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An Input-Output Analysis: What Would a Low-Carbon Economy for Brazil Mean?

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Abstract

Mixing economic growth with low-carbon objectives entails multidimensional challenges among which a shift in employment and a rapid transformation of infrastructure are involved. The aim of this paper is to provide a data-driven analysis to strengthen our understanding of what a low-carbon economy for Brazil would mean. Ultimately, our aim is to narrow the policy makers' spectrum of analysis when facing low-carbon economy objectives by using much information from the IOT in three ways: (i) identifying the current economic landscape; (ii) determining the potential transmission channels of assets that are written off balance sheets when capital becomes stranded; and (iii) understanding the sectoral implications of a low-carbon economy in the labor market. For planning low-carbon trajectories in Brazil, we find that: first, the economic landscape exhibits a significant drift towards oil-related industries--especially the chemicals sector--that may generate frictions in designing tomorrow's low-carbon economy; second, the financial and the oil sectors are highly interconnected and should be dealt with together; third, the wholesale sector appears to be basic and systemic, therefore economic policy should pay particular attention to this sector; and fourth, when assessing NDC impacts on the labor market we find that shifting activities from oil derivatives to biofuels is likely to create jobs while moving away from the extractive sector may increase unemployment.

Key words: Input Output, Leontief Model, Network, Energy Sources, Energy Substitution, Employment, Brazil

JEL Classification: C67, D57, D85, Q42

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ABSTRACT

Mixing economic growth with low-carbon objectives entails multidimensional challenges among which a shift in employment and a rapid transformation of infrastructure are involved. The aim of this paper is to provide a data-driven analysis to strengthen our understanding of what a *low-carbon economy* for Brazil would mean. Ultimately, our aim is to narrow the policy makers' spectrum of analysis when facing low-carbon economy objectives by using much information from the IOT in three ways: (i) identifying the current economic landscape; (ii) determining the potential transmission channels of assets that are written off balance sheets when capital becomes stranded; and (iii) understanding the sectoral implications of a low-carbon economy in the labor market. For planning low-carbon trajectories in Brazil, we find that: first, the economic landscape exhibits a significant drift towards oil-related industries–especially the chemicals sector–that may generate frictions in designing tomorrow's low-carbon economy; second, the financial and the oil sectors are highly interconnected and should be dealt with together; third, the wholesale sector appears to be basic and systemic, therefore economic policy should pay particular attention to this sector; and fourth, when assessing NDC impacts on the labor market we find that shifting activities from oil derivatives to biofuels is likely to create jobs while moving away from the extractive sector may increase unemployment.

1 Introduction

Given the increasing awareness of climate change and the growing concern about potential downside consequences of a temperature increase beyond $+2°C$ above pre-industrial levels, countries around the globe adopted a historic international climate agreement in Paris in December 2015. In anticipation, countries published their *Intended Nationally Determined Contributions* (hereafter INDCs)–converted into *Nationally Determined Contributions* (NDC)–that outlined the climate actions they intended to take post-2020. These contributions largely determine the milestones to be set by local governments in order to achieve the long-term goals of the Paris Agreement: to hold the increase in global average temperature to well below $+2°C$, to pursue efforts to limit the increase to $+1.5°C$, and to achieve net zero emissions in the second half of this century. NDCs communicate internationally the planned milestones taken by every country to address climate change. They reflect each country's ambitions in reducing anthropogenic greenhouse gas (hereafter GHG).

However, most of the NDCs remain purposely vague regarding the short-term actions that would be undertaken by governments towards achieving these political milestones. As an example, Brazil[1,2] does not commit itself to achieving any objective before 2025. This gives time for local governments to assess an economically sustainable trajectory towards the intended low-carbon economy.

Shaping a low-carbon economy at a large scale is a multidimensional challenge that requires tackling: (i) the emergence of a carbon-free techno-economic system that will fuel tomorrow's growth; (ii) shifts in the volume and com-

*The views expressed in this paper are those of the authors only.

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1 Available in the link: http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

2 Brazil intends to commit to reduce its GHG by 37% (resp. 43%) below 2005 levels in 2025 (resp. 2030).

3 Key sectors of most economies are likely to undergo major changes, for instance: agriculture, forestry, fishing, energy, resource intensive manufacturing, recycling, buildings, and transport.

position of employment across sectors that will affect the level and distribution of income;[3] and (iii) transformations of capital stock and infrastructure that will disrupt the financial system and ultimately the macroeconomic environment. We argue that the first dimension, that is, changes in technology from fossil to renewable energy implied by the energy shift, is well documented in the macroeconomic literature (Prinn and Reilly, 2017; Waisman et al., 2012; Waldhoff et al., 2014).[4] However, to our knowledge, there is still a gap in the assessment in terms of direct and indirect transformations of capital stock and employment. Indeed, as argued by Campiglio et al. (2017), the debate in shifting towards green energy matrices is very much focused on oil companies (Meinshausen et al., 2009) and, only more recently, on the financial costs of such transitions, or the systemic effects they entail (see e.g. Battiston et al. (2017); Dafermos et al. (2017); Monasterolo and Raberto (2018) or Giraud et al. (2017)).

We follow Campiglio et al. (2017) research agenda in investigating the potential impact of structural change on the economic landscape towards a low-carbon economy. This, by studying the interaction of the monetary flows in input-output tables together with changes in the labor market. The aim of this paper is to provide a data-driven analysis for policy makers (and perhaps economic modelers) that enhances the comprehension of what a *low-carbon economy* would mean for a country according to its specificities through an application for Brazil. Ultimately, our aim is to narrow the policy makers' spectrum of analysis when facing low-carbon economy objectives by using much information from the input-output matrices in three ways: (i) identifying the key sectors of the economy to understand the economic landscape and the short term potential growth of the economy; (ii) determining the potential transmission channels of the cascade of physical assets when a sector becomes stranded; and (iii) understanding the sectoral implication of a low-carbon economy in the labor market.

1.1 Integrated assessment models: a (key) sectoral view of the economy

The conciliation of (macro)economic development and climate change is traditionally tackled through integrated assessment models (hereafter IAMs). For Brazil, several models have been developed to understand how economic activity, the energy system, and environmental changes are related. To our knowledge, the five most relevant (groups of) models are:

- IMACLIM-S BR–(Lefèvre, 2016; Wills, 2013; Wills and Lefèvre, 2012);
- EPPA-BR–(Prinn and Reilly, 2017; Silva and Gurgel, 2012);
- ENERGY-BR–(Santos et al., 2013);
- MESSAGE–(Jalal et al., 2006; Soria et al., 2016);
- BeGreen–(Magalhães, 2013).

One can note that these models are constructed to tackle some given research questions, sometimes overlapping. According to Cattan (2017), these models can be classified as follows: (i) the last three (ENERGY-BR, MESSAGE, and BeGreen) rely on a *bottom-up* framework, based on a partial equilibrium approach that focuses on making explicit each possible energetic component and technological possibilities both on the supply and the demand sides (this approach is often assimilated as the "engineering approach"); (ii) the EPPA model is structured as a *top-down* model, this approach departs from the latter in developing the macroeconomic framework at the cost of having less detailed energy components; and (iii) IMACLIM-S BR is developed upon a *hybrid* structure taking advantage of both the *top-down* and the *bottom-up* approaches. A wide variety of sectoral decompositions can emerge throughout all these methodologies (such as a deep focus on the energetic component and/or carbon-intensive industries among others). However, to our knowledge, no study has been undertaken to provide a quantitative justification for the choice of products or industries. Indeed, in most of the models presented above, the so-called *composite* sector[5] encompasses a substantial percentage of the economic activity.

Applying the seminal works of Hirschman (1958); Rasmussen (1956) and modern development of Sonis et al. (2000) on the Leontief inverse analysis, we will derive the key sectors as well as the economic landscape of the Brazilian economy. Thus, we will be able to emphasize which are the sectors at play in short-term economic development, and therefore, the main economic-financial challenges when designing a *low-carbon* economy in a multisectoral framework.

1.2 Cascade effects: a potential future of stranded assets or how the economy is connected

As argued by Bank of England Governor Mark Carney, a too-rapid movement towards a low-carbon economy could materially imperil financial stability:

> But a wholesale reassessment of prospects, especially if it were to occur suddenly, could potentially destabilise markets, spark a pro-cyclical crystallisation of losses and a persistent tightening of financial conditions [A climate Minsky moment] (Carney, 2016).

[4]For the case of Brazil see Subsection 1.1 for further details.

[5]The sector that groups all the residual industries or products.

Conversely, insufficient uptake of adequate financial tools may prevent the world economy from investing at the required scale to achieve the Paris Agreement's goals. Indeed, as stated in the widely cited paper Meinshausen et al. (2009), if the global emissions of CO_2 in 2020 is at 25% above the level of 2000, the chances of hitting the threshold of +2°C are 53-85%. More recently, Raftery et al. (2017) assess that a likely range of global temperature increase is +2–4.9°C with median +3.2°C and a 5% (resp. 1%) chance that it will be less than +2°C (resp. +1.5°C). Similar results are found in a Monte Carlo study in Bovari et al. (2017); Nordhaus (2017). The arbitrage between finance and climate is nowadays one of the most pressing worldwide political matters. Indeed, as assessed by (Stern, 2016), the cost of transitioning is well underestimated and this leads to spurious signals in financial markets that, in turn, undervalue the climate risk (Griffin et al., 2015).[6]

Another line of analysis more focused on stranded assets has been carried out by Campiglio et al. (2017). This paper classified three categories of assets at risk of climate-related stranding: (i) industries related to fossil fuels; (ii) long-lived capital assets (e.g., chemical plants, machinery, airplanes among others); and (iii) balance sheets of both the private or the government sectors.[7] As alluded by Meinshausen et al. (2009), shifting towards a zero-emission society with a temperature anomaly of below +2°C would most likely require to leave a substantial amount of fossil fuels into their natural reservoirs. However, one can argue that the "unburnable" reservoirs of fossil fuel can actually be burned whenever the associated emissions are offset through carbon capture and sequestration (CCS) or by absorbing the carbon in forests and soils. This paper follows (Campiglio et al., 2017) point of view in saying that relying on such technologies is a risky strategy since, as of today, these techniques are not mature enough to be deployed on a large scale and be a sustainable solution for the future. This potentially leads to an increase of the transition risk borne by sectors with carbon-related businesses. Therefore, focusing on the current structure of the economy along with its short-term evolution is particularly relevant in such contexts, as the installed capital stock could not be smoothly transformed into carbon-free capital.

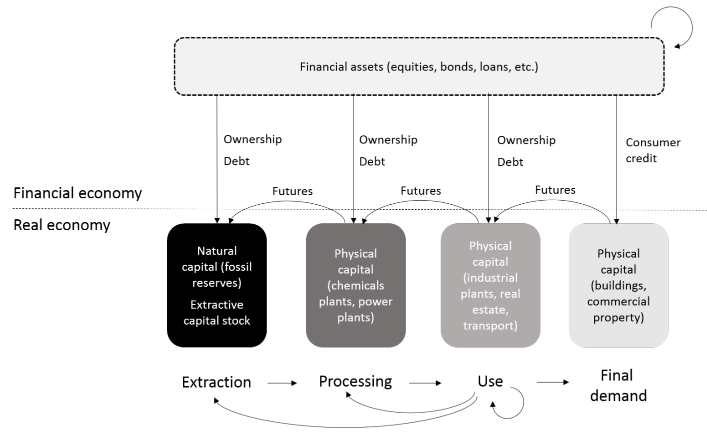

Figure 1: Natural, physical, and financial assets at risk of stranding. Source: Campiglio et al. (2017)

Still in line with Campiglio et al. (2017), Figure 1 provides an illustration of the potential cascade effect. The rationale of the graph goes as follows: when a good is produced in the real economy, it is very likely to find the extractive sector at the top of the value-added chain. Along the vertically linked activities, raw materials are embedded and become more complex objects, gaining in value. To avoid the downside effects of a sudden increase in commodity prices,[8] industries usually own future contracts–traded in the financial layer of Figure 1–in order to remove this kind of risk to their activities. To insure financial stability, this risk is diversified with other uncorrelated risks into a portfolio (with equities, bonds, loans, etc.). However, whenever a shock is too large to be handled by some sectors, a cascade effect may begin. In the context of the paper, whenever one sector becomes suddenly stranded–especially if this sector is at the top of the value-added chain–this could be the starting point of a cascade effect (or a shock) that will ultimately hit the financial system.

Such effects gain importance if one considers that, as pointed out by (Nordhaus, 2017), actions required to have a chance of limiting the temperature anomaly should be unprecedentedly strong:

> it will be extremely difficult to achieve the 2°C target of international agreements even if ambitious policies are introduced.

Therefore, as time goes on, the potential shock to the real economy and the financial sector due to strong governmental uptake actions is increasing. Hence, potential downside effects are strengthened. In this paper, using the network approach suggested by Campiglio et al. (2017), we attempt to provide a first assessment of cascade effect matters using the monetary flows provided by the input-output tables.

[6] Griffin et al. (2015) has found that the market reaction to Meinshausen et al. (2009)'s paper–which stated that more than half of the proven reserves of fossil fuel must stay in the ground–has been surprisingly mild: 1.5–2% average drop in U.S. oil and gas companies' stock prices.

[7] As they may suffer from a contagion effect originated by assets that are written off before planned.

[8] E.g., the so-called 1970s oil shocks (Hamilton, 1983).

Our analysis focuses on the real layer of Figure 1, assuming that the connections in the financial layer hold.

1.3 Would a low-carbon economy be in favor of labor-intensive sectors?

A somewhat complementary dimension to stranded assets, when designing a *low-carbon* economy, has to do with the shifts in the volume and composition of employment across sectors (Perrier and Quirion, 2016). In this regard: what does the ecological shift mean for the labor market?

A possible answer might be found in Perrier and Quirion (2016)'s paper. Instead of trying to provide the effect of an energy shift scenario on the sectoral employment market, Perrier and Quirion (2016) gives an assessment of the employment content–the absolute number of direct and indirect jobs required to produce one monetary unit of final demand for a given sector–and GHG emissions[9]–of each sector of the French economy and provides a decomposition to study the elements that build the differences in employment content between sectors. This approach provides a descriptive analysis of the first order–as sectoral employment does not disclose specific types of employment–on a few inter-sectoral substitutes that would be involved when shifting towards a low-carbon economy.

