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BRAZILIAN REGIONS IN THE GLOBAL VALUE CHAIN: TRADE AND THE ENVIRONMENT

REGIÕES BRASILEIRAS NAS CADEIAS DE VALOR GLOBAIS: COMÉRCIO E MEIO AMBIENTE

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ABSTRACT

This dissertation analyzes economic and environmental aspects related to Brazilian states' participation in global value chains. It is composed by three essays. In the first essay, a novel methodological framework is proposed for estimating a country-state input-output table, combining a world table and an interregional table. In the proposed framework, input coefficients from both datasets are employed (rather than the intermediate flows). The empirical application combines a world input-output table covering 40 countries (and the rest of the world as a 41st country) with an interregional input-output table covering all Brazilian states, for the year 2008. The essay proceeds with the analysis of the Brazilian states' trade in value added, with special focus on foreign trade. It is observed that the importance of production sharing for participating in the global value chains varies widely across states. International trade in value added is highly concentrated in the more developed Southeast and South regions. These regions are also majorly responsible for linking other states' production to final consumption abroad, that is, they act as major links connecting and extending Brazilian production networks to the global value chains. The underlying geographical structure of global value chains is the object of study in the second essay. Firstly, background perspectives are presented on how the fragmentation of production processes has lead to the reorganization of economic activities around the globe and within countries. Then, the hierarchical feedback loop methodology is applied to the previously estimated country-state input-output table. A great degree of production sharing among Brazilian states is observed. The results indicate that fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadows production sharing with neighbouring states. In this way, the geography of production within Brazil seems to remain quite similar over the years. At global level, a spatial structure is observed where the flows linking major economies across trade blocks are dominant; the results support that production fragmentation is a truly global phenomenon, not being merely circumscribed to trade blocks. Finally, the third essay turns to the environmental aspects of the integration in global value chains. More specifically, to the relationship between trade and CO_2 emissions. The interrelationships between states in environmental matters are relevant in large and heterogeneous countries such as Brazil, where the regional distributive aspect of mitigation policies is a concern. The analysis traces the CO_2 emissions from fossil fuel combustion embodied in Brazilian states' trade both within the country and internationally. The previously estimated country-state IO table is applied together with a novel database reflecting CO_2 emissions from fossil fuel combustion by state and productive industry. A central finding is that not only were 28% of global emissions (from fossil fuels) embodied in international trade, but 36% of territorial emissions (from fossil fuels) in Brazil were traded between states in 2008. Thus, international and interregional trade play a major role in emissions reduction and should be given due consideration in the climate change policy framework. The current regional mitigation initiatives in Brazil, which are limited to a few states and refer only to the emissions generated within states' territorial boundaries, ignore an important share of national emissions.

RESUMO

A presente tese analisa aspectos econômicos e ambientais da participação dos estados brasileiros nas cadeias de valor globais. É composta por três artigos. No primeiro artigo, um novo framework *metodológico é proposto para a estimação de uma matriz de insumo-produto países-estados, por meio da combinação de uma matriz mundial e de uma matriz inter-regional. No* framework *proposto, são empregados coeficientes técnicos das duas fontes de dados (alternativamente aos fluxos de insumos intermediários). A aplicação empírica combina uma matriz de insumo-produto mundial abrangendo 40 países (e o resto do mundo como o 41º país) e uma matriz de insumo-produto inter-regional abrangendo cada um dos estados brasileiros, para o ano de 2008. O artigo prossegue com a análise do comércio dos estados em termos de valor adicionado, com foco nos fluxos internacionais. Observa-se uma grande variação entre os estados da importância do compartilhamento da produção para que ocorra participação nas cadeias de valor globais. As regiões Sudeste e Sul são largamente responsáveis por conectar a produção dos demais estados à demanda final estrangeira, isto é, atuam como elos principais conectando e estendendo as cadeias domésticas às cadeias globais. A estrutura geográfica subjacente das cadeias de valor globais é o objeto de estudo do segundo ensaio. Primeiramente, apresentam-se perspectivas da literatura sobre como a fragmentação dos processos produtivos suscitou a reorganização das atividades econômicas no mundo e internamente aos países. Em seguida, a metodologia da análise de* feedback loops *é aplicada à matriz de insumo-produto países-estados anteriormente estimada. Um elevado grau de compartilhamento da produção é observado entre os estados brasileiros. Os resultados indicam que a fragmentação produtiva dentro das grandes regiões é um fenômeno importante para as regiões Sudeste e (secundariamente às ligações com São Paulo) Sul. Para os estados nas demais regiões, as ligações produtivas com os estados mais desenvolvidos do país superam as ligações com os estados vizinhos. Desse modo, a geografia da produção no Brasil parece ter se mantido grandemente inalterada ao longo do tempo. Em nível global, é observada uma estrutura espacial em que são dominantes os fluxos entre as grandes economias em diferentes blocos de comércio; os resultados indicam que a fragmentação produtiva é um fenômeno de fato global, não circunscrito aos blocos regionais. Finalmente, o terceiro artigo é voltado aos aspectos ambientais da integração às cadeias de valor globais. Mais especificamente, às relações entre comércio e emissões de* CO_2*. São relevantes para questões ambientais as inter-relações dos estados em países amplos e heterogêneos como o Brasil, em que a distribuição regional dos esforços de mitigação é um ponto premente. A análise traça as emissões de* CO_2 *decorrentes da queima de combustíveis fósseis incorporadas ao comércio dos estados brasileiros, tanto nacional quanto internacionalmente. A matriz de insumo-produto países-estados anteriormente estimada é aplicada em conjunto com uma nova base de dados referente a emissões de* CO_2 *decorrentes da queima de combustíveis fósseis, detalhadas por estados e por setores produtivos. Um resultado central é que não apenas 28% das emissões globais (decorrentes da queima de combustíveis fósseis) estavam incorporadas ao comércio internacional, mas 36% das emissões territoriais (decorrentes da queima de combustíveis fósseis) do Brasil foram transacionadas entre os estados em 2008. Portanto, os comércios internacional e inter-regional têm papel importante para a mitigação de emissões e deveriam ser analisados nas políticas de mudanças climáticas. As atuais iniciativas regionais de mitigação no Brasil, limitadas a poucos estados e referentes a apenas emissões geradas nos limites territoriais de tais estados, ignoram, assim, uma parcela expressiva das emissões nacionais.*

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LIST OF ABBREVIATIONS AND ACRONYMS

CDM: Clean Development Mechanism
EPE: *Empresa de Pesquisa Energética*
EU: European Union
GHG: Greenhouse Gas
GMRIOT: Global Multiregional Input-Output Table
GTAP: Global Trade and Analysis Project
GVC: Global Value Chain
IO: Input-Output
IOT: Input-Output Table
IRIOT: Interregional Input-Output Table
MCTI: *Ministério da Ciência, Tecnologia e Inovação* (Ministry of Science, Technology and Innovation)
MRIOT: Multiregional Input-Output Table
NAFTA: North American Free Trade Agreement
NEG: New Economic Geography
NEREUS: *Núcleo de Economia Regional e Urbana da USP* (University of São Paulo Regional and Urban Economics Lab)
NESA: *Núcleo de Economia Socioambiental da USP* (University of São Paulo Socio-environmental Economics Research Center)
OECD: Organization for Economic Co-operation and Development
PNMC: *Política Nacional de Mudanças Climáticas* (National Climate Change Policy)
RoW: Rest of the World
SUT: Supply and Use Table
TiVA: Trade in Value Added
TiCE: Trade in CO_2 Emissions
USP: *Universidade de São Paulo* (University of São Paulo)
VAX: Value-Added Exports to Gross Exports
WIOD: World Input-Output Database
WIOT: World Input-Output Table
WTO: World Trade Organization

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1 INTRODUCTION

The importance of understanding interindustry relationships for countries and subnational regions at the global level has been increasingly reinforced by the Economics literature. Two noteworthy strands are the literature on trade and on environmental issues. Discussions on the role of international trade in income generation and on appropriately connecting global consumption patterns to environmental impacts calls for analyses that take into account the interdependencies around the world.

In the trade literature, significant attention has been dedicated to the surge of international flows of intermediate products in recent years, which corresponds to Baldwin's (2006) "second wave of global unbundling" (e.g. KOOPMAN *et al*, 2014; JOHNSON; NOGUERA, 2012a; BEMS *et al*, 2011; TREFLER; ZHU, 2010). The increased trade in intermediates was mainly due to advances in transportation and communication technologies, which enabled the spatial fragmentation of production processes, with many of the production stages being outsourced to specialized sub-contractors located in foreign countries. Thus, presently, products and services, rather than being produced within a single country, are now produced in global supply chains or global value chains (GVCs): countries import intermediate goods and raw materials, to which they add one or more layers of value, before selling the product (often to a foreign producer who adds the next layer). In this way, the international fragmentation of production processes has generated a complex system of interdependent flows, linking regions all over the world. As the process of fragmentation continues, international dependency will assume even greater importance in explaining the growth and path of economic development (HEWINGS; OOSTERHAVEN, 2015).

Since the 1970s, the literature on environmental issues has shown increased attention to the relation between trade and the environment, as indicated by Tukker and Dietzenbacher (2013) (see also the survey by Wiedmann *et al* (2007)). A policy-relevant discussion centred around the Kyoto Protocol, which sets reduction targets for each Annex B country with respect to greenhouse gas (GHG) emissions within their territory, while developing countries do not have emission commitments. In this setting, given the global character of GHGs, the concern for carbon leakage (i.e. increasing CO_2 emissions in countries outside of the agreement's control) by means of international trade arises. With this in mind, questions are raised in the literature about the carbon content of trade. For example, Peters *et al* (2011) states that ignoring the connections between economies via trade might result in misleading analysis of the underlying driving forces of emission trends and lead to sub-optimal mitigation policies.

For quantitatively examining those discussions, among others, there is a need for data that provide a description of interdependent production structures which are given in input–output tables (IOTs). For analyses involving multiple countries, databases with harmonized national IOTs and bilateral trade information have been developed since the 1990s. The best-known examples are the Global Trade and Analysis Project (GTAP) and the Organization for Economic Co-operation and Development (OECD) databases. The construction of the GTAP database combines data from a large number of sources resulting from a collaboration of numerous GTAP members. In 2015, it saw its ninth release (NARAYANAN *et al*, 2015). The OECD Input-Output (IO) database, first developed in 1995 and updated several times, has been disseminated freely (YAMANO; AHMAD, 2006). Further, some true inter-country IOTs have been constructed in the recent decades. Noteworthy examples are the Asian International Input–Output tables and the BRICs International Input–Output tables, produced by the Institute of Developing Economies at the Japan External Trade Organization (IDE-JETRO), who's research efforts for obtaining international IO data started in the 1960s (MENG *et al*, 2013).

Global multiregional input-output tables (GMRIOTs), or world input-output tables (WIOTs), have only recently been finalized. These databases typically include a large number of individual countries and a derived "country" that represents the rest of the world, so that the entire global economy is captured. The availability of WIOTs permits a comprehensive analysis of each country's interdependencies, with detailed descriptions of origin and destination of interindustry flows. The main WIOT databases currently available are, Eora (LENZEN *et al*, 2012, 2013), EXIOBASE (TUKKER *et al*, 2009, 2013), GTAP-MRIO (PETERS *et al*, 2011; ANDREW; PETERS, 2013), the World Input-Output Database – WIOD (DIETZENBACHER *et al*, 2013), and the Global Resource Accounting Model – GRAM (BRUCKNER *et al*, 2012; WIEBE *et al*, 2012). In 2015, the OECD Inter-Country Input-Output (ICIO) tables covering the global economy also became available.[1]

[1] See http://www.oecd.org/sti/ind/input-outputtables.htm.

