02774)	(0.01285)	(0.13736)
Controls			
City		X	X
Year		X	X
Fit statistics			
Standard-Errors		City	
Observations	51,949	51,949	51,949
R^2	0.0207	0.9315	0.9304
Wald (1st stage), ln(Electricity Price)			89.0198
Dependent variable mean	4.8401	4.8401	4.8401

Notes: All regressions use a panel of 5566 counties per month from 2010 to 2019. Precipitation per km2 refers to total monthly rainfall in millimeters divided by the county area. All regressions include year and county fixed effects. Column 1 denotes the OLS results of the regression of the crime rate on the natural log of precipitation. Column 2 reports the results of the regression of the crime rate on precipitation and precipitation squared. Standard errors are Conley standard errors for spatial correlation and all regressions are weighted by the weighting area's adult population. P-Values: ***: 0.01, **: 0.05, *: 0.1

5 Conclusion

This paper aims to shed light on the crucial role of electricity prices in shaping GDP, particularly within the manufacturing sector. Employing an instrumental variable approach, we aimed to rigorously assess whether electricity prices have a significant influence on manufacturing GDP.

Our estimations reveal a noteworthy and statistically significant negative impact of electricity prices on a county's manufacturing GDP. Specifically, a 1% increase in electricity prices corresponds to an average decrease of 0.25823% in GDP per capita.

This finding contributes substantively to the ongoing discourse on the diversification of electricity sources, emphasizing the potential economic instability associated with an over-reliance on a single source.

However, it is important to acknowledge certain limitations in this study. The analysis is restricted to a relatively short time frame, and external factors, such as commodity prices, were not considered. Furthermore, the validity of our instrument hinges on the assumption that rain does not directly impact manufacturing GDP.

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