The paper is organized as follows: Section 2 provides an outlook on the Brazilian economy and identifies its potential leverage in terms of reducing anthropogenic GHG emissions. Section 3 presents the methodologies, the intuitions and the data. Section 4 analyzes the Brazilian economy through its input-output data. Section 5 gives a guideline to build a macroeconomic model towards a low-carbon economy. Finally, Section 6 summarizes the main conclusions and outlines areas for future research.

2 Macroeconomic outlook: a focus on anthropogenic GHG emissions

Brazil is the fifth largest economy in terms of land area (larger than either the continental US or Western Europe) and population, and holds the main part of the world's largest rainforest (the Amazon) as well as substantial freshwater resources. The country holds numerous natural assets such as agricultural lands, minerals and metal resources or fossil fuels stocks. The economy is relatively closed, supported by a historical focus on the domestic market as the driver of economic development.

Although it still is one of the world's most unequal societies, Brazil has made notable socioeconomic progress over the past decade. [10] Such progress was supported mainly by a sustained annual growth of 1.2% to 7.8% during the period 2001 - 2012, except for 2009 where the economy felt the effects of the global financial crisis. Two key factors stood out as the stimuli for this economic performance: (i) the high price of commodities at the beginning of the 2000s, and (ii) the high levels of domestic consumption (notably linked to the improvement of trade, the abundance of liquidity that improved credit access, the reduction of unemployment, especially through non-tradable domestic services, and social transfers).

However, in the aftermath of the subprime crisis, the first of these main drivers reversed as international commodity prices went down in 2012, followed by crude oil prices in mid-2014. The effects of the crisis were a reminder of the structural dependence of Brazil on commodities, especially fossil, and an element to study further if aiming to design a transition to a low-carbon economy.

2.1 The structural weaknesses of the economy and challenges for future inclusive growth

According to World Bank (2016), the current situation reveals two structural weaknesses the Brazilian economy suffers from: (i) its ability to trigger sustained productivity growth (investment and total productivity of factors were not significant drivers of growth during the last decade), due to a lack of physical infrastructure, the high cost of finance, the lack of international competition and innovation and; (ii) the structure and level of public spending that might not be sustainable regarding the current economic situation, and that hinders investment capacities of the government.

In terms of the environment challenges, particular attention should be paid to the protection of natural resources. Indeed, the management of land (unequal productivity of farms leading to sometimes illegal deforestation) and water (regional imbalances) could be more efficient. At the same time, environmental issues, such as urban sprawl increasing the environmental footprint of cities (notably, the vehicle fleet trebled between 2000 and 2015) and precarious housing (flooding or contaminated areas), due to rapid urbanization (85.2% in 2013) should be addressed. Lastly, the prospects of the more fragile population often rely on the management of natural assets that condition their livelihoods (for instance, agriculture for indigenous communities).

Under such structural constraints, the World Bank (2016) proposes three main directions for future public policy design aiming at achieving inclusive and environmentally friendly sustainable growth.

- the creation of sufficient productive and well-remunerated jobs to provide opportunities to all

[9] Not explored in this article due to a lack of clean data in sectoral direct emissions for Brazil.

[10] With regard to inequality, and according to the World Bank, 30 % of the generated income in Brazil is nowadays held by 5 % of the population. On the other hand, during the decade between 2005 and 2015, 21 million Brazilians left poverty (as defined under national standards).

working-aged Brazilians;

- the design of more efficient and better-targeted government spending by addressing the issues of the beneficiaries and purposes of public programs (aiming at reducing poverty, sharing prosperity and regaining fiscal space for public investment);
- the implementation of smarter management of natural resources and improved mitigation of environmental pollution and risks, notably by acting as a mediator between the competing private interests and the protection required for the most vulnerable people, who often have less bargaining power (aiming at improving livelihoods and economic opportunities).

Brazil's dependence upon commodity prices represents an important challenge for the transition towards a low-carbon economy. However, the fact that Petróleo Brasileiro S.A. (hereafter Petrobras)[11] has been by far the principal oil producer in the country makes the government one of the main receivers of oil-related revenues. This not only poses a different level of questions when analyzing the impact of stranded assets, but also opens the window for several policy alternatives to smooth the transition.[12]

2.2 The energy sector

Brazil's endowment of energy resources is vast, varied and more than sufficient to meet the country's needs. Today's most pressing energy challenges have already been met: almost all Brazilian households nowadays have access to electricity, and as can be seen in Figure 2, according to British Petroleum, almost 35% of the country's primary energy demand is met by renewable energy. Renewable energy, or 'green' energy, largely relies on hydropower. Wind power is not yet significant, despite huge projects in the northeast region over the past 10 years. However, the share of renewables in the overall energy mix decreased from 44% in 2011 to 39.4% in 2014 (and 43.5% in 2016, where the last increase took place mostly due to a reduction in oil and natural gas supply, combined with hydro and wind energy growth), which is due to the decrease of ethanol consumption and the increased consumption of petrol, diesel and natural gas. The decrease of "green" energy in the mix continued but remains above the World average.

Brazil's early determination to move forward with alternatives to fossil fuels was a natural choice due to the country's large hydropower potential, their agricultural-based economy, as well as the rising concerns over energy security. On the other hand, domestic discoveries of oil and gas were initially relatively modest, at least until the late 1970s, when the desire to minimize reliance on imported fuels was reinforced by the oil shocks of that decade.

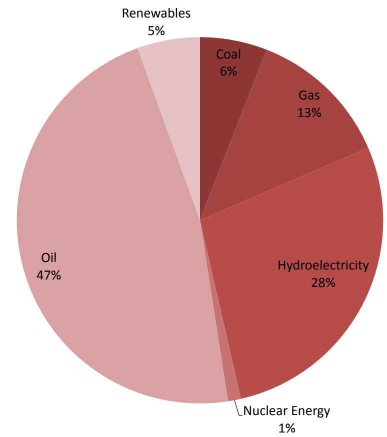

Figure 2: Brazil's primary energy demand in 2015. Source: BP

Nevertheless, as shown by Figure 2, a large part of Brazil's consumption of primary energy is based on carbon-intensive production, approximately two-thirds of total consumption.

2.2.1 Biofuels

Primarily sugarcane ethanol, it meets around 15% of demand in the transport sector, where flex-fuel accounts for approximately 90% of new passenger vehicle sales.

2.2.2 Hydro-electric

As shown by Figure 3, large hydropower plants accounted for approximately 80% of domestic electricity generation. This is mainly due to Brazil's natural endowment and its high potential in that domain. In 2012, installed hydropower capacity was 78 gigawatts,[13] around one-third of the estimated hydropower potential. Despite its high operational flexibility in the electric market, continued expansion is increasingly constrained by the remoteness and environmental sensitivity of a large part of the remaining resources.

[11] A semi-public Brazilian multinational corporation in the petroleum industry.

[12] As an example, one could consider the case of Norway's sovereign wealth fund, which uses resources coming from oil-related revenues and invests them in assets that could ensure a steady financial return once oil reserves are depleted, or their value drastically reduced.

[13] MME and EPE (2013)

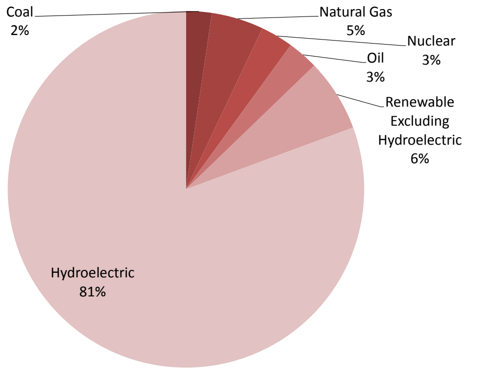

Figure 3: Brazil's electricity mix by sources in 2011. Source: BP

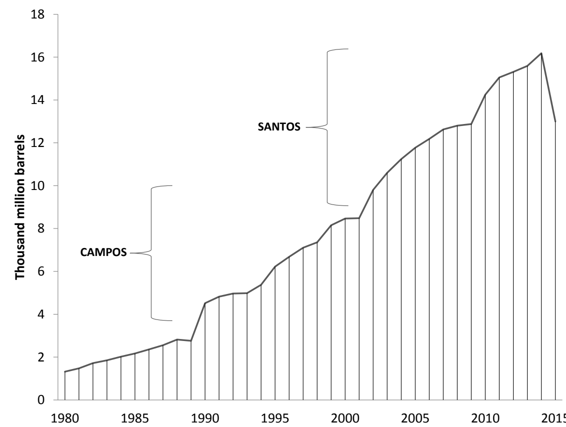

Figure 4: Evolution of Brazil's proven oil reserves. Source: BP

2.2.3 Oil and gas

Natural Gas Natural gas plays a modest role in the energy mix of Brazil. According to the *Empresa de Pesquisa Energética* (hereafter EPE), in 2016 natural gas accounted for less than 12.3% of the domestic energy supply and for 7.4% of the country's final energy consumption. Moreover, during the past two decades, while oil and renewables have remained dominant in the primary energy mix, the only significant change has been the growth in demand for natural gas from 2% in 1990 to 10% in 2013.

Oil Over the last three decades, Petrobras has made a series of large offshore discoveries, initially in the Campos basin, becoming a world leader in deepwater technology in the process. With the huge "pre-salt" findings in the Santos basin since 2006, Brazil's ambition in the oil sector has risen once again. In 2008, the government decided that the huge deepwater pre-salt resources in the offshore Santos and Campos basins should be developed under power conversion systems with Petrobras as the operator holding a share of at least 30%.[14] The development of these fields by Petrobras and its partners will be complex and costly; it has the potential to make Brazil a major exporter of oil as well as a significant producer of natural gas. Figure 4 shows the existence of oil resources as well as the series of discoveries that have been made – initially concentrated in the Campos basin but then extending into the Santos basin as well. While proven reserves were 16.2 thousand million barrels in 2014, only 13 thousand million barrels were reported in 2015; a 19.7% decrease according to the BP statistics. Petrobras explained that this change was primarily due to revisions of well estimates of pre-salt sites offshore.[15]

Despite Brazil's huge endowment of natural resources, self-sufficiency in energy resource, although mitigating external risks, does not guarantee a reliable supply at affordable costs. Efforts to preserve Brazil's biodiversity, policies on land use and water-resource management are all closely intertwined with the outlook for the energy sector. Risks of resilience in the Brazilian power system, such as those arising from the variability of rainfall patterns and hydropower inflows, have been exacerbated by climate change.[16]

In the aftermath of large offshore pre-salt oil and gas discoveries in the Santos basin, in 2009 the former president Lula, called such discoveries the *second independence of Brazil*. This occurred after the mortgage subprime crisis, when the spot price of oil–WTI–was recovering and reaching a level of approximately $\$70$ a barrel. The downward sloping trend of oil prices, which started in mid-2014 came as bad news to Brazil in light of the large deepwater drilling investment made by Petrobras in the Santos field. In 2016, Petrobas declared its biggest-ever quarterly loss in 2015: Q4. Hence, in *reais*, the total debt of the company was 40 percent greater at the end of 2015 than a year earlier.[17] In the preceding years, between 2011-2014, there were nearly US$$40$ billion in associated costs paid by Petrobras after taking over Brazil's fuel subsidies. This policy kept down domestic prices of oil while the spot oil market price was reaching high levels. In addition, higher domestic consumption as a result of lower prices (relative to the international level) have outpaced refining capacities, resulting in a heavy dependence on imports. Furthermore, the recent '*Operação Lava-Jato*' scandal has posed even greater challenges to the company and represents a substantial cause of the company's downturn, especially in terms of debt and market price.

[14] In the mid-2000, large offshore "pre-salt" oil and gas discoveries have confirmed Brazil's status as one of the world's foremost oil and gas province.

[15] Hence, a similar decline, of 8.7%, of proven gas reserves has been reported.

[16] As it was demonstrated by the 2001-2002 energy crises, an unusually dry summer of 2001: water reservoir levels in many parts of the country fell to critical levels, compromising the ability to ensure a reliable power supply.

[17] Source: Reuters.

2.3 Heading to the future: energy-related CO_2 and national climate change plan

Brazil is a leading player in climate change negotiations. It was an early mover in developing a National Climate Change Plan in December 2008, enacted it into law in December 2009, and has made a significant progress in lowering, on a voluntary basis, its CO_2 emissions.[18] Despite its large surface area, and according to the IEA (2013), the high share of low-carbon energy in its energy mix yields a low figure for energy-related CO_2. In 2005, the largest contribution to CO_2 emissions emanated from land use, land-use change and forestry. Since 2005, the Brazilian government has embarked the country on a large-scale campaign to slow deforestation. Hence, GHG emissions from land-use change and forestry have declined, and the share of energy in total emissions has doubled.

According to the NDCs, calls for reducing GHG emissions are 37% (resp. 43%) by 2025 (resp. 2030) relative to 2005. Moreover, to be consistent with its contribution to the +2°C goal, Brazil intends to adopt further measures, in particular:

1. By increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030, by expanding biofuel consumption, increasing ethanol supply, including increasing the share of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix;

2. through land-use change and forests:
   - strengthening and enforcing the implementation of the Forest Code at federal, state and municipal levels;
   - strengthening policies and measures with a view to achieving, in the Brazilian Amazon, zero illegal deforestation by 2030 and compensating for greenhouse gas emissions from legal suppression of vegetation by 2030;
   - restoring and reforesting 12 million hectares of forests by 2030, for multiple purposes;
   - enhancing sustainable native forest management systems, through georeferencing and tracking systems applicable to native forest management, with a view to curbing illegal and unsustainable practices;

3. in the energy sector, achieving 45% of renewables in the energy mix by 2030, including:
   - expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030;
   - expanding the use of non-fossil fuel energy sources domestically, increasing the share of renewables (other than hydropower) in the power supply to at least 23% by 2030, including by raising the share of wind, biomass and solar;
   - achieving 10% efficiency gains in the electricity sector by 2030.

It is worth mentioning that throughout the paper, we will rely on Hilgemberg and Guilhoto (2006)'s results in terms of CO_2 emissions as we do not have access to clean data for the sectoral emissions on CO_2 for Brazil. This study was conducted using high granularity in terms of CO_2 origins and spatial analysis. The main conclusion is that for an additional unit of final demand per sector, it can be observed that the sectors of road transport, other transports, non-hydraulic energy production, oil and other, alcohol and petroleum refining are the ones that have the highest CO_2 emission intensity.