Concerning the development of WIOTs, two aspects are remarkable, as Tukker and Dietzenbacher (2013) have indicated. Firstly, the construction of multiregional input-output tables (MRIOTs) comprehending the global economy is recent, but their concept has been previously developed by Isard (1951) for regions within a country. For decades, MRIOTs have been extensively discussed in the regional science literature and have become a widely used tool for regional policy. Secondly, linking industry level information for large groups of countries has a long tradition in economics and is not restricted to the IO methodology. For example, the Project LINK was initiated in 1968 under the leadership of Nobel laureate Lawrence R. Klein to model the international transmission mechanism of business cycles. In this project, independently developed national econometric models (that distinguish several commodity classes) are integrated through trade share matrices into a world econometric model. The project is currently part of the United Nations Development Policy and Analysis Division and consists of 78 country models.[2]

The aforementioned discussions in the literature on trade and environmental issues also apply at the regional level. As indicated by Los *et al* (2015), trends in regional income and regional employment have become much more dependent on the extent to which regions manage to contribute to GVCs. With the increasing interconnectedness of foreign and domestic production processes, the affirmation of Douglas North that "the relevant problems of regional economic development (…) revolve around a region's ability to become integrated into the larger markets of the world through exports" (NORTH, 1955, p. 951) also sheds light on the relevance of regional interactions in explaining the growth of economies. As for the environmental issue, as subnational regions increasingly become the units of action against climate change, their international and interregional dependencies must be taken into account for more effective climate policies.[3]

Quantitative studies of regional participation in GVCs require the availability of WIOTs in which one or more countries are geographically disaggregated into regions. Having this in

[2] See http://www.un.org/en/development/desa/policy/proj_link.

[3] An example of the prominent role of subnational regions in mitigation actions is the Clean Power Plan announced by the USA in August 2015. Expecting USA power plant CO_2 emissions to be 32% lower in 2030 than they were in 2005, the Environmental Protection Agency (EPA) set for each state an individual goal of cutting power plant emissions. The decisions on how to meet the goals are up to the states, so the strategies can include cooperative efforts among them, such as the current cap-and-trade system set by the Regional Greenhouse Gas Initiative (RGGI) in the Northeast. In fact, for many years the states have led the climate change efforts in the USA. (LUTSEY; SPERLING, 2008; SCHREURS, 2008). In Brazil, there has been an important emergence of subnational climate policies (see Chapter 4).

mind, the present dissertation proposes a new methodological framework for estimating combined country-state IO tables, based on WIOTs and interregional input-output tables (IRIOTs). Subsequently, we apply the proposed framework to study the integration of the Brazilian states into the network of world production.

This is one of the first studies to obtain country-state IO tables covering the global economy. To the best of our knowledge, the others are Cherubini and Los (2012), Feng *et al* (2013), and Meng *et al* (2013). Our proposed framework innovates by employing input coefficients from both WIOT and IRIOT for the estimation of IO tables.

Our empirical applications use the WIOT that was constructed in the WIOD project (see Dietzenbacher *et al*, 2013). The WIOT is a full inter-country IO table that includes 40 countries and the rest of the world as the 41st country. Brazil is included in the WIOT table. The IRIOT is for Brazil and was developed by the University of São Paulo Regional and Urban Economics Lab (NEREUS). The IRIOT covers the 27 Brazilian states (see Guilhoto *et al*, 2010). Both the WIOT and the IRIOT aggregate 28 compatible industries. The data refer to 2008, the last reference year for which both the WIOT and the IRIOT were available at the time this study was initiated

Besides this introduction and the last chapter, with concluding remarks, this dissertation is composed of three essays. In the first essay, "Trade in value added for Brazilian states," in Chapter 2, the objective is twofold. On the one hand, it presents our theoretical framework for the estimation of a combined country-state IO table. Following its application for obtaining a global IO table where the Brazilian states are disaggregated, the quality of the estimation is evaluated. On the other hand, the first essay presents an analysis of the Brazilian states' trade in value added (TiVA), with a special focus on foreign trade. The importance of TiVA analysis (in opposition to gross trade analysis) has been reinforced in recent trade literature, given that, in the presence of global production fragmentation, the problem of double-counting in gross trade analysis is particularly pervasive (KOOPMAN *et al*, 2014). Brazilian state international TiVA is quantified, which is followed by an exploration of how it takes place, that is, either by direct participation in GVCs or by means of production sharing networks within Brazil.

The underlying geographical structure of GVCs is the object of study in the second essay, “Brazilian states in global value chains: spatial production systems interpreted by feedback loop analysis”, in Chapter 3. Firstly, the essay presents background perspectives from the literature on how the fragmentation of production processes has led to a reorganization of economic activities around the globe and within countries. Then, with the objective of elucidating the spatial configuration of GVCs, the hierarchical feedback loop methodology is applied to the previously estimated country-state IO table. In essence, this methodology offers a detailed view of economic interactions, first by identifying the paths of influence across regions, and then by proposing a hierarchical extraction method to identify the paths in terms of their economic importance (POLENSKE; HEWINGS, 2004). The application described in this essay differs from previous studies adopting this methodology as it takes into account value-added flows involved in the supply chains, rather than interregional gross trade. Following the macro level application, the study concludes with an analysis of feedback loops at sectoral level, increasing our understanding of the nature of the interregional dependencies.

The study turns to the environmental aspects of integration in GVCs with the third essay, “Tracing Brazilian state CO_2 emissions in domestic and global trade”, in Chapter 4. With the aim of contributing to climate change policies that account for interrelationships between states, in economic as well as environmental terms, the objective of the study is to trace CO_2 emissions from fossil fuels combustion embodied in Brazilian states’ trade, both within the country and internationally. The previously estimated country-state IO table is applied, together with a novel database reflecting CO_2 emissions from energy use by state and industry, permitting a close examination of the flows of trade in CO_2 emissions. The essay ends with the examination of possible mitigation policies for the Brazilian states.

Finally, Chapter 5 summarizes the findings from the previous chapters and discusses avenues for future research.

2 TRADE IN VALUE ADDED FOR BRAZILIAN STATES

2.1 Introduction

Production processes have become increasingly disbursed (or fragmented) in recent years. As advances in transportation and communication technologies allow the spatial separation of production, many of the separate processes are outsourced to specialized sub-contractors located in foreign countries (i.e., offshoring). This has led to an upsurge of trade in intermediate products, which corresponds to Baldwin's (2006) "second wave of global unbundling", where the location of the production of intermediate inputs differs from the location of the production of the final products.[4] Theories that explain the relocation of the production of intermediate inputs to other countries have been developed, for example, by Grossman and Rossi-Hansberg (2008) and Costinot *et al* (2013).

Today's products and services are no longer produced within a single country but in global supply chains or global value chains (GVCs). In this way, countries import intermediate goods and raw materials to which they add one or more layers of value before selling the product (often to a foreign producer who adds the next layer). Standard trade figures that measure the value of imports and exports no longer reflect accurate information on economic welfare, which has attracted the attention of policy makers. For example, according to former EU Commissioner for Trade, Karel De Gucht: "The country that exports the final product is artificially credited with having created all of its value, even if in reality it only assembled ready-made parts. (…) This is a bit like the final runner in a relay team getting a gold medal while his teammates get silver and bronze. It doesn't take account of the fact that the final result is the product of a joint effort."[5] Recently, Pascal Lamy (former Director-General of the World Trade Organization (WTO)) launched the "made in the world" initiative jointly with the OECD and proposed "trade in value added" as a better approach for the measurement for international trade (see OECD-WTO, 2012).[6]

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[4] The first wave of global unbundling refers to the separation of the location of consumption and the location of production were separated, which led to increased trade in final products.
[5] Available at: http://trade.ec.europa.eu/doclib/docs/2012/april/tradoc_149337.pdf.
[6] The OECD TiVA database is available at: www.oecd.org/trade/valueadded.

A similar situation is evident at the regional level and perhaps even to a larger extent. Locational advantages (e.g., the presence of a seaport and/or an airport) typically cause one region to assume responsibility for most of the imports and exports of a country. Even if the production of some export goods occurs entirely within the country, it is likely that regions other than the exporting region have also contributed to the value of the exports; for example, by supplying intermediate inputs and raw materials for the final product that is sold abroad. In addition to international fragmentation, interregional fragmentation (i.e., domestic production sharing) plays a role when focusing on regions. These two fragmentation processes are fundamentally interconnected, and trends in regional income have recently become more dependent on the extent to which subnational regions can contribute to GVCs (LOS *et al*, 2015).

In the Brazilian case, the export of the Volkswagen Gol to foreign countries in Latin America is an example of regional participation in a GVC. The Anchieta plant, located in the state of São Paulo, is responsible for the Gol model assembly, which is subsequently exported through the Port of Santos also in the state of São Paulo. For the assembly process, the Anchieta Plant uses, among many other intermediate inputs, flat carbon steel products from the Companhia Siderurgica Nacional's plant in the state of Rio de Janeiro. The steel plant requires iron ore from the state of Minas Gerais. Additionally, intermediate products from abroad are required, such as electronic components assembled by Volkswagen in Germany and sub-parts produced in China. Therefore, the exports of the Gol model generate value added not only in the state of São Paulo, but also in Rio de Janeiro, Minas Gerais, Germany, China, and so forth.

This paper investigates the integration of Brazilian states in GVCs.[7] We analyze their trade in value added and answer the question: How much of the value added generated in the state of Minas Gerais, for example, is embodied in the "consumption" bundle of Mexico, for example? This provides the export of value added from Minas Gerais to Mexico. The "consumption" bundle includes household consumption, government expenditures, gross fixed capital formation, and changes in inventories. Additionally, the Mexican consumption bundle includes imported goods from other countries such as the USA, or other Brazilian

[7] Timmer *et al* (2015) define a GVC of a final good as the set of value-adding activities required for its production and identify the GVC according to the country-industry in which the last stage of production occurs. In our empirical analysis, we are not interested in specific GVCs but the GVCs as a whole.

states such as São Paulo. Indirectly, because of widespread production sharing, these goods may include value added from Minas Gerais. This is the case for the Volkswagen Gol. In principle, Minas Gerais may not export to Mexico but some of its value added may still be embodied in Mexican consumption (for example, through USA exports or São Paulo's exports that are produced using intermediate products from Minas Gerais). Thus, we will also answer the question: What is the share of output from Minas Gerais purchased by São Paulo and redirected to Mexico's final consumption? Similarly, we also analyze the import of Mexican value added by Minas Gerais.[8]

Whereas the methodology to calculate trade in value added is established, the availability of data has been a limiting factor.[9] In recent years, however, several groups of researchers have developed world input-output tables (WIOTs). These are interregional, Isard-type input-output (IO) tables for countries instead of regions. The available WIOTs typically include a large number of individual countries and a "country" that reflects the rest of the world.[10] The present paper proposes a new framework that combines the WIOTs from the World Input-Output Database (WIOD) project, which includes Brazil as one of its countries, with an interregional input-output table (IRIOT) for Brazil developed by the University of São Paulo Regional and Urban Economics Lab (NEREUS).[11]

A combined country-state table for Brazil could be constructed in two forms. On the one hand, Brazil as a whole can be assumed in the WIOT and the IRIOT adapted accordingly. On the other hand, the IRIOT can be assumed and the WIOT adapted accordingly. Three other studies have split one of the countries in a WIOT into a number of regions, and the three studies adapted the IRIOT. Cherubini and Los (2012) used WIOD data and split Italy into four regions, Feng *et al* (2013) used GTAP-MRIO data and split China into 30 provinces, and

[8] We do not present here results at the "state-country pair" level but focus on the extension of GVCs within Brazil through domestic value chains. For illustration purposes only, our empirical answers to these questions are: a) In 2008, Minas Gerais' value-added exports to Mexico amounted to US$523 million, and b) São Paulo redirected to Mexico approximately 0.55% of the output it purchased from Minas Gerais.
[9] The calculation of trade in value added is similar to the calculation of trade in emissions, the methodology for which is established (see e.g., Serrano and Dietzenbacher (2010) for a methodological overview). With respect to data availability, a rare exception is the series of inter-country IO tables for a limited set of European countries for 1965, 1970, 1975, 1980, and 1985 (VAN DER LINDEN; OOSTERHAVEN, 1995; VAN DER LINDEN, 1999). These tables are available at: http://www.rug.nl/research/reg/research/irios/irios-tables.
[10] See Tukker and Dietzenbacher (2013) for an overview. Examples are Eora (LENZEN *et al*, 2012, 2013), EXIOBASE (TUKKER *et al*, 2009, 2013), GTAP-MRIO (PETERS *et al*, 2011; ANDREW; PETERS, 2013), WIOD (DIETZENBACHER *et al*, 2013), the OECD database (NAKANO *et al*, 2009) and GRAM (BRUCKNER *et al*, 2012; WIEBE *et al*, 2012).
[11] The full database from the WIOD project (including a time series of WIOTs) is available publicly and free of charge at: http://www.wiod.org/database/index.htm.