Policies addressing the reduction of GHG emissions would undoubtedly affect the economic activity of oil-related sectors among others. As the Brazilian economy depends upon them, such an impact would have direct and indirect effects on employment and sectoral intermediaries. These policies would generate distortions throughout the economy to the extent of the strength of interconnections across sectors at both the real and financial levels. We focus on understanding the real intersectoral linkages[19] to clarify the transmission channels of potential downside effects of shifting towards a low-carbon economy. In what follows, we analyze those linkages and provide an adequate industrial clustering for studying the transition to a low-carbon economy in Brazil.

3 Data and methodologies

Before outlining the methodologies for analyzing the input-output matrices used in the paper (Campiglio et al., 2017; Perrier and Quirion, 2016; Sonis et al., 2000), let us first introduce the data and a few useful notations that will help us present the intuitions behind each methodology.

3.1 Data and notations

The *Instituto Brasileiro de Geografia e Estatística* (hereafter IBGE) computes and publishes the Brazilian input-output tables (hereafter IOT) every five years. The current available version was published in 2016 using data from 2010, and the update with 2015 information is expected in mid-2018. In the meantime, the IBGE publishes supply and use tables (hereafter SUT) every year with a lag of 2 years (i.e., in 2017, the IBGE will release the 2015 SUT). However, SUT do not include the use tables at basic prices nor valuation

[18] Brazil has adopted a National Climate Change Plan develop to a sectoral framework primarily financed by the BNDES.

[19] We leave the financial links for further research.

matrices to transform from basic into purchasers' prices. Instead, use tables are presented in purchasers' prices, with valuation vectors only. Our analysis is primarily performed on the most exhaustive tables in order to benefit from the existence of official valuation matrices required on the computation of symmetric input-output tables. This includes the possibility to correctly distinguish how imports are distributed to industries and institutional sectors, which can greatly influence the results of domestic technical coefficients.

For the years where basic price information is not available, we follow the methodology detailed in Guilhoto et al. (2005), which allocates taxes and margins proportionally to the flows of goods depicted in the use table and the final demand matrix. The shares of the margins for product i to be allocated to each industry or institutional sector j are

$$\alpha_{ij} := \frac{Z_{ij}}{\sum_j Z_{ij}}$$

where $\sum_j Z_{ij}$ represents the total demand in market prices. Similarly, under the assumption that imports follow the same distribution as domestic production, we allocate the vector of imports to intermediate consumption and final demand according to the structure of the flows with respect to the total demand. Taxes on imports are assumed to follow the same distribution as that of imports of goods.

The rectangular use table and final demand matrix at basic prices are obtained by subtracting the values in the valuation matrices (i.e., matrices showing the distribution of taxes and trade and transportation margins) from the original information at purchasers' price. The principle of proportionality by which the valuation matrices are constructed ensures that total supply and total demand will balance.

For the year 2010, the official input-output table published by the IBGE is composed by 67 industries and 127 products. The industry and production corresponding to *domestic services* is withdrawn from the analysis,[20] leaving us with 66 industries and 126 products.

It is worth mentioning that final demand is divided into six institutional sectors. Nevertheless, we only considered one aggregate sector in this analysis, resulting in a final demand vector which includes stock variation. In brief, Table 1 summarizes the useful notations to outline our methodology for the computation of symmetric input-output tables and technical coefficients.[21]

Var.	Variable name
$\mathbf{V}^T$	Supply table at basic prices (prod × ind)
$\mathbf{U}$	Use table at basic prices (prod × ind)
$\mathbf{U_d}$	Use table of domestic goods (prod × ind)
$\mathbf{U_m}$	Use table of imported goods (prod × ind)
$\mathbf{Y}$	Final demand vector (by prod)
$\mathbf{Y_d}$	Final demand vector of domestic goods (by prod)
$\mathbf{Y_m}$	Final demand vector of imported goods (by prod)
$\mathbf{T^{net}_{Ud}}$	Net tax on dom. interm. goods (prod × ind)
$\mathbf{T^{net}_{Um}}$	Net tax on imp. interm. goods (prod × ind)
$\mathbf{T^{net}_{Yd}}$	Tax on dom. final goods (by prod)
$\mathbf{T^{net}_{Ym}}$	Taxes on imp. final goods (by prod)
$\mathbf{W}$	Value added, GDP revenues, and emp.
$\mathbf{q} - \mathbf{m}$	Total domestic production (by prod)
$\mathbf{g}$	Total domestic production (by ind)

Table 1: Notations of matrices provided in the IOT 2010

The IBGE also provides matrix of domestic technical coefficients, for symmetric input-output table (industry-by-industry). The procedure detailed in Perrier and Quirion (2016) (defined shortly) requires, in addition, the square matrices denoting imported and aggregate technical coefficients. For this purpose, we follow Beutel (2008) to compute an industry-by-industry input-output table under their so-called *model D*. This process provides a matching of domestic matrices of technical coefficients with the ones published by the IBGE, and yields additional useful matrices as detailed below.

The fixed product sales structure assumption, presented as *model D*, requires a transformation matrix, $\mathbf{T^M}$, so that

$$\mathbf{T^M} := \mathbf{V}\left(\mathrm{diag}(\mathbf{q}-\mathbf{m})\right)^{-1},$$

where diag(.) is a function that takes a vector in argument and provide a matrix in which the diagonal is composed by the vector. The matrix for intermediates, $\mathbf{B^M}$, and the vector of final demand by industry, $\mathbf{F}$, are given using the transformation matrix

$$\mathbf{B^M} := \mathbf{T^M}\,\mathbf{U} \quad \text{, and} \quad \mathbf{F} := \mathbf{T^M}\,\mathbf{Y}.$$

The decomposition of the intermediaries, $\mathbf{B^M}$, into its domestic ($\mathbf{B^M_d}$) and the imported parts ($\mathbf{B^M_m}$), as well as decomposition of the final consumption, $\mathbf{F}$, into its domestic ($\mathbf{F_d}$) and imported ($\mathbf{F_m}$) parts, follow a similar procedure

$$\mathbf{B^M_d} := \mathbf{T^M}\,\mathbf{U_d}, \qquad \mathbf{B^M_m} := \mathbf{T^M}\,\mathbf{U_m}$$
$$\mathbf{F_d} := \mathbf{T^M}\,\mathbf{Y_d}, \qquad \mathbf{F_m} := \mathbf{T^M}\,\mathbf{Y_m}.$$

Let the aggregate, domestic and imported matrices of tech-

[20] *Domestic services* is not an input for any other sector and does not require intermediate consumption to produce. It uses only labor for its production and all value added is transferred to households as compensation to employees.

[21] For more details on the input-output methodology, see Beutel (2008)

nical coefficients respectively be

$$\mathbf{A} := \mathbf{B^M} \left(\text{diag}(\mathbf{g})\right)^{-1},$$
$$\mathbf{A_d} := \mathbf{B_d^M} \left(\text{diag}(\mathbf{g})\right)^{-1},$$
$$\mathbf{A_m} := \mathbf{B_m^M} \left(\text{diag}(\mathbf{g})\right)^{-1}.$$

Note that under the framework of an industry-by-industry IOT, the national account identity balancing supply and demand (including stock variation) of domestic and foreign goods at basic prices reads

$$\mathbf{g} + \mathbf{m_g} = \mathbf{A}\ \mathbf{g} + \mathbf{F},$$

where, $\mathbf{m_g} := \mathbf{T^M}\ \mathbf{m}$, denotes the vector of imports by industry (i.e., expressed in terms of the industry producing the equivalent domestic good), so that

$$\left(\mathbf{I_n} - A\right)\ \mathbf{g} = \mathbf{F} - \mathbf{m_g},$$
$$\mathbf{g} = \left(\mathbf{I_n} - A\right)^{-1}(\mathbf{F} - \mathbf{m_g}),$$

with I_n be the identify matrix of dimension n. Note that the matrix, $\mathbf{IL} := \left(\mathbf{I_n} - A\right)^{-1}$, is known as the so-called Leontief inverse matrix. The domestic counterpart can be derived by identifying the equilibrium between domestic production and total consumption of domestic goods at basic prices:

$$\mathbf{g} = \mathbf{B_d} + \mathbf{F_d}, \tag{1}$$

from which the throughput, **g**, can be written as

$$\mathbf{g} = \mathbf{A_d}\ \mathbf{g} + \mathbf{F_d}, \tag{2}$$

which yields,

$$\mathbf{g} = \left(\mathbf{I_n} - \mathbf{A_d}\right)^{-1}\mathbf{F_d}$$

where, $\mathbf{IL_d} := \left(\mathbf{I_n} - \mathbf{A_d}\right)^{-1}$, denotes the inverse of the Leontief matrix for domestic production.

3.2 Establishing the rank-size hierarchies of backward and forward linkages

The first methodology used in this paper aims at deriving the economic landscape of a country using the input-output matrix. In order to identify the key sectors of a given economy, we follow the seminal works of Hirschman (1958); Rasmussen (1956) and modern development of Sonis et al. (2000). The philosophy of this approach is to provide empirical evidence to identify the sectors whose change in demand can create above-average impacts on the rest of the economy. In the context of a low-carbon economy, this method to some degree evaluates the potential difficulties of an economy to structurally change. Indeed, if the key sectors–the ones that are creating the most economic activity per additional unit of (final) demand addressed to them–of an economy under investigation is strongly carbon-intensive, a shift in the opposite direction would be harder to tackle.

Let $\mathbf{IL} = [l_{ij}]_{ij}$ be the associated inverse matrix of $\mathbf{A}$. (Rasmussen, 1956) proposes two indicators out of the matrix $\mathbf{IL}$: (i) the power of dispersion for the backward linkages of industry j, $\mathbf{BL}_j$, as follows

$$\mathbf{BL}_j = \frac{1/n \sum_{i=1}^{n} l_{ij}}{1/n^2 \sum_{i,j=1}^{n} l_{ij}};$$

and (ii) the sensitivity of dispersion for forward linkages, $\mathbf{FL}_j$, as

$$\mathbf{FL}_j = \frac{1/n \sum_{j=1}^{n} l_{ij}}{1/n^2 \sum_{i,j=1}^{n} l_{ij}}.$$

The common interpretation is that if $\mathbf{BL}_j > 1$, this indicates that a unit of change in the final demand in sector j will create an above average increase in activity in the economy. Similarly, if $\mathbf{FL}_i > 1$, this means that a unit of change in all sector's final demand would create an above average increase in sector i. As illustrated in Figure 5, a key sector of the economy would be usually defined as one for which both indexes are greater than 1.

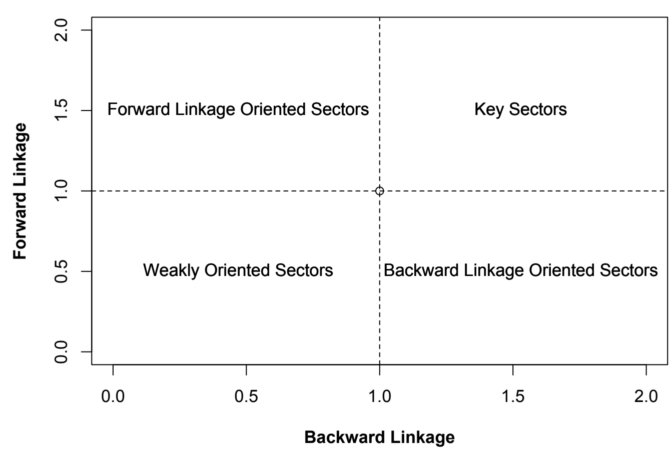

Figure 5: Graphical view of sectoral classification

As pointed out by Sonis et al. (1997, 2000), the backwards and forward linkages imply a rank-size hierarchy. To visualize the economic structure (or landscape) of the economy, one can introduce the input-output multiplier product matrix (hereafter MPM):

$$M = \frac{1}{\sum_{i,j=1}^{n} b_{ij}} \left[\left(\sum_{j=1}^{n} b_{ij} \right)_i \cdot \left(\sum_{i=1}^{n} b_{ij} \right)_j \right]$$

where $[x.y]$ is the scalar product of vector *x* and vector *y*. The MPM matrix will be reorganized in such a way that the larger crosses are located in the diagonal in descending order so that the *economic landscape* will be apparent. The

MPM matrix, M, describes the intensity of the first-order economic impacts of a change in the matrix of direct input A. In other words, it gives us what could be the potential gradient of future economic development. This means that the matrix MPM provides an assessment of whether the future economic development of the country under consideration is drifting towards a low-carbon economy or not.

3.3 Establishing the networking

Network analysis is widely used to enhance our understanding of the role of interdependency in economics on business cycle (Acemoglu et al., 2012; Blöchl et al., 2011), or finance risk (Addo et al., 2015; Battiston et al., 2017).

We closely follow the methodology developed by Campiglio et al. (2017) in this subsection. The aim is to find a structure in highly interconnected economies. When using the matrix of intermediaries, $\mathbf{B^M}$, to find a network, a first limitation arises from the fact that the matrix is not sparse. That is, one given sector buys from and sells to nearly all other sectors. Moreover, the direction in which the purchase (and therefore the sale) is made matters. The use of weight seems convenient to overcome that situation. Using a random walk centrality measure,[22] Blöchl et al. (2011) found in an input-output study that the highest centrality was, by 2/3, the wholesale sector. This result is not surprising in the sense that the normal course of business makes unavoidable use of the trade sector. As the goal of this paper is to highlight the cascade effects, we will rely on the nearest neighbor of the sector of interest. We, shall therefore adapt the matrix, $\mathbf{B^M}$, in order to pinpoint the link of interest. To do so, a starting point could be the threshold method in order to construct a *minimal fully-connected network*. This threshold is evaluated to be the largest value that leaves the network fully connected.

This method will give us a better understanding of how assets are interconnected. Indeed, the monetary flows provided by the intermediaries, $\mathbf{B^M}$, is a valuable source of information on which monetary flows (and ultimately financial) are at stake whenever one sector faces uncertainty on its future economy activity.

3.4 Establishing the employment impact

Perrier and Quirion (2016) puts forward a methodology in order to decompose the employment content spread between input-output sectors into five factors: (i) import rate of final product; (ii) import rate of intermediate consumption; (iii) net taxes rate; (iv) labor intensity; and (v) wage share in the value added.