Meng *et al* (2013) used WIOD data and split China into four regions.[12, 13] In this study, we follow a different approach and employ the input coefficients from both datasets rather than the deliveries themselves.

In summary, the increasing interconnectedness of domestic and global production processes suggests growing relevance in quantifying the contribution of subnational regions to GVCs and recognizing the variations within countries. Therefore, our objective is twofold. First, we propose a theoretical framework for the estimation of a combined country-state IO table, which can be applied to various datasets with different geographical detail. Additionally, we intend to analyze the integration of Brazilian states in GVCs as a whole. For this, we apply the proposed framework to obtain a global table for the year 2008 in which Brazil is geographically disaggregated into its 27 states.

Our empirical application proceeds along two lines. First, to assess the importance of the Brazilian states' participation in GVCs, we quantify the states' international trade in value added. Second, we analyze how value-added participation occurs. We are particularly interested in production sharing between states that leads to indirect participation in global markets.

This second line of the empirical application begins with the examination of the value-added exports to gross exports ratio (VAX ratio), which is a well-known measure of the intensity of production sharing. We verify that the VAX ratio varies widely across Brazilian states, indicating differences in GVC engagement. One explanation is that cross-state variation in VAX ratios is caused by the industry composition of exports. We find that this is not the case

[12] Cherubini and Los (2012), and Feng *et al* (2013) do not detail their procedure for adapting the IRIOT and only indicate how they managed international imports and exports by domestic region. Cherubini and Los (2012) use trade statistics from Istat (the Italian National Institute of Statistics) to disaggregate and allocate Italy's total international imports and exports given by the WIOD. These data are available by product, region, and country of origin/destination. Feng *et al* (2013) also use data on total provincial foreign trade to split GTAP's international import and export matrices for China. However, the authors assume that provincial international exports/international imports are distributed among/sourced from countries in the same proportions as China's total exports/imports. Meng *et al* (2013) estimate what they call an embedded international IO table (EMIIO) by taking the WIOT and inserting China's IRIOT while ensuring consistency through a linear programing model. In addition to the structures of the existing IO tables, the estimation is based on regional import/export data from customs statistics, by sector, and by country origin/destination broken down by end-use categories (intermediate goods, household consumption goods, and capital goods).

[13] As reported by Los *et al* (2015), for the project "Smart Specialization for Regional Innovation," Mark Thissen and others are regionalizing the EU component of the WIOD tables at the NUTS 2 level (270 regions) for the period 2000 to 2010. However, at the time of this study, no information was available on the regionalization methodology.

for differences within industries across states also account for this finding. Given this result, we then investigate the differences in Brazilian states' domestic production-sharing participation in GVCs. Indirect exports and imports are quantified, and the mechanism of indirect participation is elucidated by the decomposition of bilateral trade flows into absorption, reflection, and redirection components. This way, we identify the states that act as links extending the GVCs into Brazilian value chains.

The remainder of the paper is structured as follows. The next section presents the methodology used to estimate the country-state IO table, and section 2.3 reflects on the compatibility of the applied datasets. The empirical results are presented and discussed in section 2.4, and section 2.5 concludes.

2.2 Methodology

We combine a WIOT with an IRIOT for our analysis. We use the WIOT for 2008 that was constructed in the WIOD project (see Dietzenbacher *et al*, 2013) for the empirical application. The WIOT is a full inter-country IO table that includes 40 countries and the rest of the world as the 41st country. Brazil is included in the WIOT table. The IRIOT for 2008 is for Brazil and covers the 27 Brazilian states (see Guilhoto *et al*, 2010). Both the WIOT and the IRIOT aggregate 28 compatible industries. Appendix A.1 shows the classification of regions (i.e., countries and Brazilian states) and industries.

We use a smaller case as an example to outline the methodology. Without loss of generality, we employ a WIOT for a world that consists of three countries (*R*, *S*, and *T*). For country *T*, we have an IRIOT that distinguishes two regions (east *E* and west *W*). Figure 2.1 shows the WIOT, and Figure 2.2 shows the IRIOT.

	Intermediate use			Final use			Gross
	in R	in S	in T	in R	in S	in T	Output
Product flows from							
country R	$\mathbf{Z}^{RR}$	$\mathbf{Z}^{RS}$	$\mathbf{Z}^{RT}$	$\mathbf{c}^{RR}$	$\mathbf{c}^{RS}$	$\mathbf{c}^{RT}$	$\mathbf{x}^{R}$
country S	$\mathbf{Z}^{SR}$	$\mathbf{Z}^{SS}$	$\mathbf{Z}^{ST}$	$\mathbf{c}^{SR}$	$\mathbf{c}^{SS}$	$\mathbf{c}^{ST}$	$\mathbf{x}^{S}$
country T	$\mathbf{Z}^{TR}$	$\mathbf{Z}^{TS}$	$\mathbf{Z}^{TT}$	$\mathbf{c}^{TR}$	$\mathbf{c}^{TS}$	$\mathbf{c}^{TT}$	$\mathbf{x}^{T}$
Value added	$(\mathbf{v}^{R})'$	$(\mathbf{v}^{S})'$	$(\mathbf{v}^{T})'$				
Total inputs	$(\mathbf{x}^{R})'$	$(\mathbf{x}^{S})'$	$(\mathbf{x}^{T})'$				

Figure 2.1 – World Input-Output Table

For example, $\mathbf{Z}^{RS}$ is an $n \times n$ matrix, and its typical element z_{ij}^{RS} indicates the delivery of intermediate inputs from industry i in country R to industry j in country S.[14] Note that $i, j = 1, \ldots, n$ where n is the number of industries. In case $R \neq S$, the matrix $\mathbf{Z}^{RS}$ indicates the exports of country R to industries in country S. $\mathbf{c}^{RS}$ is an n-element vector, and its typical element c_{i}^{RS} indicates the final use (also termed final demand) in country S of goods and services produced by industry i in country R. Final use covers household and government consumption, consumption of non-profit organizations, gross fixed capital formation, and changes in inventories. If $R \neq S$, $\mathbf{c}^{RS}$ indicates the exports of country R to final users in country S. $\mathbf{x}^{R}$ is an n-element vector with its typical element x_{i}^{R} indicating the gross output of industry i in country R. $\mathbf{v}^{R}$ is an n-element vector, and its typical element v_{i}^{R} gives the value added in industry i of country R.

[14] Matrices are shown in bold capital letters (e.g., $\mathbf{Z}^{RS}$), vectors are shown in bold lower case letters (e.g., $\mathbf{x}^{R}$), and scalars (including matrix or vector elements) are given in italicized lower case letters (e.g., x_{i}^{R}). Vectors are columns by definition, row vectors are obtained by transposition, which is indicated by a prime (e.g., $(\mathbf{v}^{R})'$). We use a circumflex or "hat" to indicate a diagonal matrix (e.g., $\hat{\mathbf{x}}^{R}$) with the elements of the corresponding vector (i.e., $\mathbf{x}^{R}$) on the main diagonal, and all other elements are equal to zero.

	Intermediate use in E	Intermediate use in W	Final use in E	Final use in W	Exports	Gross output
Product flows from						
region E	$\mathbf{Z}^{EE}$	$\mathbf{Z}^{EW}$	$\mathbf{c}^{EE}$	$\mathbf{c}^{EW}$	$\mathbf{e}^{E}$	$\mathbf{x}^{E}$
region W	$\mathbf{Z}^{WE}$	$\mathbf{Z}^{WW}$	$\mathbf{c}^{WE}$	$\mathbf{c}^{WW}$	$\mathbf{e}^{W}$	$\mathbf{x}^{W}$
Imports	$(\mathbf{m}^{E})'$	$(\mathbf{m}^{W})'$	h^{E}	h^{W}		
Value added	$(\mathbf{v}^{E})'$	$(\mathbf{v}^{W})'$				
Total inputs	$(\mathbf{x}^{E})'$	$(\mathbf{x}^{W})'$				

Figure 2.2 – Interregional Input-Output Table

The interpretation of the matrices **Z** and the vectors **c**, **x,** and **v** for the IRIOT in Figure 2.2 is similar to the interpretation in the case of the WIOT in Figure 2.1. For example, z_{ij}^{EW} gives the flows of goods and services from industry *i* in region *E* to industry *j* in region *W*, c_i^{EW} indicates the delivery by industry *i* in region *E* to final users in region *W*, and x_i^E, and v_i^E give the gross output and value added in industry *i* in region *E*. Additionally, $\mathbf{e}^E$ is an *n*-element export vector, and its typical element e_i^E gives the total exports by industry *i* in region *E*. Information for the distribution of exports over destinations (i.e., countries, their industries, and final users) is unavailable. The Brazilian IRIOT provides total industry imports information, that is, without making a distinction between the countries of origin. For region *E,* for example, $\mathbf{m}^E$ is the *n*-element import vector, and its typical element m_i^E indicates the total imports by industry *i* in region *E*. Finally, the scalar h^E gives the total imports purchased by final users in region *E*. How much each country of origin delivers to final users in *E* is unknown, only the total of deliveries is known. Other import information is available (and will be used and discussed later) that is not indicated in Figure 2.2.

To combine the information from the WIOT and the IRIOT, we construct an enlarged IO table. The information for country *T* in the WIOT is replaced by the information for regions *E* and *W* from the IRIOT. However, the information for country *T* in the WIOT is not entirely consistent with the summation of the information for regions *E* and *W*. Therefore, we conduct the analysis using the WIOT for calculations at the country level, using the IRIOT for calculations at the regional level, and iterating back and forth.

Our first question is: What are the output levels (in countries R and S and regions E and W) necessary to satisfy an arbitrary final demand vector? We split this question and consider the outputs necessary for arbitrary final demand vectors $\mathbf{y}^R$ and $\mathbf{y}^S$ first. We use a round-by-round approach that is common in IO analysis. In the first round, the final demands must be produced themselves. That is, $\mathbf{y}^R$ in country R and $\mathbf{y}^S$ in country S. In the second round, we calculate the amount of inputs required (i.e., the direct inputs). Let the input matrices be defined as usual. That is, for example, $\mathbf{A}^{RS} = \mathbf{Z}^{RS}(\hat{\mathbf{x}}^S)^{-1}$ with its typical element $a_{ij}^{RS} = z_{ij}^{RS}/x_j^S$ indicating the input from industry i in country R that goes to (and is measured per unit of output of) industry j in country S. The direct inputs amount to $\mathbf{A}^{RR}\mathbf{y}^R + \mathbf{A}^{RS}\mathbf{y}^S$ in country R and to $\mathbf{A}^{SR}\mathbf{y}^R + \mathbf{A}^{SS}\mathbf{y}^S$ in country S.

From the WIOT, it follows that the direct inputs required from country T amount to $\mathbf{A}^{TR}\mathbf{y}^R + \mathbf{A}^{TS}\mathbf{y}^S$. These are exports of country T to country R ($\mathbf{A}^{TR}\mathbf{y}^R$) and to country S ($\mathbf{A}^{TS}\mathbf{y}^S$). For our analysis, we require the exports of region E to country R (i.e., $\mathbf{A}^{ER}\mathbf{y}^R$) and from region W to country R (i.e., $\mathbf{A}^{WR}\mathbf{y}^R$), but the input matrices $\mathbf{A}^{ER}$ and $\mathbf{A}^{WR}$ are unknown. Based on information that is not listed in the Brazilian IRIOT, by deriving export shares, we estimate the amount of exports to R , for example, that originates from region E and how much from W. Let the vector $\boldsymbol{\sigma}^{ER}$ denote the vector of export shares, and its elements are defined as follows:

$$\sigma_i^{ER} = e_i^{ER}/(e_i^{ER} + e_i^{WR}),$$

which indicates the share of the exports of product i to country R that originates from region E. The shares from region W are defined similarly, and the shares add up to one (i.e., $\sigma_i^{ER} + \sigma_i^{WR} = 1$).

We assume that the export shares apply irrespective of the destination industry in country R. Our estimate (indicated by a tilde) for the input coefficients then yields $\tilde{a}_{ij}^{ER} = \sigma_i^{ER} a_{ij}^{TR}$. The direct inputs from region E (which are exported to country R) then become $\tilde{\mathbf{A}}^{ER}\mathbf{y}^R = \hat{\boldsymbol{\sigma}}^{ER}\mathbf{A}^{TR}\mathbf{y}^R$, and the direct inputs from region W are given by $\tilde{\mathbf{A}}^{WR}\mathbf{y}^R = \hat{\boldsymbol{\sigma}}^{WR}\mathbf{A}^{TR}\mathbf{y}^R$.

Similarly, the exports of country T to country S ($\mathbf{A}^{TS}\mathbf{y}^S$) in this first round must be split into the exports from region E and those from region W, which are estimated using the export shares for exports to *S*. That is, using $\sigma_i^{ES} = e_i^{ES}/(e_i^{ES} + e_i^{WS})$ and $\sigma_i^{WS} = e_i^{WS}/(e_i^{ES} + e_i^{WS})$, the exports from region *E* and region *W* are estimated as $\widetilde{\mathbf{A}}^{ES}\mathbf{y}^S = \widehat{\boldsymbol{\sigma}}^{ES}\mathbf{A}^{TS}\mathbf{y}^S$ and $\widetilde{\mathbf{A}}^{WS}\mathbf{y}^S = \widehat{\boldsymbol{\sigma}}^{WS}\mathbf{A}^{TS}\mathbf{y}^S$. The direct inputs necessary for the final demand vectors $\mathbf{y}^R$ and $\mathbf{y}^S$ are given by

$$\begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} \\ \widetilde{\mathbf{A}}^{ER} & \widetilde{\mathbf{A}}^{ES} \\ \widetilde{\mathbf{A}}^{WR} & \widetilde{\mathbf{A}}^{WS} \end{bmatrix} \begin{pmatrix} \mathbf{y}^R \\ \mathbf{y}^S \end{pmatrix} = \begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} \\ \widehat{\boldsymbol{\sigma}}^{ER}\mathbf{A}^{TR} & \widehat{\boldsymbol{\sigma}}^{ES}\mathbf{A}^{TS} \\ \widehat{\boldsymbol{\sigma}}^{WR}\mathbf{A}^{TR} & \widehat{\boldsymbol{\sigma}}^{WS}\mathbf{A}^{TS} \end{bmatrix} \begin{pmatrix} \mathbf{y}^R \\ \mathbf{y}^S \end{pmatrix} \tag{2.1}$$

The second question is similar to the first question. What are the output levels (in countries *R* and *S*, and regions *E* and *W*) necessary to satisfy arbitrary final demand vectors $\mathbf{y}^E$ and $\mathbf{y}^W$? In the first round, these final demands are produced themselves. For the direct inputs, the input matrices are obtained from the IRIOT. For example, we have $\mathbf{A}^{EW} = \mathbf{Z}^{EW}(\hat{\mathbf{x}}^W)^{-1}$ with its typical element $a_{ij}^{EW} = z_{ij}^{EW}/x_j^W$ indicating the input from industry *i* in region *E* that goes to (and is measured per unit of output of) industry *j* in region *W*. The direct regional inputs amount to $\mathbf{A}^{EE}\mathbf{y}^E + \mathbf{A}^{EW}\mathbf{y}^W$ in region *E* and to $\mathbf{A}^{WE}\mathbf{y}^E + \mathbf{A}^{WW}\mathbf{y}^W$ in region *W*.

To calculate the direct (imported) inputs from country *R*, we require the input coefficients a_{ij}^{RE} and a_{ij}^{RW}. Because they are not available, we estimate the input coefficients from the information given in Figures 2.1 and 2.2. From the WIOT, we know the value of a_{ij}^{RT}. By definition, this should equal $(z_{ij}^{RE} + z_{ij}^{RW})/(x_j^E + x_j^W)$. Because the information for z_{ij}^{RE} and z_{ij}^{RW} is lacking, we first estimate their sum by

$$\tilde{z}_{ij}^{RE} + \tilde{z}_{ij}^{RW} = a_{ij}^{RT}(x_j^E + x_j^W)$$

Next, we use the average import shares that are obtained from information that is not listed in the Brazilian IRIOT. That is, for region *E* it is known for each product *i* (i.e. the typical product or service produced by industry *i*) how much is imported from country *R* and how much from country *S*. The same applies to the imports by region *W*. Information concerning the distribution over the (intermediate and final) users in the importing region is unavailable. Let the vector $\boldsymbol{\lambda}^{RE}$ denote the vector of import shares, the elements of which are defined as follows:

$$\lambda_i^{RE} = \frac{\text{total imports of product } i \text{ by region } E \text{ from country } R}{\text{total imports of product } i \text{ (by regions } E \text{ and } W\text{) from country } R}$$

A similar definition holds for λ_i^{RW}, and we have $\lambda_i^{RE} + \lambda_i^{RW} = 1$. The shares for the imports from country *S* are defined similarly and add up to one again (i.e., $\lambda_i^{SE} + \lambda_i^{SW} = 1$). We assume that these average import shares apply to each industry *j* of the destination. That is,

$$\tilde{z}_{ij}^{RE} = \lambda_i^{RE}(\tilde{z}_{ij}^{RE} + \tilde{z}_{ij}^{RW}) = \lambda_i^{RE} a_{ij}^{RT}(x_j^E + x_j^W).$$

Let the vector $\boldsymbol{\mu}^E$ denote the vector of output shares in region *E* with its elements defined as

$$\mu_i^E = x_i^E/(x_i^E + x_i^W)$$

and a similar definition for the output shares of region *W*. For the estimated input coefficients, this yields

$$\tilde{a}_{ij}^{RE} = \frac{\tilde{z}_{ij}^{RE}}{x_j^E} = \frac{\lambda_i^{RE} a_{ij}^{RT}(x_j^E + x_j^W)}{x_j^E} = \frac{\lambda_i^{RE} a_{ij}^{RT}}{\mu_j^E}.$$

In matrix notation, we have $\tilde{\mathbf{A}}^{RE} = \hat{\boldsymbol{\lambda}}^{RE}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^E)^{-1}$ for region *E*. Similarly, we have $\tilde{\mathbf{A}}^{RW} = \hat{\boldsymbol{\lambda}}^{RW}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^W)^{-1}$for region *W*.

The direct inputs in country *R* necessary to satisfy the final demand vectors $\mathbf{y}^E$ and $\mathbf{y}^W$ are then given by $\tilde{\mathbf{A}}^{RE}\mathbf{y}^E + \tilde{\mathbf{A}}^{RW}\mathbf{y}^W$. The direct inputs in country *S* are given by $\tilde{\mathbf{A}}^{SE}\mathbf{y}^E + \tilde{\mathbf{A}}^{SW}\mathbf{y}^W$. Together with the direct regional inputs, this yields

$$\begin{bmatrix} \tilde{\mathbf{A}}^{RE} & \tilde{\mathbf{A}}^{RW} \\ \tilde{\mathbf{A}}^{SE} & \tilde{\mathbf{A}}^{SW} \\ \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{y}^E \\ \mathbf{y}^W \end{pmatrix} = \begin{bmatrix} \hat{\boldsymbol{\lambda}}^{RE}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^E)^{-1} & \hat{\boldsymbol{\lambda}}^{RW}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^W)^{-1} \\ \hat{\boldsymbol{\lambda}}^{SE}\mathbf{A}^{ST}(\hat{\boldsymbol{\mu}}^E)^{-1} & \hat{\boldsymbol{\lambda}}^{SW}\mathbf{A}^{ST}(\hat{\boldsymbol{\mu}}^W)^{-1} \\ \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{y}^E \\ \mathbf{y}^W \end{pmatrix} \tag{2.2}$$

Finally, combining equations (2.1) and (2.2) gives us the direct inputs (in countries *R* and *S* and regions *E* and *W*) that are necessary for an arbitrary final demand vector. The direct inputs are given by

$$\begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} & \widetilde{\mathbf{A}}^{RE} & \widetilde{\mathbf{A}}^{RW} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} & \widetilde{\mathbf{A}}^{SE} & \widetilde{\mathbf{A}}^{SW} \\ \widetilde{\mathbf{A}}^{ER} & \widetilde{\mathbf{A}}^{ES} & \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \widetilde{\mathbf{A}}^{WR} & \widetilde{\mathbf{A}}^{WS} & \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{y}^R \\ \mathbf{y}^S \\ \mathbf{y}^E \\ \mathbf{y}^W \end{pmatrix} =$$

$$= \begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} & \hat{\boldsymbol{\lambda}}^{RE}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^E)^{-1} & \hat{\boldsymbol{\lambda}}^{RW}\mathbf{A}^{RT}(\hat{\boldsymbol{\mu}}^W)^{-1} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} & \hat{\boldsymbol{\lambda}}^{SE}\mathbf{A}^{ST}(\hat{\boldsymbol{\mu}}^E)^{-1} & \hat{\boldsymbol{\lambda}}^{SW}\mathbf{A}^{ST}(\hat{\boldsymbol{\mu}}^W)^{-1} \\ \hat{\boldsymbol{\sigma}}^{ER}\mathbf{A}^{TR} & \hat{\boldsymbol{\sigma}}^{ES}\mathbf{A}^{TS} & \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \hat{\boldsymbol{\sigma}}^{WR}\mathbf{A}^{TR} & \hat{\boldsymbol{\sigma}}^{WS}\mathbf{A}^{TS} & \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{y}^R \\ \mathbf{y}^S \\ \mathbf{y}^E \\ \mathbf{y}^W \end{pmatrix} \tag{2.3}$$

Let us write these direct inputs in condensed form as $\mathbf{Ay}$. The production of the direct inputs requires further inputs to the amount of $\mathbf{A}^2\mathbf{y}$ and so on. Combined with the initial outputs ($\mathbf{y}$), this yields $(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \cdots)\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{Ly}$, where $\mathbf{L}$ denotes the Leontief inverse that can be partitioned in the same way as $\mathbf{A}$.