The intermediary objective of the methodology is to define the employment content of a given economy as the absolute number of jobs ($\mathbf{FTE_j}$) that are necessary to produce 1 million *reais* of final demand towards a given sector j in a given year. This number of jobs includes both direct and indirect jobs. Let, e^T, be a row vector defining the direct employment content. For each industry j, the element e_j^T is obtained by

$$e_j^T := \frac{\mathbf{FTE_j}}{\mathbf{g}_j}.$$

The employment content associated with industry j, ce_j^T, is built following so that

$$ce^T := e^T\, \mathbf{IL_d}.$$

For a more complete assessment, the equation above is redefined so as to obtain the matrix $\mathbf{EC^d}$, whose element $\mathbf{EC^d}_{ij}$ denotes the number of jobs created by industry i due to the final demand addressed to industry j,

$$\mathbf{EC^d} := \text{diag}(e^T)\, \mathbf{IL_d}.$$

To decompose the employment content, we first introduce some definitions. Let, $\mathbf{VA}$, be a row vector of gross value added by industry, included in the matrix all the components of the revenue measure of GDP as well as the number of employees in each industry, $\mathbf{W}$. We define, $\mathbf{VA^d}$, as the row vector representing value added augmented by taxes, where each element VA_j^d is obtained by adding total taxes on domestic and imported inputs of firm j, to its gross value added

$$\mathbf{VA^d} := \mathbf{VA} + \mathbf{1_n}^T\ \left(\mathbf{T^{net}_{Ud}} + \mathbf{T^{net}_{Um}}\right),$$

where, $\mathbf{1_n}$, is a column vector of ones.

Let $\mathbf{VA^{HT}}$ represents the gross value added after other net indirect taxes on production, $\mathbf{T^{O.net}}$, so that

$$\mathbf{VA^{HT}} := \mathbf{VA} - \mathbf{T^{O.net}}.$$

Finally, $\mathbf{COMP}$ is the row vector of compensation to employees, the employment content for each firm j can be decomposed as follows

$$e_j := \frac{\mathbf{FTE_j}}{\mathbf{g}_j} = \frac{\mathbf{VA^d_j}}{\mathbf{g}_j}\, \frac{\mathbf{VA^{HT}_j}}{\mathbf{VA^d_j}}\, \frac{\mathbf{COMP_j}}{\mathbf{VA^{HT}_j}}\, \frac{\mathbf{FTE_j}}{\mathbf{COMP_j}}.$$

Given the definition of $\mathbf{VA^{HT}_j}$ (what remains to be distributed in terms of compensation to employees and gross operating surplus, that is the GDP at basic price), the ratio $\mathbf{VA^{HT}_j}\ /\ \mathbf{VA^d_j}$, represents the weight of taxes in the gross value added, while the ratio $\mathbf{COMP_j}\ /\ \mathbf{VA^{HT}_j}$, shows the relative importance of payment for labor with respect to the capital counterpart (i.e., the wage share). Finally, the ratio $\mathbf{FTE_j}\ /\ \mathbf{COMP_j}$ is the inverse of the mean wage paid in sector j. These last three ratios are hereafter called $\overline{\mathbf{T}}_j$, $\overline{\mathbf{L}}_j$, and $\overline{\mathbf{S}}_j$ respectively.

Let $\overline{\mathbf{MI}}$ be the matrix defined as the element-wise ratio of the inverse of the domestic Leontief, and the global Leontief inverse, so that for each (i, j)

$$\overline{\mathbf{MI}}_{ji} := \frac{\mathbf{IL_d}_{ij}}{\mathbf{IL}_{ij}}$$

[22] The random walk centrality measures the frequency to which each node of the directed graph are visited using a random walk.

As for the vectoral form, employment content (including direct and indirect jobs) is obtained by multiplying the direct employment content for each industry i with the respective elements from the inverse of the domestic Leontief, $\mathbf{IL}_d$

$$ce_i := \mathbf{MF_i} \sum_j \mathbf{IL}_{ji} \mathbf{MI}_{ji} \frac{\mathbf{VA^d_j}}{\mathbf{g}_j} \,\overline{\mathbf{T}}_j \,\overline{\mathbf{L}}_j \,\overline{\mathbf{S}}_j$$

where $\mathbf{MF_i}$ represents the share of total final demand of good i addressed to domestic products $\mathbf{F_{d_i}} \,/\, \mathbf{F_i}$.

By defining, $\mathbf{V_{ji}} := \mathbf{IL}_{ji} \frac{\mathbf{VA^d_j}}{\mathbf{g}_j}$, equation above becomes

$$\begin{aligned} ce_i &= \sum_j \mathbf{EC}_{ij}, \\ &:= \sum_j \mathbf{MF_i} \mathbf{V}_{ji} \mathbf{MI}_{ji} \overline{\mathbf{T}}_j \overline{\mathbf{L}}_j \overline{\mathbf{S}}_j. \end{aligned}$$

Set as a reference decomposition, Perrier and Quirion (2016) introduce the mean employment content $ce_{m,i}$

$$\begin{aligned} ce_{m,i} &= \sum_j \mathbf{EC}_{m,ij} \\ &:= \sum_j \mathbf{MF_m} \mathbf{V}_{m,ji} \,\mathbf{MI}_{m,ji} \,\overline{\mathbf{T}}_\mathbf{m} \,\overline{\mathbf{L}}_\mathbf{m} \,\overline{\mathbf{S}}_\mathbf{m} \end{aligned}$$

with,

$$\begin{aligned} \mathbf{MF_m} &:= \frac{\sum_i \mathbf{F_{d_i}}}{\sum_i \mathbf{F_i}} \\ \overline{\mathbf{T}}_\mathbf{m} &:= \frac{\sum_j \mathbf{VA^{HT}_j}}{\sum_j \mathbf{VA^d_j}} \\ \overline{\mathbf{L}}_\mathbf{m} &:= \frac{\sum_j \mathbf{COMP_j}}{\sum_j \mathbf{VA^{HT}_j}} \\ \overline{\mathbf{S}}_\mathbf{m} &:= \frac{\sum_j \mathbf{FTE_j}}{\sum_j \mathbf{COMP_j}} \\ \mathbf{V}_{m,ji} &:= \mathbf{IL_{m,ji}} \frac{\sum_j \mathbf{VA^d_j}}{\sum_j \mathbf{g}_j} \end{aligned}$$

where the elements of the matrix, $\mathbf{M_m}$, are built so that $\forall i$, $\mathbf{M_{m,ii}} = \mathbf{IL_{d,ii}}/\mathbf{IL_{ii}}$, and $\mathbf{M_{m,ij}} = \mathbf{IL_{d,ij}}/\mathbf{IL_{ij}}$, elsewhere.

The matrix $\mathbf{IL_m}$ is also an intermediate one, built so that $\forall i$, $\mathbf{IL_{m,ii}} = \frac{\sum_i \mathbf{IL_{ii}}}{\#\text{ of sectors}}$, and $\forall i \neq j$, $\mathbf{IL_{m,ij}} = \frac{\sum_i \mathbf{IL_{ji}}}{\#\text{ of sectors}}$.

The employment content for a given industry i, ce_i, can then be defined as a spread with respect to the mean ($ce_{m,i}$)

$$\begin{aligned} ce_i - ce_{m,i} = &\mathbf{MF_i} \sum_j \mathbf{V}_{ji} \,\mathbf{MI}_{ji} \,\overline{\mathbf{T}}_j \,\overline{\mathbf{L}}_j \,\overline{\mathbf{S}}_j \\ &- \mathbf{MF_m} \sum_j \mathbf{V}_{m,ji} \,\mathbf{MI}_{m,ji} \,\overline{\mathbf{T}}_\mathbf{m} \,\overline{\mathbf{L}}_\mathbf{m} \,\overline{\mathbf{S}}_\mathbf{m} \end{aligned}$$

As in Perrier and Quirion (2016), we follow the logarithmic mean Divisia index (LMDI) approach detailed in Ang (2005) to decompose the difference above into the sum of terms, where each of them represents the contribution of a coefficient to the global change in employment content for a given industry i

$$ce_i - ce_{m,i} = \Delta\mathbf{MF_i} + \Delta\mathbf{MI}_i + \Delta\overline{\mathbf{T}}_i + \Delta\overline{\mathbf{L}}_i + \Delta\overline{\mathbf{S}}_i$$

where,

$$\begin{aligned} \Delta\mathbf{MF_i} &= \sum_j \omega_{ij} \ln\Big(\frac{\mathbf{MF_i}}{\mathbf{MF_m}}\Big), \\ \Delta\mathbf{MI}_i &= \sum_j \omega_{ij} \ln\Big(k_{ij} \,\frac{\mathbf{MI_{ji}}}{\mathbf{MI_m}}\Big), \\ \Delta\overline{\mathbf{T}}_i &= \sum_j \omega_{ij} \ln\Big(k_{ij} \frac{\overline{\mathbf{T}}_i}{\overline{\mathbf{T}}_m}\Big), \\ \Delta\overline{\mathbf{L}}_i &= \sum_j \omega_{ij} \ln\Big(k_{ij} \frac{\overline{\mathbf{L}}_i}{\overline{\mathbf{L}}_m}\Big), \\ \Delta\overline{\mathbf{S}}_i &= \sum_j \omega_{ij} \ln\Big(k_{ij} \frac{\overline{\mathbf{S}}_i}{\overline{\mathbf{S}}_m}\Big), \\ k_{ij} &= \Big(\frac{\mathbf{V}_{ji}}{\mathbf{V}_{m,ji}}\Big)^{1/4}, \\ \omega_{ij} &= \frac{\mathbf{EC}_{ij} - \mathbf{EC}_{m,ij}}{\ln(\mathbf{CE}_{ij}) - \ln(\mathbf{CE}_{m,ij})}. \end{aligned}$$

4 Results

This section applies the methodology presented in Section 3. It provides an analysis of the Brazilian economy using input-output tables.

4.1 Where is the economy drifting?

The applications are centered on the Brazilian IOT for the year 2010; a description of the sectors is available in Appendix A. Figure 6 (scatter) plots all the sectors according to their backward linkages on the x-axis and the forward linkages on the y-axis.

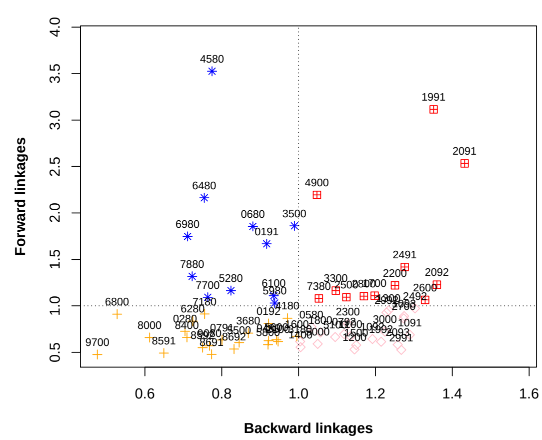

Figure 6: Sector analysis of the Brazilian economy, 2010

According to the classification given by Figure 5, Figure 6 shows the key sectors of the economy in red boxes at the upper right of the quadrant. We can clearly see two groups from the graph that are: (i) the three points that represent oil refining and coke ovens (1991), manufactures of organic and inorganic chemicals, resins and elastomer (2091), and ground transportation (4900); and (ii) the others that are the manufacture of pulp and paper products (1700), manufacture of rubber and plastic products (2200), production of pig iron/ferrous alloys, steel and seamless steel tubes (2491), manufacture of metal products (2500), manufacture of electronic equipment (2600), manufacture of machinery (2800), maintenance, repair and installation of machinery and equipment (3300), and finally other professional, scientific and technical activities (7380).

When analyzing these two lists, we see that that most of the sectors related to manufacturing seem to be key for the Brazilian economy since seven out of the twelve listed sectors are clearly linked to this activity. This result echoes the twofold conclusions of Marconi et al. (2016) that conducted a similar analysis on an 18-sector Brazilian input-output table by averaging from 2000-2009. The conclusions are: first, as they do not show strong linkages, agriculture and mineral commodities production do not show a strong capacity to boost the economy; and second, the sectors related to manufacturing can stimulate the other sectors as it shows high linkages for the other sectors. Our results confirm these conclusions. Furthermore, we notice that the first group, which showed the higher combination of forward and backward linkages, is somehow related to the oil industry. Moreover, we can observe an additional element that is the sector 4580 (wholesale and retail trade) that shows a particularly high forward linkage regarding all the others, which is not surprising given the central role of this sector.

However, one of the deficiencies of the Rasmussen-Hitschman measure is that the sector's weight in the economy is not taken into account: they are not normalized according to each sector's weight. Various approaches have been suggested in the literature (Cuello et al., 1992; Marconi et al., 2016; Miller and Blair, 2009), for instance, by using the proportion of the industry's final demand to total final demand in the economy or by the proportion of the industry's total output to total output in the economy. As a caveat, choosing one method rather than another may alter the results.[23] As this paper focuses on analyzing the interconnection between industry, we will use Gorska (2015)'s weights build upon the intermediate consumption matrix, $\mathbf{B^M}$, in normalizing it by dividing each element of the matrix by the sum of the other elements. Finally these weights will be premultiplied by the Leontief inverse, $\mathbf{IL}$, so that the new Leontief matrix is $\mathbf{ILB^M}/\mathbf{B^T}$, where $\mathbf{B^T}$ is the scalar that represents the sum of all the elements of $\mathbf{B^M}$. Figure 9 shows the result of the normalization procedure.

[23]We leave the test of various methods for another analysis.

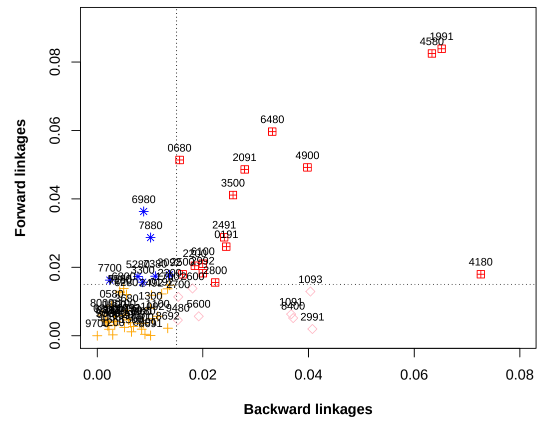

Figure 7: Sector analysis of the *normalized* Brazilian economy, 2010

In order to identify the key sectors, the threshold is set to the mean value of each axis. The main differences given by Figure 9 compared to Figure 6 are threefold: (i) two sectors are clearly central to the economy, that is, 1991 and 4580; (ii) new sectors related to commodities are coming into the picture: extraction of oil and gas (0680), electricity natural gas and utilities (3500) and finally agriculture (0191); and (iii) the sector of financial intermediation (6480) also seem to be a key player in the Brazilian economy.