Our application does not focus on the output levels (necessary for an arbitrary final demand vector) but on the value added. Define the value-added coefficients for country R as $g_i^R = v_i^R/x_i^R$ indicating the value added per unit of output. In matrix notation, this becomes $(\mathbf{g}^R)' = (\mathbf{v}^R)'(\hat{\mathbf{x}}^R)^{-1}$. The total value added created in country *R*, in country *S*, in region *E*, and in region *W* necessary for the final demand vector **y** are given by the four elements of the vector

$$\begin{bmatrix} \hat{\mathbf{g}}^R & 0 & 0 & 0 \\ 0 & \hat{\mathbf{g}}^S & 0 & 0 \\ 0 & 0 & \hat{\mathbf{g}}^E & 0 \\ 0 & 0 & 0 & \hat{\mathbf{g}}^W \end{bmatrix} \begin{bmatrix} \mathbf{L}^{RR} & \mathbf{L}^{RS} & \mathbf{L}^{RE} & \mathbf{L}^{RW} \\ \mathbf{L}^{SR} & \mathbf{L}^{SS} & \mathbf{L}^{SE} & \mathbf{L}^{SW} \\ \mathbf{L}^{ER} & \mathbf{L}^{ES} & \mathbf{L}^{EE} & \mathbf{L}^{EW} \\ \mathbf{L}^{WR} & \mathbf{L}^{WS} & \mathbf{L}^{WE} & \mathbf{L}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{y}^R \\ \mathbf{y}^S \\ \mathbf{y}^E \\ \mathbf{y}^W \end{pmatrix} \tag{2.4}$$

The central question in our application is how much of the value added generated in region *E* (or *W*) is contained in the final use of, for example, country *R*? This represents the export of value added from region *E* (or *W*) to country *R*. We apply equation (2.4) and take the final demand vector of country *R* instead of an arbitrary final demand vector. Final users in country *R* demand $\mathbf{c}^{RR}$ of domestically produced goods and services and import $\mathbf{c}^{SR}$ from country *S* and $\mathbf{c}^{TR}$ from country *T*. As with the input matrices, we use the export shares of regions *E* and *W* to split $\mathbf{c}^{TR}$. That is, $\hat{\boldsymbol{\sigma}}^{ER}\mathbf{c}^{TR}$ gives the exports from region *E* to final users in country *R*, and $\hat{\boldsymbol{\sigma}}^{WR}\mathbf{c}^{TR}$ gives the exports from region *W*. This yields

$$\begin{bmatrix} \hat{\mathbf{g}}^R & 0 & 0 & 0 \\ 0 & \hat{\mathbf{g}}^S & 0 & 0 \\ 0 & 0 & \hat{\mathbf{g}}^E & 0 \\ 0 & 0 & 0 & \hat{\mathbf{g}}^W \end{bmatrix} \begin{bmatrix} \mathbf{L}^{RR} & \mathbf{L}^{RS} & \mathbf{L}^{RE} & \mathbf{L}^{RW} \\ \mathbf{L}^{SR} & \mathbf{L}^{SS} & \mathbf{L}^{SE} & \mathbf{L}^{SW} \\ \mathbf{L}^{ER} & \mathbf{L}^{ES} & \mathbf{L}^{EE} & \mathbf{L}^{EW} \\ \mathbf{L}^{WR} & \mathbf{L}^{WS} & \mathbf{L}^{WE} & \mathbf{L}^{WW} \end{bmatrix} \begin{pmatrix} \mathbf{c}^{RR} \\ \mathbf{c}^{SR} \\ \hat{\boldsymbol{\sigma}}^{ER}\mathbf{c}^{TR} \\ \hat{\boldsymbol{\sigma}}^{WR}\mathbf{c}^{TR} \end{pmatrix} \tag{2.5}$$

The third element of this vector gives the value added of region E that is embodied in the final use of country R, and the fourth element gives the value-added exports of region W to country R.

Similarly, we are also interested in the value added generated in country R that is imported by region E. That is, in answering the question how much of country R's value added is embodied in the final use of region E, the final demand for goods and services produced in region E is given by $\mathbf{c}^{EE}$, for imports from region W by $\mathbf{c}^{WE}$. The imports by region E's final users of country R products are unknown. As with the input matrices for the imports, the imports for final use in region E are estimated using import shares, which yields $\hat{\boldsymbol{\lambda}}^{RE}\mathbf{c}^{RT}$. The same procedure is followed for the imports by final users from country S. This yields

$$\begin{bmatrix} \hat{\mathbf{g}}^R & 0 & 0 & 0 \\ 0 & \hat{\mathbf{g}}^S & 0 & 0 \\ 0 & 0 & \hat{\mathbf{g}}^E & 0 \\ 0 & 0 & 0 & \hat{\mathbf{g}}^W \end{bmatrix} \begin{bmatrix} \mathbf{L}^{RR} & \mathbf{L}^{RS} & \mathbf{L}^{RE} & \mathbf{L}^{RW} \\ \mathbf{L}^{SR} & \mathbf{L}^{SS} & \mathbf{L}^{SE} & \mathbf{L}^{SW} \\ \mathbf{L}^{ER} & \mathbf{L}^{ES} & \mathbf{L}^{EE} & \mathbf{L}^{EW} \\ \mathbf{L}^{WR} & \mathbf{L}^{WS} & \mathbf{L}^{WE} & \mathbf{L}^{WW} \end{bmatrix} \begin{pmatrix} \hat{\boldsymbol{\lambda}}^{RE}\mathbf{c}^{RT} \\ \hat{\boldsymbol{\lambda}}^{SE}\mathbf{c}^{ST} \\ \mathbf{c}^{EE} \\ \mathbf{c}^{WE} \end{pmatrix} \tag{2.6}$$

The first element of this vector gives the value added generated in country R embodied in final use in region E, and the second element gives the import of value added of country S by region E.

2.3 Testing the quality of the estimation

This section verifies the compatibility of the two datasets (WIOT from the WIOD project and the Brazilian IRIOT), and the resulting quality of the estimation of input coefficients in our country-state table.

First, we obtain a national version of the IRIOT for Brazil by aggregating the 27 Brazilian states (i.e., based on Figure 2.2, regions E and W together making up country T = Brazil). The national version of the IRIOT is then comparable to the elements corresponding to Brazil in the WIOT based on Figure 2.1. We separately compare the intermediate deliveries (i.e., $\mathbf{Z}^{TT}$ in the WIOT and $\mathbf{Z}^{EE} + \mathbf{Z}^{EW} + \mathbf{Z}^{WE} + \mathbf{Z}^{WW}$ in the IRIOT), the domestic final use (i.e., $\boldsymbol{c}^{TT}$ and $\mathbf{c}^{EE} + \mathbf{c}^{EW} + \mathbf{c}^{WE} + \mathbf{c}^{WW}$), the exports (i.e., $\mathbf{Z}^{TR}\mathbf{u} + \mathbf{Z}^{TS}\mathbf{u} + \mathbf{c}^{TR} + \mathbf{c}^{TS}$ and $\mathbf{e}^{E} + \mathbf{e}^{W}$), the imports (i.e., $\mathbf{u}'(\mathbf{Z}^{RT} + \mathbf{Z}^{ST})$ and $(\mathbf{m}^{E})' + (\mathbf{m}^{W})'$), the sum of imported final goods (i.e., $\mathbf{u}'(\mathbf{c}^{RT} + \mathbf{c}^{ST})$ and $h^{E} + h^{W}$), the value added (i.e., $(\mathbf{v}^{T})'$ and $(\mathbf{v}^{E})' + (\mathbf{v}^{W})'$), and the outputs (i.e., $\mathbf{x}^{T}$ and $\mathbf{x}^{E} + \mathbf{x}^{W}$). (Note: $\mathbf{u}$ indicates the column summation vector consisting of ones.)

The comparison is based on the weighted absolute percentage error (WAPE), which has been frequently applied in the literature (OOSTERHAVEN *et al*, 2008; JIANG *et al*, 2010). The WAPE indicator is defined as the weighted average of the absolute variation rates of the *(i,j)*th element with respect to the same *(i,j)*th element of the other matrix, which is taken as a reference dataset (ARTO *et al*, 2014). The indicator attributes larger weights to errors in larger cells. For example, the WAPE for the intermediate deliveries for country *T* is defined as:

$$WAPE = 100 \times \frac{\sum_i \sum_j z_{ij}^{TT} \left| \frac{\tilde{z}_{ij}^{TT} - z_{ij}^{TT}}{z_{ij}^{TT}} \right|}{\sum_i \sum_j z_{ij}^{TT}} = 100 \times \frac{\sum_i \sum_j \left| \tilde{z}_{ij}^{TT} - z_{ij}^{TT} \right|}{\sum_i \sum_j z_{ij}^{TT}}$$

Table 2.1 presents the results for WAPE in the comparison between Brazil in the WIOT and the national version of the IRIOT (Note: we use Brazil in the WIOT as the reference dataset). The WAPEs for the intermediate deliveries and the imports are considerably larger than the WAPEs for the other elements in the datasets. This points at methodological differences in the estimation of the WIOT and the IRIOT.

The IRIOT is based on (the Brazilian IO table which itself is based on) the official supply and use table (SUT) for 2008 (GUILHOTO *et al*, 2010). However, the WIOT is based on the Brazilian SUT that was estimated in the WIOD project using the SUT-RAS method (TIMMER *et al*, 2012). Because they are based on different sources, we expect to observe inconsistencies to some extent in all variables.

Another cause of inconsistency is that we were unable to obtain a sectoral classification that was perfectly common for both datasets, which particularly affects the services subsectors.

The detailed results show that the largest (absolute percentage) errors are found in sectors 21 (transport), 22 (post and telecommunications; other business activities), and 28 (other community, social and personal services; private households with employed persons). These are precisely the sectors with classification problems. If we aggregate these three sectors (and thus remove the classification problems) and run the calculations at the 26-sector level, the WAPEs decrease, as shown in Table 2.1.

Table 2.1 – Comparison between Brazil in the WIOT and national version of the IRIOT, WAPEs (%)

	WIOT	IRIOT	28 sectors	26 sectors
			WAPE	
Intermediate deliveries	$\mathbf{Z}^{TT}$	$\mathbf{Z}^{EE}+\mathbf{Z}^{EW}+\mathbf{Z}^{WE}+\mathbf{Z}^{WW}$	25.18	8.38
Domestic final use	$\boldsymbol{c}^{TT}$	$\mathbf{c}^{EE}+\mathbf{c}^{EW}+\mathbf{c}^{WE}+\mathbf{c}^{WW}$	7.54	3.41
Brazilian exports	$\mathbf{Z}^{TR}\mathbf{u}+\mathbf{Z}^{TS}\mathbf{u}+\mathbf{c}^{TR}+\mathbf{c}^{TS}$	$\mathbf{e}^{E}+\mathbf{e}^{W}$	4.76	1.34
Brazilian imports	$\mathbf{u}'(\mathbf{Z}^{RT}+\mathbf{Z}^{ST})$	$\mathbf{m}^{E}+\mathbf{m}^{W}$	13.07	10.76
Imported final goods	$\mathbf{u}'(\mathbf{c}^{RT}+\mathbf{c}^{ST})$	$h^{E}+h^{W}$	31.43	31.43
Values added	$(\mathbf{v}^{T})'$	$(\mathbf{v}^{E})'+(\mathbf{v}^{W})'$	9.04	8.23
Outputs	$\mathbf{x}^{T}$	$\mathbf{x}^{E}+\mathbf{x}^{W}$	1.80	0.82

The intermediate imports by industry and the value of imported final goods exhibit large differences in the datasets, although the total imports are close (approximately 6% larger in the IRIOT dataset). The differences are caused by the different procedures in the breakdown of the use table into domestic and imported origin. The Brazilian IO table that is the basis for the IRIOT adopts the standard assumption of import proportionality where the same fixed percentage of total use of a product is assumed to be imported, irrespective of its purchaser (GUILHOTO; SESSO FILHO, 2010). The WIOD project, however, has developed an improved estimation method that does not rely on this standard import proportionality assumption.[15] Additionally, the WIOD project's treatment of international margins also responds to the differences in sectoral imports between the datasets.[16]

[15] The WIOD project's estimation method relies on a classification of detailed products from international trade statistics, which enables the allocation of imports across end-use categories (i.e., "intermediate consumption", "final consumption", or "gross fixed capital formation"). Then, within each end-use category, the allocation is based on the proportionality assumption (DIETZENBACHER *et al*, 2013).