Turning to the analysis of the MPM, Figure 8 shows the 2010 economic landscape of Brazil.

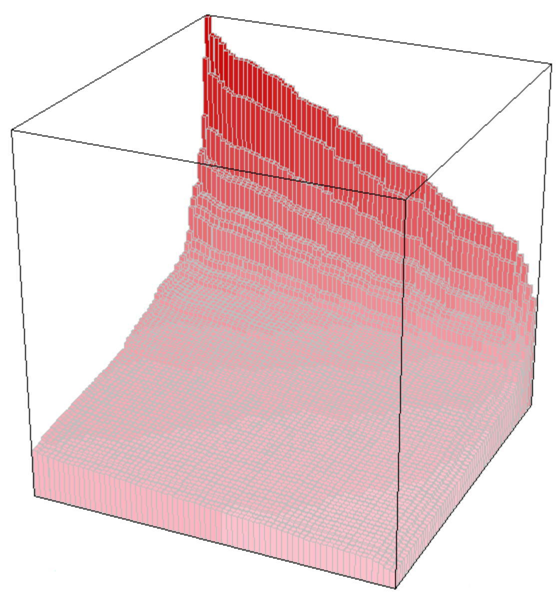

Figure 8: MPM sector analysis of the Brazilian economy, 2010

It shows that some key relationships are far stronger than the others, making the economic landscape concentrated into a few relationships. To see which sectors are concerned, we analyze Table 2, which reports a sub-matrix of the highest values the MPM of dimension 8×8.[24]

	2091	2092	1991	2600	2492	1091	2491	1093
4580	15.94	15.13	15.04	14.79	14.50	14.35	14.20	14.18
1991	14.08	13.37	13.29	13.07	12.81	12.68	12.55	12.53
2091	11.45	10.88	10.81	10.63	10.42	10.31	10.21	10.19
4900	9.92	9.42	9.36	9.21	9.03	8.93	8.84	8.83
6480	9.78	9.29	9.23	9.08	8.90	8.81	8.71	8.70
3500	8.41	7.99	7.94	7.81	7.66	7.58	7.50	7.49
0680	8.39	7.96	7.92	7.79	7.63	7.55	7.47	7.47
6980	7.90	7.50	7.45	7.33	7.19	7.11	7.04	7.03

Table 2: The sub-matrix of the MPM matrix in dimension 8×8 (scale 10^2)

When analyzing the diagonal we observe that the potential of economic activities relies mostly on the interaction of four sectors of activity: 2091, 4580, 1991, plus pesticides and various chemicals (2092). Note also that the use of sectors 3500 and 0680 is also emphasized by Table 2.

We challenge our result using the normalization technique as previously described. Figure 9 plots the updated economic landscape. The latter is much more compressed towards the top left corner of the graph. Table 3 provides the figures attached to this economic landscape.

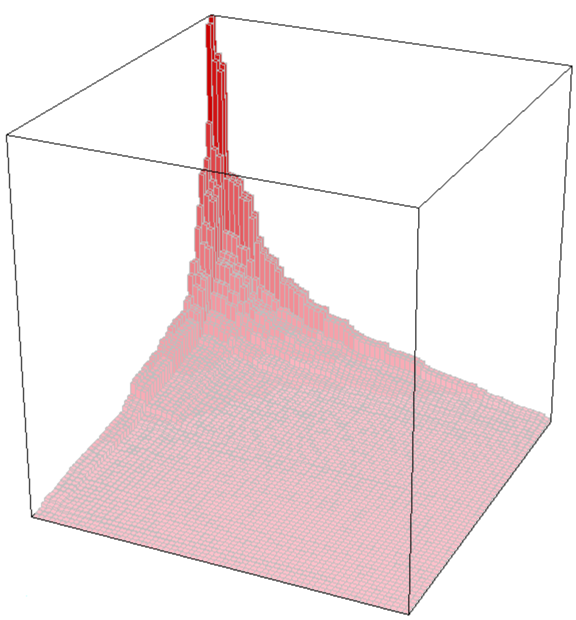

Figure 9: MPM sector analysis of the *normalized* Brazilian economy, 2010

Two sectors remain on the list of the top sectors (4580 and 1991) and two others jump in (4180 and 6480). We can note that a sector like 0680 is ranked just after them.

	4180	1991	4580	2991	1093	4900	8400	1091
1991	1.27	1.14	1.11	0.71	0.71	0.70	0.65	0.64
4580	1.25	1.12	1.09	0.70	0.70	0.69	0.64	0.63
6480	0.90	0.81	0.79	0.51	0.50	0.50	0.46	0.46
0680	0.78	0.70	0.68	0.44	0.43	0.43	0.40	0.39
4900	0.75	0.67	0.65	0.42	0.41	0.41	0.38	0.38
2091	0.74	0.66	0.64	0.41	0.41	0.40	0.38	0.37
3500	0.62	0.56	0.54	0.35	0.35	0.34	0.32	0.32
6980	0.55	0.49	0.48	0.31	0.31	0.30	0.28	0.28

Table 3: The sub-matrix of the *weighted* MPM matrix in dimension 8×8 (scale 10^2)

To conclude, it appears from this economic landscape that Brazilian activities are likely to drift towards sectors that have, most of the time, a direct connection with oil products and that are thus intensive in CO_2 emissions (Hilgemberg and Guilhoto, 2006). From this analysis, we show that the short-term highest leverage for economic growth in Brazil is to go towards CO_2-intensive activities, making it harder to incentivize a low-carbon economy. This result is confirmed by more recent data showing an evolution of the share of green energy that diminished from 44% in 2011 to 39.4% in 2014. Moreover, we use the data from 2010 to 2014 as mentioned in Subsection 3.1, and we replicate the same analysis. The figures displayed in Appendix C show that our conclusions remain unchanged for more recent data and across data-building methodologies.

4.2 Examining the cascade effects

This Subsection is an application of the nearest neighbor methodology outlined in Subsection 3.3. According to Campiglio et al. (2017)'s classification of the basic industry–a sector with intermediate consumptions that are all below the threshold and whose production is used, in turn, as an intermediate consumption–the extractive sector takes a large place. For Brazilian input-output data, groups of sectors are: (i) the extractive activities (coal and non-metallic minerals, 0580; non-ferrous metal ores, 0792), (ii) forest and aquatic activities (0280), and (iii) service activities (printing, 1800; accommodation, 5500; entertainment, 5980; patents, 7380; surveillance and security, 8000). The considered threshold is 1.6 billion *reais*, which implies that almost 91% of the data are taken out from the matrix of intermediaries, $\mathbf{B}^{\mathrm{M}}$.[25]

Another way to account for key sector(s) is the concept of *basic centrality*, which applies to the sectors that have a large preponderance of the forward and the backward linkages and low random walk centrality score. The (scatter) plot illustrated in Figure 10 applies this definition and shows that the unique sector that matches with the concept of *basic centrality* is the wholesale. This finding seems at odds with Campiglio et al. (2017) when applying that definition for France, however, we also find that the other sector

[24]A larger table, 20×20, is available in Appendix B.

[25]In light of Campiglio et al. (2017), finding that the extractive sector is a basic sector is not surprising. However, the sensitivity analysis of that result with multiple countries is left for further research.

that is the closest in line with this definition is agriculture (0191).

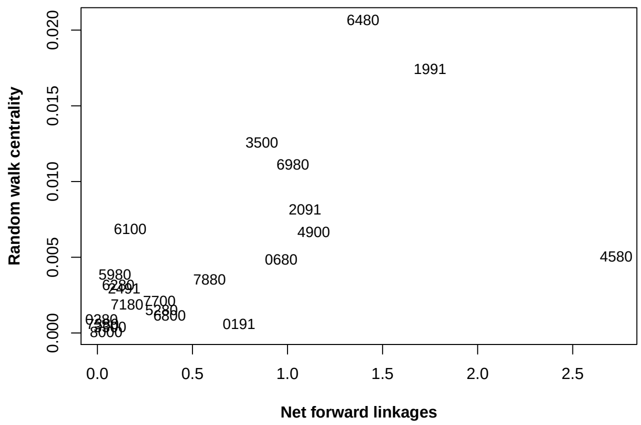

Figure 10: Random walk centrality vs. net forward linkages for sectors with positive net forward linkages in Brazil, 2010

Additionally, in the light of Figure 10, the financial intermediation (6480) sector is shown to be frequently visited (approximately 20% in the y-axis), which demonstrate a particularly high centrality, given the methodology with threshold under consideration. This confirms the World Bank (2016)'s views about the high cost of finance and its central role in the Brazilian economy. In comparison with France, where the financial services sector does not appear on a similar graph, financial intermediation in Brazil sees high value monetary flows transiting throughout this sector that makes it potentially systemic. Moreover, sectors related to the use of fossil fuels show a rather high centrality: oil refining (1991), chemical manufacturing (2091), or oil extraction (0680), combined represent 30% of the visits. Also, the sector of electricity (3500) has high centrality. Finally, three other sectors are visited more than 5% that are justice (6980), telecommunications (6100), and ground transportation (4900).

An inverted pyramid is illustrated in Figure 11 with the sector of oil extraction (0680) at the base. The nearest neighbors to this sector are shown in the row above, the nearest neighbors of the nearest neighbors in the new row, and so on, meaning that the higher it appears, the less connected it is.

[26]In this analysis we link sector 0680 to this company.

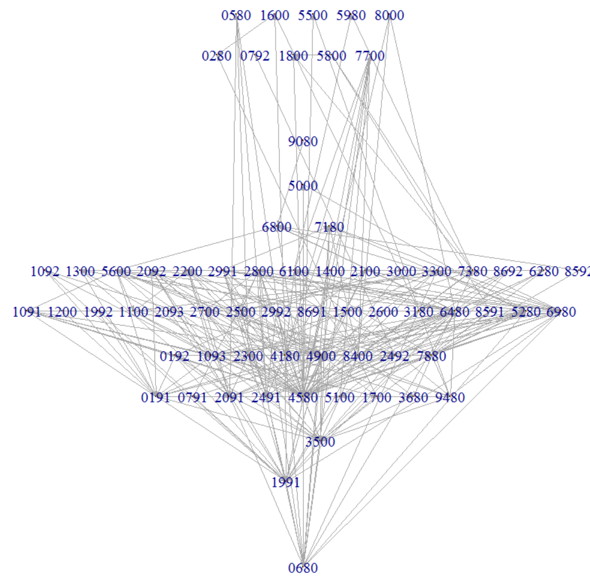

Figure 11: The inverted pyramid: Minimal fully-connected network with oil extraction at the base, Brazil, 2010

The connections shown in Figure 11 illustrate a situation when the assets of major oil company (0680) is put as risk.[26] The cascade goes as follows: the nearest neighbor to 0680 is coke and refined petroleum (1991) and closely the utilities (3500) as the latter also accounts for the transportation of natural gas. Interestingly, the nearest neighbors or the nearest neighbors can be classified into seven groups: (i) agriculture (0191,0192,1093); (ii) minerals (0791,2300,2491,2492); (iii) transport (4900,5100); (iv) construction (4180); (v) wholesale (4580); (vi) manufacture of organic and inorganic chemicals, resins, and elastomer (2091); (vii) public administration (8400,7880); (viii) water (3680); (ix) paper (1700); and association activities (9480).

4.3 Will the energy shift be in favor of sectors with high employment content?

Which factors may explain differences across the sectoral employment content? Let us first consider the standard deviation of each factor derived in Subsection 3.4. The higher the value is, the more variation it explains.

Factor	Stand. dev
$\Delta\bar{\mathbf{S}}$	17.69
$\Delta\bar{\mathbf{L}}$	7.41
$\Delta\mathbf{MI}$	1.67
$\Delta\mathbf{MF}$	1.27
$\Delta\bar{\mathbf{T}}$	1.02

Table 4: Standard deviation of each factors ranked ascendingly, 2010

Table 4 shows the result of the LMDI decomposition applied for 66 sectors in the Brazilian economy in 2010. We do not perform a sensitivity analysis with the other years as the assumptions made on these data are not suitable for the decomposition under consideration. We note that the most significant factor to explain discrepancies in employment between sectors is wages ($\Delta\overline{\mathbf{S}}$), followed by the wage share in value added ($\Delta\overline{\mathbf{L}}$); the other factors, in magnitude are of second order and are ranked as follow, the import rate of products for the intermediate consumption ($\Delta\mathbf{MI}$), and of final products ($\Delta\mathbf{MF}$), and interestingly, taxes and subsidies ($\Delta\overline{\mathbf{T}}$) plays a rather minor role. This classification is consistent with the finding of Perrier and Quirion (2016) when applying this methodology for France.

We show in Appendix D the result of the methodology for the 66 sectors in 2010 of the Brazilian economy. In general, we can see that the industrial related sectors are below national average with few notable exceptions in apparel and food-related industries. Moreover, the key sectors of Subsection 4.1 are shown to be uniformly under the mean value. This suggests that there is an implicit trade-off between maximizing (fossil) GDP and minimizing unemployment. However, it is worth noticing that all the energy sectors are also below average, with one exception: the manufacture of biofuel. Let us now turn to the analysis of two examples.

Figure 12: Employment content decomposition of oil refining versus manufacture of biofuel

Figure 12 shows the employment content of the two sectors under consideration. We note that the sector of biofuel has a positive employment content against a negative one for the sector of oil refining. We explain the difference primarily by the more attractive wages in the biofuel sector. Second, (net) taxes are strongly penalizing the indicator for sector 1991 and slightly diminishing that for 1992. We conclude that a policy which targets biofuel rather than refined oil is more likely to create jobs to the extent of 20 jobs per million *reais*. Again, as pointed out by Perrier and Quirion (2016), this methodology does not take into account inter-sectoral frictions or the inertia in the goods and the labor market.

Example 1: increase the share of sustainable biofuel In its NDC, Brazil is committed to increase the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030 by expanding biofuel consumption, increasing ethanol supply, including by increasing the share of advanced biofuels (second generation), and increasing the share of biodiesel in the diesel mix. In terms of our sectoral representation, this would mean that the demand for manufacturing biofuel (1992) will increase to the detriment of oil refining and coke ovens (1991). Before starting the analysis, a caveat would be that an increase in demand of one *real* in the sector (1992) would not write off one *real* of demand for the sector (1991). The idea is to provide a first-order approximation of what would be the employment content in the short run when substituting, say, a subsidy of one *real* from one sector to the other.