[16] The original datasets also present large differences in the valuation of exports. In the original IRIOT, departing from the values in purchasers' prices of the official SUT for 2008, trade and transport margins are subtracted from the exporting sectors and allocated to the respective margins sector (GUILHOTO *et al*, 2010). This valuation treatment, however, is not applied in the Brazilian IO table from the WIOD project. Because of this, the values for national exports of sectors that are mainly producers of goods are larger according to the WIOT dataset than in the IRIOT; the opposite is observed for the services sectors (with the exception of sector 28, other community, social, and personal services; private households with employed persons). In the present study, to eliminate this source of inconsistency, we have rearranged the margins in the IRIOT.

Because the value added in each industry is given by the difference of its total output and its total domestic and imported intermediate consumption, given the inconsistencies in intermediate deliveries and imports the vectors of value added also exhibit differences in the datasets. [17]

These inconsistencies are reflected in the quality of the estimation of input coefficients in our country-state table. Consider the constructed input matrix. That is,

$$\begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} & \widetilde{\mathbf{A}}^{RE} & \widetilde{\mathbf{A}}^{RW} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} & \widetilde{\mathbf{A}}^{SE} & \widetilde{\mathbf{A}}^{SW} \\ \widetilde{\mathbf{A}}^{ER} & \widetilde{\mathbf{A}}^{ES} & \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \widetilde{\mathbf{A}}^{WR} & \widetilde{\mathbf{A}}^{WS} & \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix}$$

We conduct two sets of comparisons. First, aggregating over the 27 Brazilian states (i.e., regions *E* and *W* together represent country *T* = Brazil) yields

$$\begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} & \widetilde{\mathbf{A}}^{RT} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} & \widetilde{\mathbf{A}}^{ST} \\ \mathbf{A}^{TR} & \mathbf{A}^{TS} & \widetilde{\mathbf{A}}^{TT} \end{bmatrix}$$

(Appendix A.2.1 details how the matrices $\widetilde{\mathbf{A}}^{TT}$, $\widetilde{\mathbf{A}}^{RT}$, and $\widetilde{\mathbf{A}}^{ST}$ are obtained) How does this compare to the input coefficients matrix from the WIOT? By construction, differences only exist in the column with input matrices for Brazil. We compare the domestic input coefficients (i.e., $\widetilde{\mathbf{A}}^{TT}$ and $\mathbf{A}^{TT}$ with *T* for Brazil) and the whole set of import coefficients matrices (i.e., $\widetilde{\mathbf{A}}^{iT}$ and $\mathbf{A}^{iT}$ for all $i \neq T$) separately.

The second comparison aggregates the constructed input matrix over all 40 countries and compares it with the Brazilian IRIOT. Aggregation (see Appendix A.2.1 for the details) yields estimates for the vectors of state exports (i.e., $\tilde{\mathbf{e}}^{ER}$, $\tilde{\mathbf{e}}^{ES}$, $\tilde{\mathbf{e}}^{WR}$, and $\tilde{\mathbf{e}}^{WS}$) and for the vectors of state import coefficients (i.e., estimates of $(\mathbf{m}^{E})'(\hat{\mathbf{x}}^{E})^{-1}$ and $(\mathbf{m}^{W})'(\hat{\mathbf{x}}^{W})^{-1}$).

To identify the effect of the sectoral classification problem on the quality of our estimation, we compare the model estimated at both the 28-sector level and the 26-sector level. Table 2.2

[17] That is, $[\mathbf{v}^{T} = (\mathbf{x}^{T})' - \mathbf{u}'\mathbf{Z}^{TT} - \mathbf{u}'(\mathbf{Z}^{RT} + \mathbf{Z}^{ST})]$ for Brazil in the WIOT and $[(\mathbf{v}^{E} + \mathbf{v}^{W}) = (\mathbf{x}^{E})' + (\boldsymbol{x}^{W})' - \boldsymbol{u}'(\mathbf{Z}^{EE} + \mathbf{Z}^{EW} + \mathbf{Z}^{WE} + \mathbf{Z}^{WW}) - \mathbf{m}^{E} - \mathbf{m}^{W}]$ for the national version of the IRIOT.

shows the results for the WAPE for the two comparisons (In comparison 1, we take the WIOT as the reference dataset. In comparison 2, we use the IRIOT).

Table 2.2 – WAPEs of the estimations (%)

		28 sectors	26 sectors
		WAPE	
Comparison 1: aggregate states and compare with Brazil in WIOT	Brazilian domestic input coefficients	20.14	7.81
	Brazilian import coefficients	4.90	3.43
	Total	0.41	0.11
Comparison 2: aggregate countries and compare with state trade in IRIOT	Exports of Brazilian states	4.76	3.08
	Import coefficients of Brazilian states	36.05	36.03

In the first comparison, the WAPE for the domestic input coefficients is considerably larger than the WAPE for the import coefficients. The estimated domestic input coefficients $\tilde{\mathbf{A}}^{TT}$ are largely based on the IRIOT, whereas the estimated import coefficients $\tilde{\mathbf{A}}^{iT}$ are largely based on the import coefficients from the WIOT. The difference in the WAPEs, therefore, reflects the inconsistencies between the datasets.

As in the comparison between the original datasets (Table 2.1), if we aggregate the three sectors with classification problems and run the calculations at the 26-sector level, the WAPE for the domestic input coefficients drops considerably. Additionally, the errors show both pluses and minuses. In our calculations (of the export/import of value added of Brazilian states) in the next section, the errors cancel each other out to some extent. Moreover, the transport sector, which is key to environmental analysis, at the 26-sector level is aggregated to services activities with little direct environmental impact; ignoring this could affect our analysis. Therefore, we have chosen to retain the 28-sector classification.

In comparison 2, because Brazilian exports are similar in the two datasets (as shown in Table 2.1), and the states' export shares are compatible with both datasets,[18] the WAPE for the exports of Brazilian states is relatively small. However, the WAPE for the vectors of state import coefficients is considerably larger than those in the first comparison. The sectoral

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[18] A RAS algorithm was applied to obtain consistency in the export data from AliceWeb. Thus aggregating the AliceWeb data over the destination country would result in the IRIOT's vectors of total exports by state and by industry, whereas aggregating the AliceWeb data over the originating state would result in the WIOT's total export figures for Brazil by country of destination. We computed the states' export share based on this treatment of AliceWeb data.

classification is not a main source of inconsistency in this case because the WAPEs are not significantly different at the 26-sector level.

The inconsistency in the state import coefficients reflects the differences between the values of Brazilian intermediate imports in the datasets, as already analyzed. Additionally, the detailed results show that the largest (absolute percentage) errors are concentrated in the states (Amazonas, Maranhão, and Mato Grosso do Sul) that exhibit large import coefficients in the IRIOT, which are reduced in our country-state table.

Comparison 2 indicates that in our approach the import structure of Brazil (based on the WIOT) is different from the import structure in the IRIOT. Because the WIOD project has developed an enhanced approach to global trade, we consider it appropriate to base our estimates of Brazilian international trade on the WIOT. The WAPEs in comparison 2 might indicate that improvements are introduced into the IRIOT.

Therefore, we observe that aggregating our data leads to inconsistencies with both the WIOT and the IRIOT. In our approach, we choose not to take one of the datasets (the WIOT, for example) as a starting point and adapt the other dataset (i.e., the IRIOT) accordingly. In this case, comparison 1 yields no errors, but the errors in comparison 2 reflect all the inconsistencies between WIOT and IRIOT. Such an approach is appropriate if one of the datasets contains superior information. In the current situation, we do not consider this to be the case. Therefore, we have chosen to construct input coefficients using both datasets: the domestic intersectoral flows are largely based on the IRIOT, whereas the international transactions are largely based on coefficients from the WIOT.

2.4 Results

In our empirical application, we first evaluate the relevance of GVCs for Brazilian states by computing their value-added exports and imports. The remainder of the chapter examines GVC engagement by states, considering production sharing at global and regional levels. Subsection 2.4.2 investigates the value-added content of Brazilian states' trade and verifies if the industry composition of exports explains content variation. An important implication of such variation is that bilateral trade balances differ when measured by gross or value-added terms, as we verify in subsection 2.4.3. Next, we quantify states' indirect participation (by means of production sharing) in international trade. The final two subsections elucidate the mechanism of indirect participation in GVCs noting the degree of redirection of incoming flows to third parties by the various states and countries in our model.

2.4.1 Multilateral value-added exports and imports

To assess the significance of Brazilian state's GVC participation, we quantify their international value-added trade. We use the country-state IO table that was previously estimated. The value-added exports for a given foreign country are obtained by applying equation (2.4) and taking the final demand vector for the country. To compute a given state's value-added imports, we apply this state's final demand vector in equation (2.4). Figure 2.3 summarizes the results for Brazilian states' multilateral international value-added trade. Table A.2.1 in Appendix A.2.2 presents the monetary figures.

In Figure 2.3, the bars represent the monetary figures of each state's multilateral value-added exports (upwards) and value-added imports (downwards) in US$ millions. To assess the importance of the states' international value-added trade, Figure 2.3 includes diamond shapes that depict the share (%) of multilateral value-added exports in each state's total value added (upwards) and multilateral value-added imports in the total value added embodied in consumption (downwards).

We observe that international trade in value added is highly concentrated in the Southeast and South regions. In 2008, these states accounted for 79% of value-added exports and 72% of value-added imports for Brazil. São Paulo alone accounted for one-third of Brazil's international value-added trade.

In relative terms, value-added exports are particularly important for Espírito Santo, Mato Grosso, and Pará. In these states, significant shares of value added are caused by the final consumption of foreign countries (in 2008, 27%, 23%, and 26% respectively. In Brazil, on average, value-added exports corresponded to 13% of total value added in 2008). The indication of Cherubini and Los (2012) for the Northern regions in Italy that are more integrated into GVCs than the rest of the country also applies to these states in Brazil. One of the consequences is that these states are hit less hard by declining domestic consumption, while benefiting from more rapid growth in other global regions. Value-added imports are important for Amazonas: in 2008, 22% of value added embodied in the state's final consumption was generated abroad.[19] In São Paulo and Paraná, foreign sourcing of value added was also significant (14% of value added in consumption).