Example 2: achieving 45% of renewables Brazil aims to achieve 45% of renewables in the energy mix by 2030, including expanding the use of renewable energy sources other than hydropower in the total energy mix to between 28% and 33% by 2030; and expanding the use of non-fossil fuel energy sources domestically, increasing the share of renewables (other than hydropower) in the power supply to at least 23% by 2030, including by raising the share of wind, biomass and solar. In the sectoral decomposition of the Brazilian economy, it is impossible to distinguish what is nuclear, wind, or solar in the electricity sector (3500) as well as spatial decomposition. However, comparing the sector (3500) to the extraction of oil (0680) and the extraction of coal and non-metallic minerals (0580) give insights on the impact of such a policy within the labor market.

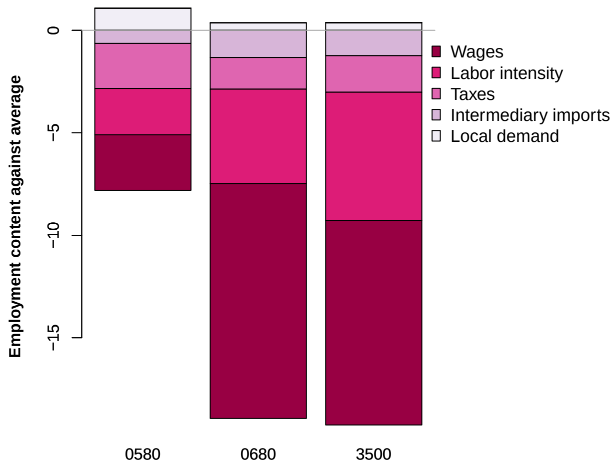

Figure 13: Employment content decomposition of coal extraction, oil extraction and utilities

Figure 13 displays the employment content of the three sectors under consideration. Interestingly, it seems that the sector of utilities (3500) and the one of oil extraction (0680) look alike. Despite the fact that all three sectors are below average, shifting one million *reais* from the sector of coal extraction (0580) to utilities (3500) will come with the destruction of almost 12 jobs as wages and labor intensity are significantly less attractive in the utilities sector.

To conclude both examples, we took two examples from the orientations given by the NDC and we show that shifting activities from 1991 to 1992 is likely to be a job-creating shift while going away from the extracting sector may increase unemployment.

5 On building a multisectoral model

So far, we have extensively used IOT information to provide an exhaustive economic landscape of Brazil. This section aims to sum up our conclusions and provide guidance for macroeconomic modelers in elaborating their financial models of economic activities put at risk in a low-carbon economy. Of course, every model should be designed to answer one specific research question. In this paper, we emphasize the role of the key sectors for developing a macroeconomic model focusing on the objective of shaping a low-carbon economy.

5.1 Analyzing other institutional sectors

In terms of institutional sectors, the input-output matrix provides a useful source of information on: (i) public administration (8400, for the government); and (ii) financial intermediaries (6480, for the financial sector). Those sectors are previously mentioned as particularly important for Brazil.

Moving to the analysis of public administration, the inverted matrix is shown in Figure 14.

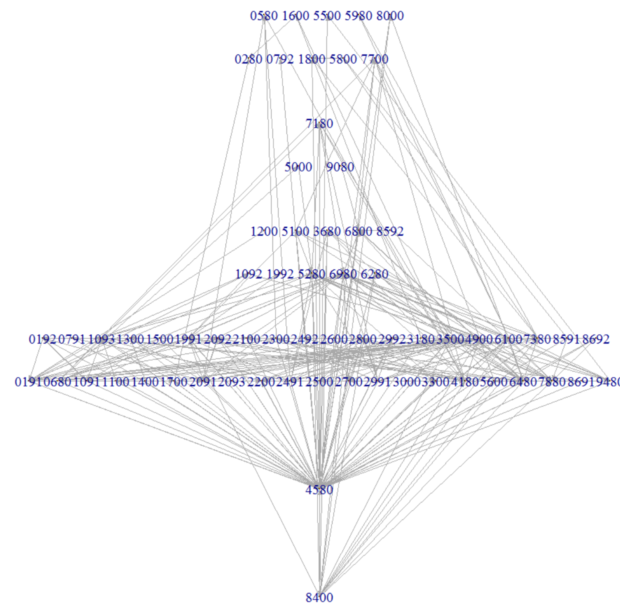

Figure 14: The inverted pyramid: Minimal fully-connected network with public administration at the base, Brazil, 2010

The nearest neighbor is unambiguously the wholesale sector (4580), and the latter's nearest neighbors encompass almost 2/3 of the economy. This once again emphasizes the pivotal role of the wholesale sector in the Brazilian sectoral network. It shows that we should pay, depending on the research question, particular attention to this sector as a shrinking of activity (or balance sheet) may have potential systemic consequences throughout the other sectors.

The other sector under investigation is financial intermediaries. Each nearest neighbor that we will find are, by design, using high value monetary flows of finance as input. Figure 15 plots the inverse pyramid.

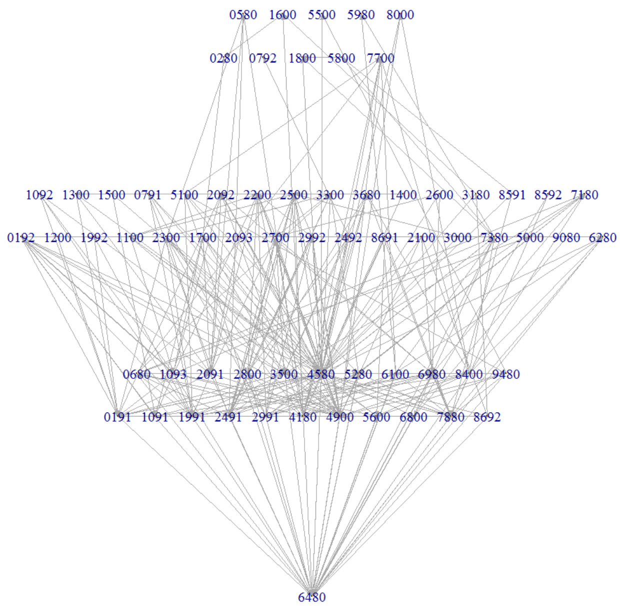

Figure 15: The inverted pyramid: Minimal fully-connected network with financial intermediation at the base, Brazil, 2010

We can design the following groups: (i) oil sector (0680,1991); (ii) agriculture and food (0191, 1091, 1093); (iii) physical capital (2800, 2991, 4180); (iv) transport (4900, 5280, 6100); (v) services (6980, 6800, 7880, 8692, 9480); (vi) government (8400); (vii) utilities (3500); (viii) chemicals (2091); and production of pig iron (2491). With few exceptions, in general, this list and the one described in Subsection 4.2 look alike, showing a non-obvious interlink between finance and the oil industry. Moreover, the data shows that there is a high interdependence between the financial and energy sectors that should be dealt with as a common topic by the policy makers when designing a low-carbon policy.

5.2 A sectoral decomposition

Again, the goal is not to provide "the" optimal decomposition of the economy for a holistic model, but rather to have an outline of the basic building blocks in conceptualizing a low-carbon economy. Of course, this decomposition can be altered depending on the research question.

Sector group	Sectors code
Oil	(0680,1991)
Agriculture	(0191, 0192, 1091, 1093)
Physical capital	(2800, 2991, 4180)
Transports	(4900, 5100, 5280, 6100)
Utilities	(3500)
Government	(8400, 7880)
Chemicals	(2091)
Minerals	(0791,2300,2491,2492)
Wholesale	(4580)
Water	(3680)
Finance	(6480)
Services	(6980, 6800, 7880, 8692, 9480)
Composite1	(2491, 1700)
Composite2	The other 35 sectors

Table 5: Proposition of sectoral decomposition

Table 5 illustrates a proposition of sectoral decomposition with, in green, the nearest neighbor of finance, in orange, the ones of the oil extracting sector, and, in black, the common ones (at the exception of the sectors themselves). A few comments are worth making: first, most of the proposed decomposition seems intuitive as the majority of the Brazilian models listed in Subsection 1.1 entail similar frameworks; second, two composite goods are put forward, with one that gathers 35 sectors; third, the major part of mineral activities depend on oil rather than finance, as well as wholesale and water.

The choice of isolating the chemical, wholesale and water sectors is derived from the previous analysis. The chemicals sector has been shown to have a high potential for future growth according to the MPM methodology. Furthermore, its high centrality demonstrates that this sector is a key player in the Brazilian economy. The MPM methods clearly shows that wholesale has a great potential to generate economic activity and this sector is as well the one corresponding to the concept of basic centrality. Finally, the choice to isolate the water sector is motivated by the World Bank (2016)'s recommendations. Indeed, this sector has faced and will face a great deal of climate challenges and remain at the core of Brazil electricity matrix development in the planning for the ten years ahead.

As illustrated in Figure 1, the interlinkages are not limited to the real economy; flow of funds should be taken into account more carefully. We do not tackle this aspect at length in this paper and leave it for further research. However, stranding of financial assets may lead to credit tightening in a given sector, depression of investment and increasing default risks. Nevertheless, using input-output information, this paper's conclusion echoes Jerneck (2017)'s results concerning the strong interconnectedness of modern financial systems and the financialization of the energy sector. As concluded by Campiglio et al. (2017), the SFC approach seems to be better suited in order to deal with the challenges of stranded assets and financial contagion.

6 Concluding remarks

The change of economic model expected in the aftermath of the Paris Agreement will certainly have direct and indirect negative impacts on specific sectors for every country. Further exacerbated by recent research (Meinshausen et al., 2009; Nordhaus, 2017; Stern, 2016) that plead for a strong uptake in action, these impacts could be even stronger than previously anticipated. To assess the transmission channel of these impacts, two layers of the economy can be put forward: First, the real economic (or physical) layer through the network provided by intersectoral dependencies in the production structure; and second, the financial layer through the balance sheet structure of the institutional sectors. In this paper, we focus on the first channel, and we perform an analysis of the industrial linkages obtained from the Brazilian input-output matrix for 2010. The principal goal is to provide a better understanding of the current main challenges for the Brazilian economy to move towards a low-carbon transition in Brazil.

Using forward and backward linkages methods, we have identified two groups of key industries for the economy: (i) oil refining and coke ovens (1991), manufacture of organic and inorganic chemicals, resins and elastomer (2091), and ground transportation (4900); and (ii) the others, which are the manufacture of pulp and paper products (1700), manufacture of rubber and plastic products (2200), production of pig iron/ferrous alloys, steel and seamless steel tubes (2491), manufacture of metal products (2500), manufacture of electronic equipment (2600), manufacture of machinery (2800), maintenance, repair and installation of machinery and equipment (3300), and finally other professional, scientific and technical activities. Results show that the production of agricultural and mineral commodities does not have a strong capacity to stimulate the domestic economy, while manufacturing sectors, through stronger links, do so.

The analysis of a normalized intermediate consumption matrix shows that (i) sectors 1991 and wholesale (4580) are clearly central to the economy; and (ii) new sectors related to commodities are coming into the picture, namely extraction of oil and gas (0680), electricity natural gas and utilities (3500) and finally, agriculture (0191); and (iii) the sector of financial intermediation (6480) also seems to be a key player in the Brazilian economy. Results on the importance of sectors linked to the production of fossil energies are reinforced when studying the economic landscape of the country. Brazilian activities seem likely to drift towards sectors that have, most often, a direct connection with oil products and that are intensive in CO_2 emissions. This shows that the short-term highest leverage for economic growth in Brazil implies going towards CO_2-intensive activities, which makes it harder to incentivize a low-carbon economy. Such a result is confirmed by more recent data that shows a decrease of nearly five percentage points in the share of green energy from 2011 to 2014. Beyond the significant importance of the oil-related sectors for the Brazilian economy, there is the fact that the main firm in that sector is a semi-public company. This implies a particular configuration on how the effects of a shift will affect the different institutional agents and provides the possibility for alternative measures to palliate such an impact. In addition, it reinforces the need for a further analysis where balance sheets are explicitly taken into account to assess the channels by which the shock will spread.

This paper is complemented by studying the differences in employment content and its composition under the assumption of shifting demand from fossil to green energies. Indeed, a shift in activities from the oil refining sector (1991) to biofuels (1992) is likely to be job-creating, while moving away from the extracting sector may increase unemployment.

Furthermore, we suggest a disaggregation of industries satisfying a minimal requirement of sectors and allowing us to classify the industries interdependency in order to track possible contagion effects of stranded assets within the real economy. Results show a high interdependence between the financial and the energy sectors that should be accounted for when dealing with policy design for a low-carbon transition. Moreover, we find what we consider to be an intuitive intuitive disaggregation except for the wholesale and chemicals sectors that should be treated with a particular attention.

A follow-up of this paper would be to pursue this analysis using capital stock and flow of funds data on the sectors analyzed in this paper and further complemented with a macroeconomic model. In terms of IAM models in Brazil, the state-of-the-art is listed in Subsection 1.1. All models (besides MESSAGE) rely on the class of macroeconomic models known as computable general equilibrium (or CGE). To the best of our knowledge, most of these models neither represent financial intermediation nor financial assets. The noticeable exception of IMACLIM-S BR considers the financial market (and thus interest payments) to build its social accounting matrix (SAM). Households, firms and government have access to credit, which is a cost and an income inside the system. However, this modelling approach is inherently centered on flows that gravitate around an equilibrium, making it difficult to distinguish flows and stocks. Indeed, interest rates and financial capital flows are flexible enough to guarantee fixed capital market equilibrium. Therefore, modelling change in behaviors whenever some stocks are weakening the balance sheet of a particular agent is difficult to take into account (Koo, 2011, 2013). This drawback represents a strong limitation in tackling the "cascade effects" in a macroeconomic model as described in an earlier subsection. We argue that a so-called stock-flow consistent approach (hereafter SFC), based on detailed balance sheet, transactions and flow of funds of the economy under investigation seems the most legitimate to grasp the dynamics of balance sheet contagion effects.