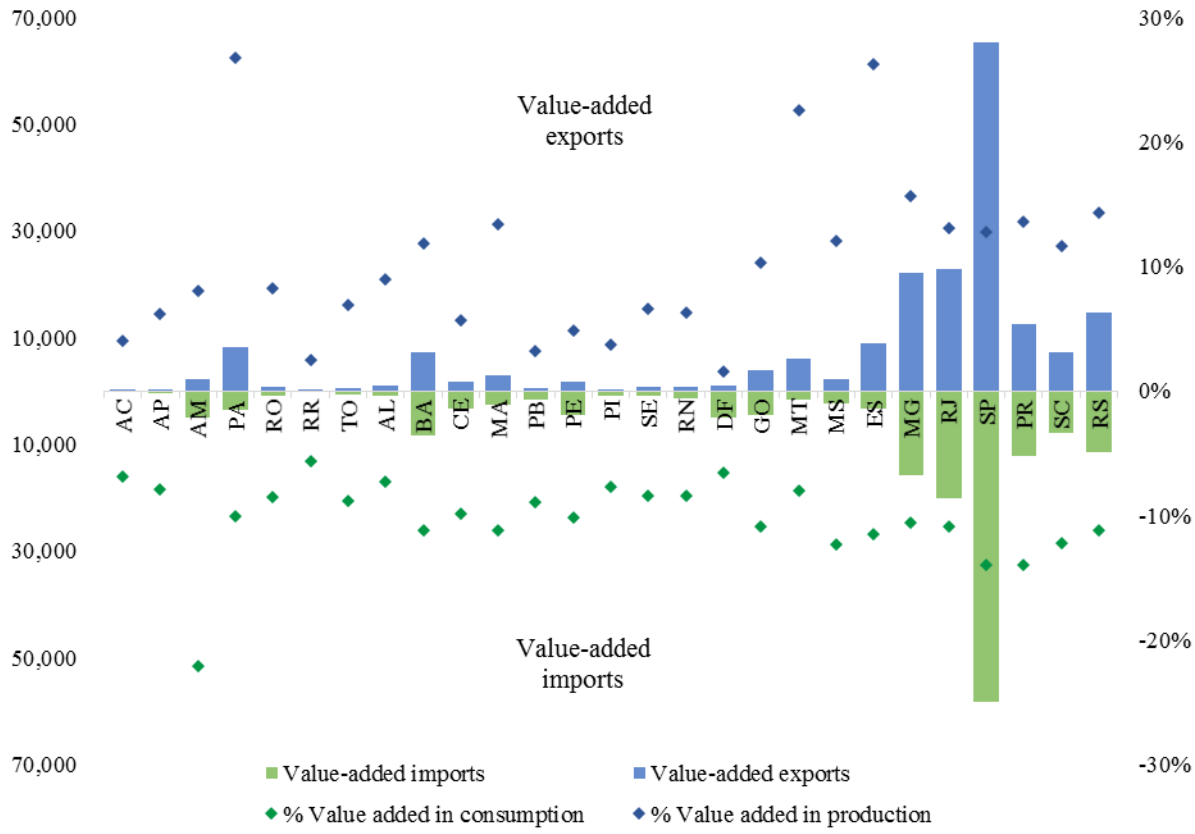


Figure 2.3 – Brazilian states' multilateral value-added exports and imports (US$ millions)
Note: the left axis correspond to the bars, which represent the monetary figures (US$ millions) of multilateral value-added exports (upwards) and value-added imports (downwards). The right axis correspond to the diamonds, which represent the shares (%) of multilateral value-added exports in the state's total value added (upwards) and of multilateral value-added imports in the total value added embodied in the state's consumption (downwards)

[19] This result is partially attributed to the data employed to estimate the country-state IO table. Because no information is available with respect to the distribution of imports for (intermediate and final) users in the importing state, identical import shares were applied in estimating both intermediate input coefficients and final demand vectors. These import shares reflect the average imported content across user categories for each state. Because Amazonas' manufacturing in the Free Trade Zone of Manaus requires a large amount of imported inputs, we observe high average import shares for the state. Because these shares are also applied when estimating the state's final demand, the imported content of its consumption is likely to be overestimated.

2.4.2 Value-added content of exports

The most well-known indicator of value-added content of trade, the value-added exports to gross exports ratio or the "VAX ratio", was proposed by Johnson and Noguera (2012). The VAX ratio is also available in the OECD TiVA database, as well as in Koopman *et al* (2014) and Timmer *et al* (2015).[20]

The VAX ratio is a measure of the intensity of production sharing. A country specializing in the final stages of production processes and thus including significant amounts of foreign value added in its exports will typically present a low average VAX ratio. On the other hand, a high national VAX ratio can be a result of specialization in products which, by nature, require short processing (YÜCER *et al*, 2014).

Table 2.3 presents aggregate VAX ratios for Brazilian states and other countries in our model.[21] These figures were obtained considering multilateral trade. VAX ratios differ significantly across trade partners, and we analyze these differences in the next subsection.

Among the countries in our model, Brazil's VAX ratio is below that of Russia only. Across states, value-added exports represent approximately 87% of gross exports. As indicated by Yücer *et al* (2014), a high VAX ratio is expected for Brazil because its specialization is mainly in early supply chain tasks compared to China, for example. However, the high VAX ratio does not imply a low level of production sharing along the domestic value chains, given the high level of heterogeneity among Brazilian states.

At the regional level, the VAX ratios are lower for South, Southeast, and Central-West regions, and higher for North and Northeast regions. For most of these latter regions, exports in gross terms are smaller than in value-added terms. Within regions, Pará and Bahia have

[20] Timmer *et al* (2015) compared the VAX ratios based on the WIOD with the VAX ratios from the OECD TiVA database, Johnson and Noguera (2012a), and Koopman *et al* (2014). The authors found remarkable agreement across alternative datasets. The pairwise correlation between the four datasets ranged from 0.93 to 0.98 (Spearman rank correlation).

[21] In this section, we aggregate some of the countries in our model as "Other EU27" (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden) and as "Other countries + RoW" (Australia, Indonesia, Turkey, and ROW) for presentation purposes. We aggregate only the final results; all the calculations use the full model composed of 67 distinct regions (27 Brazilian states + 39 countries + RoW).

low VAX ratios in North and Northeast regions, respectively, while Distrito Federal and Rio de Janeiro have high VAX ratios in Central-West and Southeast regions, respectively.

Table 2.3 – Value-added exports, gross exports (US$ millions), and VAX ratios

	Value-added exports	Gross exports	VAX ratio
Acre	138	39	3.51
Amapá	218	216	1.01
Amazonas	2,100	1,507	1.39
Pará	8,185	10,891	0.75
Rondônia	735	657	1.12
Roraima	63	30	2.09
Tocantins	465	336	1.39
Alagoas	894	994	0.90
Bahia	7,298	9,760	0.75
Ceará	1,729	1,548	1.12
Maranhão	2,833	2,720	1.04
Paraíba	413	317	1.30
Pernambuco	1,708	1,294	1.32
Piauí	314	180	1.74
Sergipe	656	178	3.69
Rio Grande do Norte	809	475	1.70
Distrito Federal	965	660	1.46
Goiás	3,984	4,455	0.89
Mato Grosso	6,138	8,191	0.75
Mato Grosso do Sul	2,113	2,233	0.95
Espírito Santo	8,933	10,349	0.86
Minas Gerais	22,227	26,649	0.83
Rio de Janeiro	22,929	21,029	1.09
São Paulo	65,211	76,443	0.85
Paraná	12,483	16,373	0.76
Santa Catarina	7,321	8,347	0.88
Rio Grande do Sul	14,749	20,035	0.74
Brazil	195,610	225,905	0.87
China	1,570,973	2,277,153	0.69
India	200,154	258,056	0.78
Russia	390,022	424,322	0.92
USA	1,329,839	1,696,466	0.78
Mexico	198,580	282,714	0.70
Canada	390,496	511,294	0.76
Germany	1,156,546	1,671,905	0.69
Spain	255,235	366,589	0.70
France	499,395	704,786	0.71
United Kingdom	576,860	737,344	0.78
Italy	454,887	620,329	0.73
Other EU27	1,715,356	2,840,322	0.60
Japan	690,451	858,425	0.80
Korea	284,605	492,391	0.58
Taiwan	147,014	278,579	0.53
Other countries + RoW	2,611,707	3,926,846	0.67
Foreign countries	12,472,122	17,947,521	0.69

The industry composition of exports may drive the variation in the VAX ratios across Brazilian states because the VAX ratios are typically less than one in manufacturing industries and greater than one in other industries. Table A.2.2 in Appendix A.2.2 presents the states' VAX ratios for two composite industries, manufacturing and non-manufacturing (pooling agriculture, mining, and services activities into a single composite industry). As indicated by Johnson and Noguera (2012a), in addition to differences in value added to output ratios this cross-industry variation of VAX ratios is primarily because of differences in industry trade engagement; that is, the extent to which sectoral output is directly exported versus indirectly exported and embodied in the goods of other industries that are then exported. We observe that an industry's VAX ratio is less than one when its exports embody other industries' value added. This is the case of manufacturing industries, which typically purchase inputs from non-manufacturing industries and hence embody value added from other sectors in their direct exports.

To verify if the export composition drives VAX ratios across Brazilian states, we follow Johnson and Noguera (2012a) and apply a between-within decomposition of the aggregate VAX ratio, as follows:

$$VAX_i - \overline{VAX} = \sum_s [VAX_i(s) - \overline{VAX}(s)] \left(\frac{\omega_i(s) + \bar{\omega}(s)}{2} \right) + \sum_s [\omega_i(s) - \bar{\omega}(s)] \left(\frac{VAX_i(s) + \overline{VAX}(s)}{2} \right)$$

where i denotes state, s denotes industry, and $\omega_i(s)$ and $VAX_i(s)$ are export share and VAX ratio in industry s of state i. Bars denote reference variables, which are constructed based on Brazil as a whole. The first term on the right side of the equation is the "within term", and the second term on the right side is the "between term." The within term varies because of differences in VAX ratios within industries across states, whereas the between term varies because of differences in industry composition of exports.

Our decomposition uses two composite industries, manufacturing and non-manufacturing. We observe that both industry composition and differences within industries explain the cross-state variation in aggregate VAX ratios. Figure 2.4 shows the plotted VAX ratio deviations against the within and between terms. Both terms are positively correlated with VAX ratio deviations.[22, 23] This result contrasts with Johnson and Noguera (2012a), who found the within term weakly negatively correlated with the VAX ratio deviations of national economies.

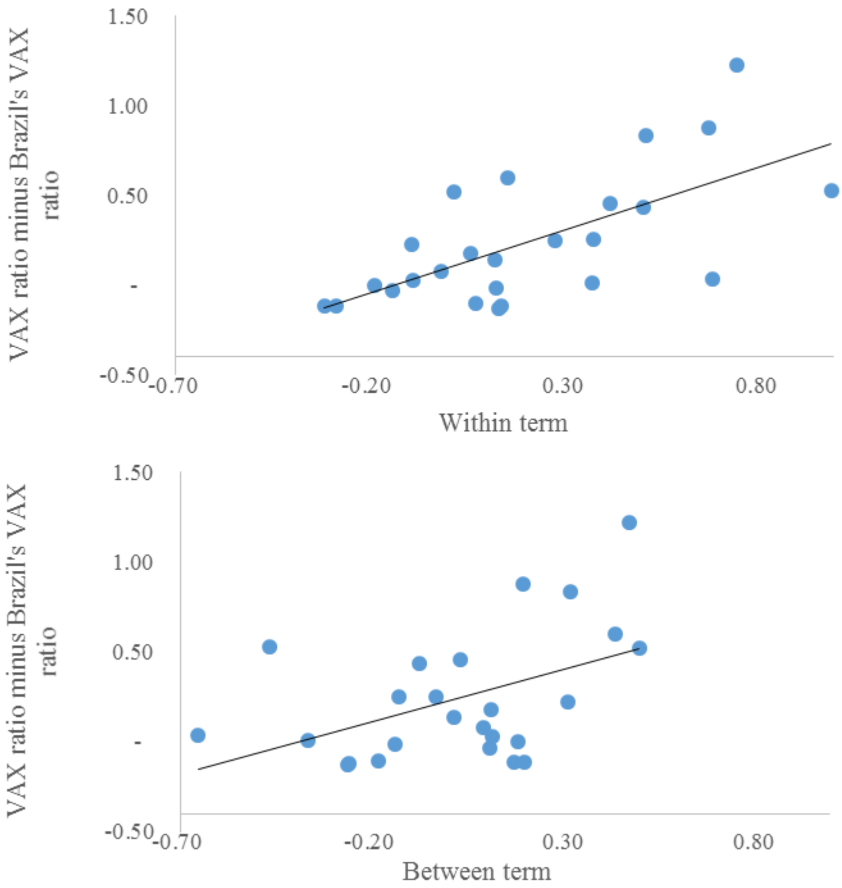


Figure 2.4 – Between-within decomposition of aggregate VAX ratios, Brazilian states

Therefore, differences within industries are also relevant in explaining the aggregate VAX ratio deviations, and we are unable to affirm that industry composition of exports drives aggregate VAX ratios. Next to the differentials in VAX ratios across industries, so that states that export predominantly manufacturing tend to have low aggregate VAX ratios, there are also large differences in VAX ratios within industries across the Brazilian states. Engagement in international trade particularly varies significantly given the interregional fragmentation of production processes. While some states export value added mostly directly or indirectly via

[22] The regression line in the top panel is $(VAX_i - \overline{VAX})$ = 0.70 * within term + 0.09 (standard error 0.16 and R^2 = 0.43). The regression in the bottom panel is $(VAX_i - \overline{VAX})$ = 0.58 * between term + 0.22 (standard error 0.23 and R^2 = 0.22).