Finally, we answer the question "What would a low-carbon economy for Brazil mean?" by: A lot of challenges. Indeed, somewhat driven by what Lula called *the second independence of Brazil*, our results show that the trend of the economy is towards a CO_2-intensive industry, along with a high linkage between finance and oil sector at a time when the oil industry in Brazil is one of the most indebted sectors in the world. Moreover, breaking the trend found in the data will likely have a mixed effect on the labor market. Yet, history has proven that, in Brazil, large-scale reforms can be reached at milestones (*Plano real*, 1994; the *Fiscal Responsibility Law*, 2000; or the *Amazônia Legal*, 2004).

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Appendices

A Sector codes

Code	Portuguese label	English label
0191	Agricultura, inclusive o apoio agricultura e a pós-colheita	Agriculture, including support for agriculture and post-harvest
0192	Pecuária, inclusive o apoio à pecuária	Livestock, including support for livestock
0280	Produção florestal; pesca e aquicultura	Forest production; fisheries and aquaculture
0580	Extração de carvão mineral e de minerais não-metálicos	Extraction of coal and non-metallic minerals
0680	Extração de petróleo e gás, inclusive as atividades de apoio	Extraction of oil and gas, including support activities
0791	Extração de minério de ferro inclusive beneficiamentos e a aglomeração	Extraction of iron ore, including processing and agglomeration
0792	Extração de minerais metálicos não-ferrosos, inclusive beneficiamentos	Extraction of non-ferrous metal ores, incl.
1091	Abate e produtos de carne, inclusive os produtos do laticínio e da pesca	Slaughter and meat products, including dairy products and fishery products
1092	Fabricação e refino de açúcar	Manufacture and refining of sugar
1093	Outros produtos alimentares	Other food products
1100	Fabricação de bebidas	Manufacture of beverages
1200	Fabricação de produtos do fumo	Manufacture of tobacco products
1300	Fabricação de produtos têxteis	Manufacture of textiles
1400	Confecção de artefatos do vestuário e acessórios	Manufacture of wearing apparel and accessories
1500	Fabricação de calçados e de artefatos de couro	Manufacture of footwear and leather goods
1600	Fabricação de produtos da madeira	Manufacture of wood products
1700	Fabricação de celulose, papel e produtos de papel	Manufacture of pulp, paper and paper products
1800	Impressão e reprodução de gravações	Printing and reproduction of recordings
1991	Refino de petróleo e coquerias	Oil refining and coke ovens
1992	Fabricação de biocombustíveis	Manufacture of biofuels
2091	Fabricação de químicos orgânicos e inorgânicos, resinas e elastômeros	Manufacture of organic and inorganic chemicals, resins and elastomers
2092	Fabricação de defensivos, desinfestantes, tintas e químicos diversos	Manufacture of pesticides, disinfectants, dyes and various chemicals
2093	cosméticos/perfumaria e higiene pessoal Fabricação de produtos de limpeza,	Manufacture of cleaning products, cosmetics/perfumes and toilet preparations
2100	Fabricação de produtos farmoquímicos e farmacêuticos	Manufacture of pharmaceutical and pharmaceutical goods
2200	Fabricação de produtos de borracha e de material plástico	Manufacture of rubber and plastic products
2300	Fabricação de produtos de minerais não-metálicos	Manufacture of non-metallic mineral products
2491	Produção de ferro-gusa/ferroligas, siderurgia e tubos de aço sem costura	Production of pig iron/ferrous alloys, steel and seamless steel tubes
2492	Metalurgia de metais não-ferrosos e a fundição de metais	Non-ferrous metal metallurgy and metal casting
2500	Fabricação de produtos de metal, exceto máquinas e equipamentos	Manufacture of metal products, except machinery and equipment
2600	Fabricação de equipamentos de informática, produtos eletrônicos e ópticos	Manufacture of computer equipment, electronic and optical products

Note that for the year 2010, items 4500 and 4680 are compounded and makes 4580 *Comércio por atacado e varejo* (Wholesale and retail trade).

Code	Portuguese label	English label
2700	Fabricação de máquinas e equipamentos elétricos	Manufacture of electrical machinery and equipment
2800	Fabricação de máquinas e equipamentos mecânicos	Manufacture of machinery and mechanical equipment
2991	Fabricação de automóveis, caminhões e ônibus, exceto peças	Manufacture of cars, trucks and buses, except part
2992	Fabricação de peças e acessórios para veículos automotores	Manufacture of parts and accessories for motor vehicles
3000	Fabricação de outros equipamentos de transporte, exceto veículos automotores	Manufacture of other transport equipment, except motor vehicles
3180	Fabricação de móveis e de produtos de indústrias diversas	Manufacture of furniture and products of other
3300	Manutenção, reparação e instalação de máquinas e equipamentos	Maintenance, repair and installation of machinery and equipment
3500	Energia elétrica, gás natural e outras utilidades	Electricity, natural gas and other utilities
3680	Água, esgoto e gestão de resíduos	Water, sewage and waste management
4180	Construção	Construction
4500	Comércio e reparação de veículos automotores e motocicletas	Trade and repair of motor vehicles and motorcycles
4680	Comércio por atacado e a varejo, exceto veículos automotores	Wholesale and retail trade, except motor vehicles
4900	Transporte terrestre	Ground transportation
5000	Transporte aquaviário	Waterway transport
5100	Transporte aéreo	Air transport
5280	Armazenamento, atividades auxiliares dos transportes e correio	Storage, auxiliary transport and mail activities
5500	Alojamento	Accommodation
5600	Alimentação	Power supply
5800	Edição e edição integrada à impressão	Print-integrated editing and editing
5980	Atividades de televisão, rádio, cinema e gravação/edição de som e imagem	Television, radio, cinema and sound recording and reproducing activities
6100	Telecomunicações	Telecommunications
6280	Desenvolvimento de sistemas e outros serviços de informação	Development of systems and other information services
6480	Intermediação financeira, seguros e previdência complementar	Financial intermediation, insurance and supplementary pension
6800	Atividades imobiliárias	Real estate activities
6980	Atividades jurídicas, contábeis, consultoria e sedes de empresas	Legal, accounting, consulting and corporate headquarters activities
7180	Serviços de arquitetura, engenharia, testes/análises técnicas e P&D	Architectural, engineering, testing/technical analysis and R&D
7380	Outras atividades profissionais, científicas e técnicas	Other professional scientific and technical activities
7700	Aluguéis não-imobiliários e gestão de ativos de propriedade intelectual	Non-Real Estate Rentals and Intellectual Property Asset Management
7880	Outras atividades administrativas e serviços complementares	Other administrative and supplementary services
8000	Atividades de vigilância, segurança e investigação	Surveillance, security and investigation activities
8400	Administração pública, defesa e seguridade social	Public administration, defense and social security
8591	Educação pública	Public education
8592	Educação privada	Private education
8691	Saúde pública	Public health
8692	Saúde privada	Private health
9080	Atividades artísticas, criativas e de espetáculos	Artistic, creative and entertainment activities
9480	Organizações associativas e outros serviços pessoais	Associations and other personal services

B Tables of the MPM matrix

	2091	2092	1991	2600	2492	1091	2491	1093	2700	2991	2093	2200	1300	2992	3000	1992	1700	1092	2800	1500
4580	15.94	15.13	15.04	14.79	14.50	14.35	14.20	14.18	14.17	14.10	14.00	13.92	13.74	13.68	13.63	13.52	13.33	13.27	13.02	12.80
1991	14.08	13.37	13.29	13.07	12.81	12.68	12.55	12.53	12.52	12.46	12.37	12.30	12.14	12.08	12.04	11.95	11.78	11.72	11.50	11.31
2091	11.45	10.88	10.81	10.63	10.42	10.31	10.21	10.19	10.18	10.13	10.06	10.00	9.87	9.83	9.79	9.71	9.58	9.53	9.36	9.20
4900	9.92	9.42	9.36	9.21	9.03	8.93	8.84	8.83	8.82	8.78	8.72	8.67	8.55	8.51	8.48	8.42	8.30	8.26	8.10	7.97
6480	9.78	9.29	9.23	9.08	8.90	8.81	8.71	8.70	8.70	8.65	8.59	8.54	8.43	8.39	8.36	8.30	8.18	8.14	7.99	7.85
3500	8.41	7.99	7.94	7.81	7.66	7.58	7.50	7.49	7.48	7.45	7.39	7.35	7.25	7.22	7.20	7.14	7.04	7.00	6.87	6.76
0680	8.39	7.96	7.92	7.79	7.63	7.55	7.47	7.47	7.46	7.42	7.37	7.33	7.23	7.20	7.17	7.12	7.02	6.98	6.85	6.74
6980	7.90	7.50	7.45	7.33	7.19	7.11	7.04	7.03	7.03	6.99	6.94	6.90	6.81	6.78	6.76	6.70	6.61	6.58	6.45	6.34
0191	7.54	7.16	7.11	7.00	6.86	6.79	6.72	6.71	6.70	6.67	6.62	6.58	6.50	6.47	6.45	6.40	6.31	6.28	6.16	6.05
2491	6.41	6.09	6.05	5.95	5.83	5.77	5.71	5.71	5.70	5.67	5.63	5.60	5.53	5.50	5.48	5.44	5.36	5.34	5.24	5.15
7880	5.96	5.66	5.62	5.53	5.42	5.36	5.31	5.30	5.30	5.27	5.23	5.20	5.13	5.11	5.09	5.05	4.98	4.96	4.87	4.78
2092	5.55	5.27	5.24	5.15	5.05	5.00	4.95	4.94	4.94	4.91	4.88	4.85	4.78	4.76	4.75	4.71	4.64	4.62	4.54	4.46
2200	5.52	5.24	5.21	5.12	5.02	4.97	4.92	4.91	4.91	4.88	4.85	4.82	4.76	4.74	4.72	4.68	4.62	4.59	4.51	4.43
5280	5.26	5.00	4.97	4.89	4.79	4.74	4.69	4.68	4.68	4.66	4.62	4.60	4.54	4.52	4.50	4.46	4.40	4.38	4.30	4.23
3300	5.26	5.00	4.97	4.89	4.79	4.74	4.69	4.68	4.68	4.66	4.62	4.60	4.54	4.52	4.50	4.46	4.40	4.38	4.30	4.23
1700	5.02	4.76	4.73	4.66	4.56	4.52	4.47	4.46	4.46	4.44	4.41	4.38	4.32	4.30	4.29	4.25	4.19	4.18	4.10	4.03
6100	5.01	4.76	4.73	4.65	4.56	4.52	4.47	4.46	4.46	4.44	4.41	4.38	4.32	4.30	4.29	4.25	4.19	4.17	4.10	4.03
2800	4.99	4.74	4.71	4.63	4.54	4.49	4.45	4.44	4.44	4.42	4.39	4.36	4.30	4.28	4.27	4.23	4.18	4.16	4.08	4.01
2500	4.94	4.69	4.66	4.59	4.50	4.45	4.40	4.40	4.40	4.37	4.34	4.32	4.26	4.24	4.23	4.19	4.13	4.11	4.04	3.97
7700	4.94	4.69	4.66	4.58	4.49	4.45	4.40	4.39	4.39	4.37	4.34	4.31	4.26	4.24	4.22	4.19	4.13	4.11	4.03	3.96

Table 6: The first 20 entries of the MPM matrix (10^2)

	4180	1991	4580	2991	1093	4900	8400	1091	6480	2091	3500	0191	2491	2800	6100	2992	5600	2200	2600	2500
1991	1.27	1.14	1.11	0.71	0.71	0.70	0.65	0.64	0.58	0.49	0.45	0.43	0.42	0.39	0.35	0.35	0.34	0.32	0.32	0.28
4580	1.25	1.12	1.09	0.70	0.70	0.69	0.64	0.63	0.57	0.48	0.44	0.42	0.41	0.38	0.34	0.34	0.33	0.32	0.31	0.28
6480	0.90	0.81	0.79	0.51	0.50	0.50	0.46	0.46	0.41	0.35	0.32	0.30	0.30	0.28	0.25	0.25	0.24	0.23	0.22	0.20
0680	0.78	0.70	0.68	0.44	0.43	0.43	0.40	0.39	0.36	0.30	0.28	0.26	0.26	0.24	0.21	0.21	0.21	0.20	0.19	0.17
4900	0.75	0.67	0.65	0.42	0.41	0.41	0.38	0.38	0.34	0.29	0.26	0.25	0.25	0.23	0.21	0.21	0.20	0.19	0.19	0.17
2091	0.74	0.66	0.64	0.41	0.41	0.40	0.38	0.37	0.34	0.28	0.26	0.25	0.24	0.23	0.20	0.20	0.20	0.19	0.18	0.16
3500	0.62	0.56	0.54	0.35	0.35	0.34	0.32	0.32	0.28	0.24	0.22	0.21	0.21	0.19	0.17	0.17	0.16	0.16	0.15	0.14
6980	0.55	0.49	0.48	0.31	0.31	0.30	0.28	0.28	0.25	0.21	0.19	0.19	0.18	0.17	0.15	0.15	0.15	0.14	0.14	0.12
2491	0.44	0.39	0.38	0.24	0.24	0.24	0.22	0.22	0.20	0.17	0.15	0.15	0.14	0.13	0.12	0.12	0.12	0.11	0.11	0.10
7880	0.44	0.39	0.38	0.24	0.24	0.24	0.22	0.22	0.20	0.17	0.15	0.15	0.14	0.13	0.12	0.12	0.12	0.11	0.11	0.10
0191	0.39	0.35	0.34	0.22	0.22	0.22	0.20	0.20	0.18	0.15	0.14	0.13	0.13	0.12	0.11	0.11	0.10	0.10	0.10	0.09
6100	0.32	0.29	0.28	0.18	0.18	0.17	0.16	0.16	0.15	0.12	0.11	0.11	0.11	0.10	0.09	0.09	0.08	0.08	0.08	0.07
2200	0.31	0.28	0.27	0.17	0.17	0.17	0.16	0.16	0.14	0.12	0.11	0.10	0.10	0.10	0.09	0.09	0.08	0.08	0.08	0.07
2992	0.28	0.25	0.24	0.16	0.15	0.15	0.14	0.14	0.13	0.11	0.10	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.07	0.06
4180	0.27	0.24	0.24	0.15	0.15	0.15	0.14	0.14	0.12	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07	0.06
2500	0.27	0.24	0.24	0.15	0.15	0.15	0.14	0.14	0.12	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07	0.06
2092	0.27	0.24	0.24	0.15	0.15	0.15	0.14	0.14	0.12	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07	0.06
7380	0.26	0.24	0.23	0.15	0.15	0.14	0.13	0.13	0.12	0.10	0.09	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07	0.06
5280	0.26	0.24	0.23	0.15	0.15	0.14	0.13	0.13	0.12	0.10	0.09	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.07	0.06
7700	0.25	0.22	0.21	0.14	0.14	0.13	0.13	0.12	0.11	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.05

Table 7: The first 20 entries of the weighted MPM matrix (10^2)

C Sensitivity along the years

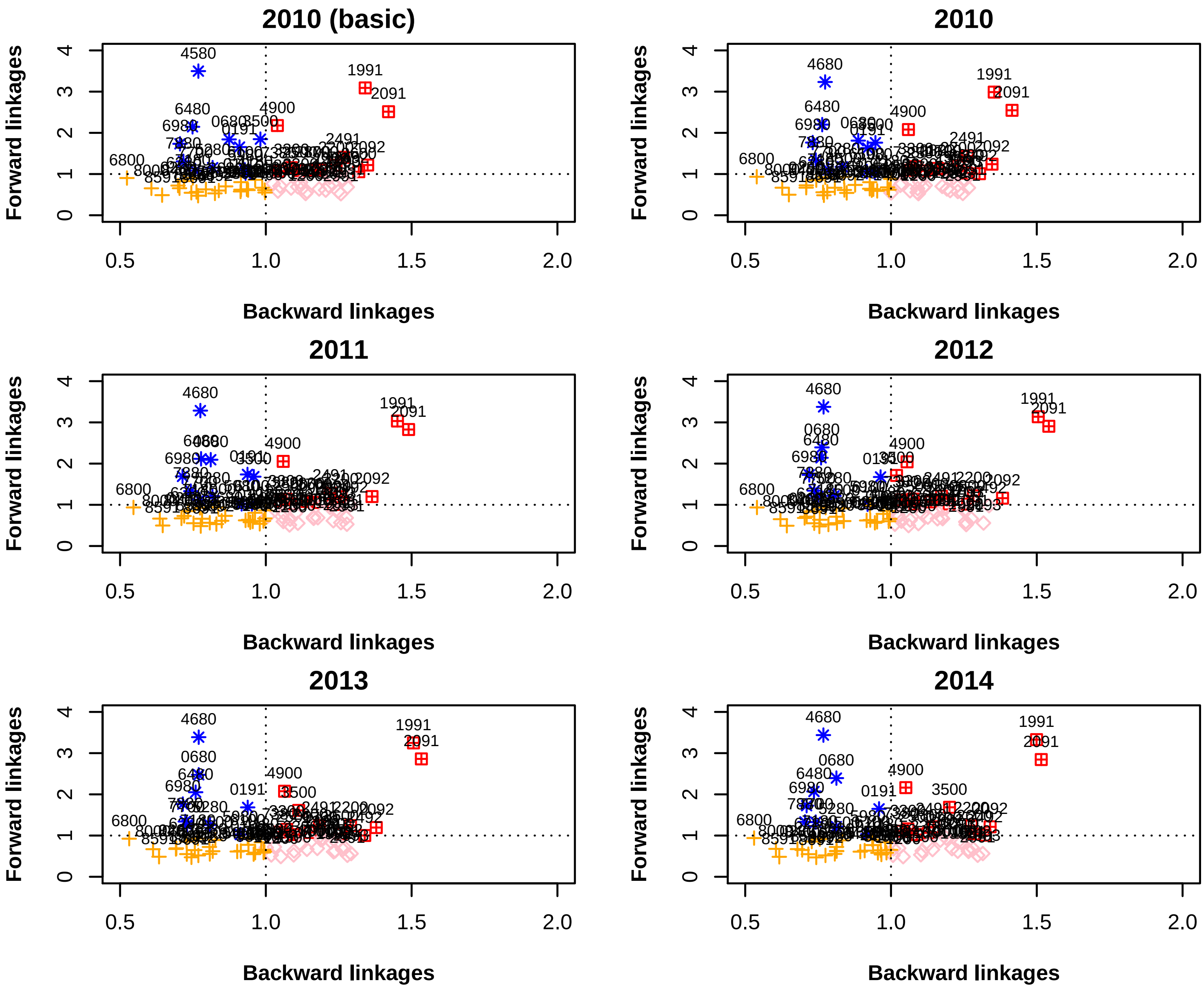

Figure 16: Key sector analysis of the Brazilian economy, 2010-2014

Figure 16 plots the sectoral classification of all the data available. Remember, according to Subsection 3.1, we have two kinds of data: (i) the data with full information on trade and transport margins (available in 2010 and label **2010 (basic)** in the graph); and (ii) the data with some assumptions on weighted repartition. As pointed out by Appendix B, one sector label is slightly modified from the two classifications, indeed items 4500 and 4680 are compounded and makes 4580 *Comércio por atacado e varejo* (Wholesale and retail trade). Interestingly, we note that the information along the years are not changing significantly and that using the first of the second kind of data for the key sectors analysis does not change the conclusions.

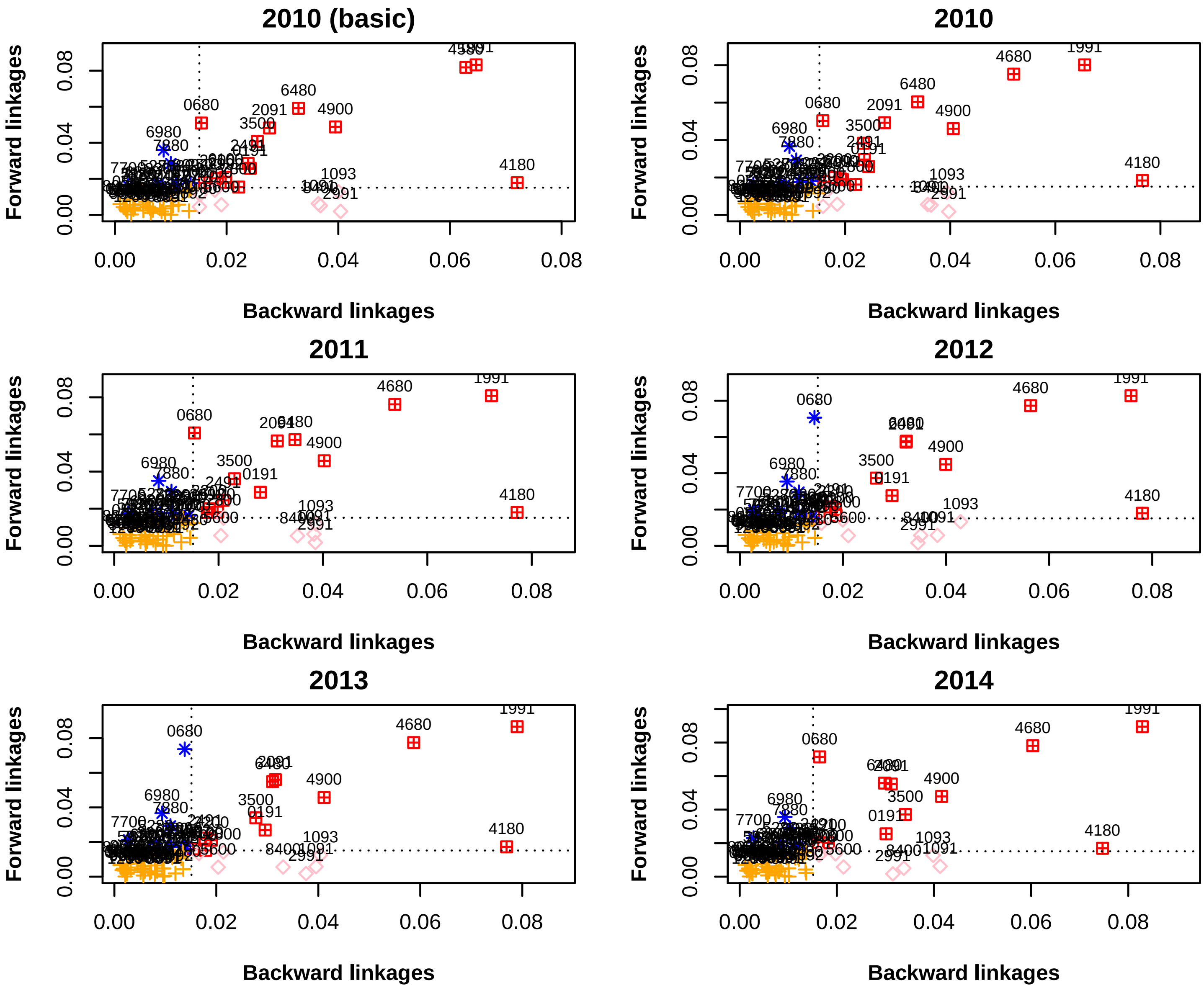

Figure 17: Key sector analysis of the *normalized* Brazilian economy, 2010-2014

Figure 17 shows the last plot counterpart where the Brazilian economy in normalized. Again, we do not see major differences, and therefore our conclusions remain unchanged.

D Employment decomposition

It is worth mentioning here that the average employment content is 24.671.

Code	Empl. cont.	$\Delta\mathbf{MF}$	$\Delta\mathbf{MI}$	$\Delta\overline{\mathbf{T}}$	$\Delta\overline{\mathbf{L}}$	$\Delta\overline{\mathbf{S}}$
0191	46.30	0.15	0.08	-1.55	-19.97	42.92
0192	101.69	1.27	1.91	-2.04	-17.93	93.81
0280	56.84	0.26	1.26	0.82	-36.37	66.20
0580	17.94	1.08	-0.64	-2.20	-2.26	-2.71
0680	6.10	0.37	-1.33	-1.55	-4.61	-11.46
0791	5.63	0.34	-1.18	-1.50	-7.61	-9.09
0792	11.89	0.15	-1.09	-1.99	-1.33	-8.52
1091	53.86	0.33	6.74	1.16	2.48	18.48
1092	32.94	0.57	2.98	-0.54	0.90	4.36
1093	31.73	0.20	1.34	-1.97	-0.02	7.52
1100	15.73	-0.17	0.83	-1.70	-3.88	-4.01
1200	20.37	-3.15	2.33	0.02	-3.47	-0.03
1300	28.90	-0.75	-1.84	-3.90	4.96	5.75
1400	44.33	-1.95	-0.02	-2.90	3.19	21.33
1500	34.75	-0.63	-0.05	-2.70	7.08	6.38
1600	40.25	0.63	1.32	-2.00	0.25	15.39
1700	16.93	0.28	-0.16	-1.93	-0.84	-5.09
1800	20.08	-0.65	-0.75	-1.92	1.44	-2.72
1991	6.68	0.01	-2.15	-4.53	-3.45	-7.87
1992	31.16	0.55	3.19	-0.14	-1.55	4.43
2091	8.25	-0.99	-3.23	-2.54	-1.10	-8.56
2092	11.73	-0.41	-2.02	-2.60	0.90	-8.81
2093	14.96	-3.88	-0.89	-2.82	-0.83	-1.29
2100	9.13	-1.80	-0.75	-1.21	-3.01	-8.77
2200	15.13	-0.79	-1.82	-2.66	1.29	-5.56
2300	19.47	-0.38	-0.52	-2.37	0.25	-2.18
2491	12.05	0.31	-1.37	-2.30	-0.71	-8.55
2492	14.20	-0.01	-1.44	-2.79	0.98	-7.21
2500	17.57	-0.96	-1.00	-2.37	1.25	-4.03
2600	7.64	-3.15	-5.29	-2.28	0.96	-7.27
2700	12.52	-2.14	-1.58	-2.42	2.41	-8.42
2800	11.26	-3.34	-1.67	-1.94	1.43	-7.89
2991	10.94	-1.17	-0.64	-1.80	-1.21	-8.91
2992	13.60	-1.06	-1.07	-2.26	1.90	-8.58
3000	10.47	-1.95	-2.63	-2.10	1.93	-9.45
3180	25.82	-1.33	0.03	-1.66	-2.79	6.91
3300	19.04	-0.66	-1.96	-2.20	-1.80	0.98
3500	5.79	0.37	-1.24	-1.78	-6.26	-9.98
3680	19.98	0.67	0.13	-1.75	-5.32	1.57
4180	27.10	0.78	0.21	-2.74	-3.60	7.78
4580	33.35	0.79	0.75	-1.13	-1.16	9.43
4900	23.45	0.40	-0.64	-2.68	-1.18	2.88

Code	Empl. mult.	$\Delta\mathbf{MF}$	$\Delta\mathbf{MI}$	$\Delta\overline{\mathbf{T}}$	$\Delta\overline{\mathbf{L}}$	$\Delta\overline{\mathbf{S}}$
5000	13.11	0.50	-1.92	-3.45	2.81	-9.50
5100	9.16	-1.33	-1.99	-4.14	2.60	-10.65
5280	17.85	0.62	0.15	-1.54	2.17	-8.22
5500	27.47	-4.54	0.90	-1.82	3.37	4.89
5600	44.31	-0.10	1.00	-3.01	-4.54	26.28
5800	14.95	-0.77	-0.20	-2.20	0.71	-7.27
5980	16.32	0.58	-0.14	-2.02	1.40	-8.17
6100	10.98	0.41	0.20	-1.58	-5.48	-7.25
6280	13.38	-0.57	-0.34	-1.34	1.13	-10.17
6480	8.56	0.43	-0.22	-1.61	-1.99	-12.72
6800	2.05	0.28	-1.37	-1.91	-19.57	-0.05
6980	18.23	0.65	0.20	-1.27	-2.94	-3.08
7180	16.54	0.60	-0.20	-1.75	-0.61	-6.17
7380	17.91	0.61	-0.05	-2.53	-3.86	-0.92
7700	16.18	0.18	-0.45	-1.51	-4.06	-2.66
7880	33.00	0.58	0.92	-1.34	5.94	2.24
8000	37.53	0.90	1.30	-0.34	14.04	-3.05
8400	15.97	0.60	0.47	-1.04	6.39	-15.12
8591	28.88	0.80	1.28	-0.02	12.46	-10.31
8592	37.35	0.80	1.02	-1.50	13.29	-0.94
8691	23.59	0.73	1.02	-0.72	9.41	-11.52
8692	28.57	0.79	0.50	-2.04	3.19	1.45
9080	41.52	-1.85	0.86	-1.32	0.07	19.09
9480	45.55	1.03	-0.07	-3.69	4.06	19.54

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