[23] In the depicted decomposition, we omit Acre and Sergipe. If these states are included, the regression line in the top panel would be $(VAX_i - \overline{VAX})$ = 1.06 * within term + 0.04 (standard error 0.09 and R^2 = 0.84); the regression line in the bottom panel would be $(VAX_i - \overline{VAX})$ = 1.25 * between term + 0.35 (standard error 0.43 and R^2 = 0.25).

their own industries, others indirectly engage in international trade by providing inputs to other states. We analyze this finding in the following sections.

2.4.3 Trade and value-added balances

A consequence of the different VAX ratios across countries is that bilateral trade balances differ when measured in gross or value-added terms.[24] Table 2.4 presents bilateral trade and value- added balances for Brazil. Table A.2.3 in Appendix A.2.2 shows the VAX ratio and the ratio of value-added imports to gross imports by trade partner. Note that for each country the multilateral trade balance must be the same for both gross terms and value added (see Stehrer (2012) for a formal demonstration), so that an increase in the bilateral value-added balance relative to the gross trade balance with a trade partner necessarily implies a decline with some other partner. This is important for the interpretation of our results.

For China, with the adjustment in converting gross imbalance to value-added terms, the surplus becomes a deficit. This indicates that large amounts of intermediate products from Brazil are processed in China and then re-exported: they are considered exports to China in gross terms but, in terms of value added, they are considered Brazil's exports to the countries who absorb them in the final demand. Thus, Brazil's exports to China sharply decline when measured in value-added terms. Brazil's bilateral VAX ratio was only 0.69 in 2008. This variation was not entirely balanced by the decline in China's exports to Brazil in value-added terms relative to gross trade (China's bilateral VAX ratio was 0.78). With respect to triangular production sharing within Asia, where other countries supply intermediates to China that are then embodied in Chinese gross exports, the deficits are larger for Brazil with Japan, Korea, and Taiwan in value-added terms.

The measurement based on gross trade also overstates the Brazilian surplus with the EU as a whole. The Brazil-Germany imbalance is converted from a gross trade surplus to a value-

[24] The difference in VAX ratios and the absolute level of the average VAX ratio between partners both influence the adjustment in converting gross imbalances to value-added terms (JOHNSON; NOGUERA, 2012a). Taking the Brazil-China balance as an example, the average VAX ratio is 0.74. Thus, it is less than one, and the value-added balance is scaled down relative to the gross trade balance. If VAX ratios for both exports and imports were equal to 0.74, this "level effect" would imply a value-added surplus of Brazil that is 26% smaller than the gross surplus (US$ 733 million in 2008). However, Brazil presents a deficit in value-added terms with China because its ratio of value-added imports to gross imports (0.78) is high relative to its VAX (0.69). Thus, in the case of the Brazil-China balance, the difference in VAX ratios accounts for most of the adjustment from gross to value-added balances.

added deficit. Similarly to the trade relation with China, a significant share of the Brazilian export of intermediates is embodied in Germany's production that is ultimately consumed in other countries and does not comprise a value-added export to Germany. In 2008, Brazilian value-added exports to Germany were 27% less than its gross bilateral exports.

Table 2.4 shows that change in imbalances are also observed in the Brazil-Russia pair. This case, however, is evidence of Russia's significant export of intermediate inputs (mostly from its mining industries) to third countries that process and re-export them to Brazil. Russia's bilateral exports in value-added terms were 159% larger than its gross exports.

Balancing these declines and keeping Brazil's multilateral trade balance the same as in gross terms, we observe larger surpluses in Brazil-USA and Brazil-RoW balances in value-added terms than in gross trade. This is an indication of Brazil's significant indirect value-added exports to these world regions via GVCs. We return to this subject in subsection 2.4.6.

Table 2.4 – Bilateral trade and value-added balances for Brazil, by partner (US$ millions)

	Gross trade	Trade in value added
China	996	-1,830
India	-1,624	-510
Russia	1,279	-143
USA	7,868	9,704
Mexico	2,743	2,097
Canada	-3,832	-3,034
Germany	1,914	-1,640
Spain	791	1,616
France	-479	74
United Kingdom	-618	33
Italy	-1,039	-340
Other EU27	5,288	2,119
Japan	-254	-804
Korea	-935	-1,044
Taiwan	-728	-944
Other countries + RoW	6,053	12,069
Foreign countries	17,423	17,423

There are also differences between gross trade and value-added balances for the states. Table 2.5 presents the results of both measurements for Rio de Janeiro. Note that although a country's trade balance with the rest of the world must be the same both in gross terms and in value added, this is not necessarily the case for subnational regions because their trade balances include interregional transactions.

Excluding China and Russia, the adjustment in converting Rio de Janeiro's gross imbalances to value-added terms is a reduction in the deficit/rise in the surplus with all countries depicted in Table 2.5. Except with China, Rio de Janeiro's exports were larger in value-added terms (i.e., the exports presented bilateral VAX ratios larger than one). Next to international production sharing, as noted for Brazil as a whole, we must interpret these results considering the interregional fragmentation of production.[25] The international multilateral trade balance of Rio de Janeiro changes from a deficit to a surplus when converted to value-added terms. This is evidence that substantial amounts of Rio de Janeiro's intermediates are embodied in the production of other Brazilian states that is ultimately exported and consumed abroad. Thus, Rio de Janeiro has prominent indirect participation in exports to foreign countries through production sharing in Brazil's domestic value chains.

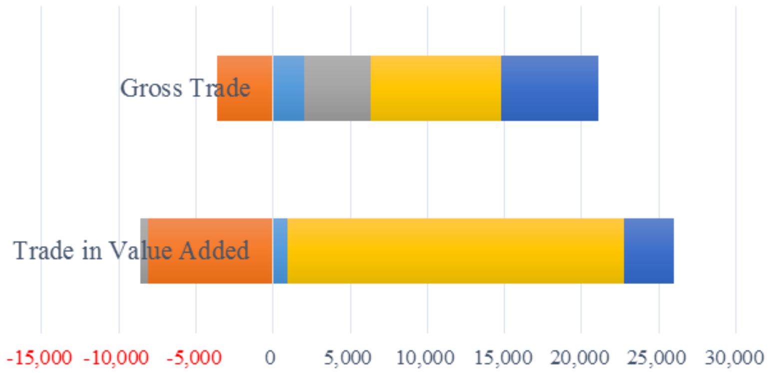
Table 2.5 – Bilateral trade and value-added balances for Rio de Janeiro, by partner (US$ millions)

	Gross trade	Trade in value added
China	8,610	2,997
India	-115	65
Russia	-78	-129
USA	-2,262	259
Mexico	84	199
Canada	-639	-428
Germany	-712	-514
Spain	-44	161
France	-643	-341
United Kingdom	-348	-175
Italy	-458	-181
Other EU27	43	43
Japan	-302	-31
Korea	-144	-16
Taiwan	-68	-65
Other countries + RoW	-3,482	926
Foreign countries	-556	2,771

The case of Rio de Janeiro is an indication that Brazilian states engaging in international trade differ in meaningful ways. This can also be perceived from Brazilian regions' participation in the country's multilateral trade and value-added balances, as illustrated in Figure 2.5. This Figure conceals important differences among states within each region, but it is informative in terms of their average trade relations. Table A.2.5 in Appendix A.2.2 presents the multilateral trade and value-added balances for each state.

[25] The particular industry composition of Rio de Janeiro's exports also explains the results. The "mining and quarrying" industry, which presents a high value-added to output ratio, corresponded to more than 60% of Rio de Janeiro's gross exports.

To interpret Figure 2.5, we must recognize the differences in the (multilateral) value-added imports to gross imports ratios as well as the differences in VAX ratios across regions. The value-added imports to gross imports ratio is low in the Southeast region (in São Paulo, it is 0.70) while in the Northeast and the Central-West region it is larger than one as the value-added imports surpass the gross imports. Thus, indirect value-added imports are also fundamental for the adjustment in converting gross imbalances to value-added terms.



	Trade in Value Added	Gross Trade
North	966	2,028
Northeast	-8,130	-3,649
Central West	-436	4,257
Southeast	21,782	8,469
South	3,242	6,319

Figure 2.5 – Brazil's trade and value-added balances decomposed by domestic regions (US$ millions)

These findings show that the Brazilian regions engage in international trade indirectly as sources of intermediates that are embodied in the exports of other regions and as final consumers of products and services that embody foreign inputs. Therefore, production sharing plays an important role in Brazilian states' engagement in international trade. As indicated by Meng *et al* (2013), while these findings are not surprising, our method allows us to analyze the extent and mechanisms of the phenomenon in the following subsections.

2.4.4 Decomposition of Brazilian states' international value-added flows

To measure the indirect participation of each Brazilian state in international trade, we depart from Meng *et al*. (2013) and decompose the regional value-added exports into four parts (considering E as the exporting region and R as the destination foreign country):

a) $\mathbf{g}^{E}\mathbf{L}^{EE}\mathbf{y}^{ER}$: value added embodied in *E*'s direct exports of final products to *R*;
b) $\mathbf{g}^{E}\mathbf{L}^{ER}\mathbf{y}^{RR}$: value added embodied in *E*'s exports of intermediate products that are imported by *R* and attributed to *R'*s final demand;
c) $\sum_{i\neq E}\mathbf{g}^{E}\mathbf{L}^{Ei}\mathbf{y}^{iR}$, i is a Brazilian state: value added embodied in *E*'s outflows of intermediate products to other states than *R* and attributed to *R'*s final demand;
d) $\sum_{j\neq R}\mathbf{g}^{E}\mathbf{L}^{Ej}\mathbf{y}^{jR}$, j is a foreign country: value added embodied in *E*'s exports of intermediate products to other countries than *R* and attributed to *R'*s final demand.

Timmer *et al* (2015) define a GVC of a final good as the set of value-adding activities needed in its production, and identify it by the country-industry in which the last stage of production happens occurs. Therefore, in this decomposition we measure how much of the value-added exports of given state *E* to final destination country *R* occurs by means of: a) *E*'s own GVCs; b) *E*'s sourcing of intermediate inputs to *R*'s GVCs; c) *E*'s sourcing of intermediate inputs to other states' GVCs; and d) *E*'s sourcing of intermediate inputs to other foreign country GVCs. We designate the last two components as indirect value-added exports from state *E* to country *R* through, respectively, Brazilian value chains and foreign value chains.

Figure 2.6 presents the results for these four components of each state's value-added exports aggregating the final destination countries (Table A.2.6 in Appendix A.2.2 presents the monetary figures). All Brazilian states participate in GVCs mainly sourcing intermediate rather than final products. On average, 23% of states' value-added exports are embodied in intermediate inputs that are processed by (at least) another state or another foreign country before being absorbed by the final destination country.

However, Figure 2.6 confirms that state integration in production sharing is highly diverse. States with substantial mineral resources export (particularly Pará and Minas Gerais) their value added directly or by integrating themselves in foreign countries' GVCs. Pará is weakly integrated into Brazilian GVCs as a source of intermediate inputs as only 4% of its value-added exports occur through this route. Southeast and South region states also directly export their own value added. Among them, the indirect export components are significant for Rio de Janeiro; in absolute terms, the state shows the second largest amount of indirect value-added exports after São Paulo, both via Brazilian states' and foreign countries' GVCs. For most states in the other regions in the country, indirect value-added exports mainly occur by providing intermediate inputs to final producers elsewhere in Brazil, that is, through Brazil's GVCs. Amazonas is noteworthy in this regard because of the Free Trade Zone of Manaus, which is an industrial hub servicing the rest of the country.

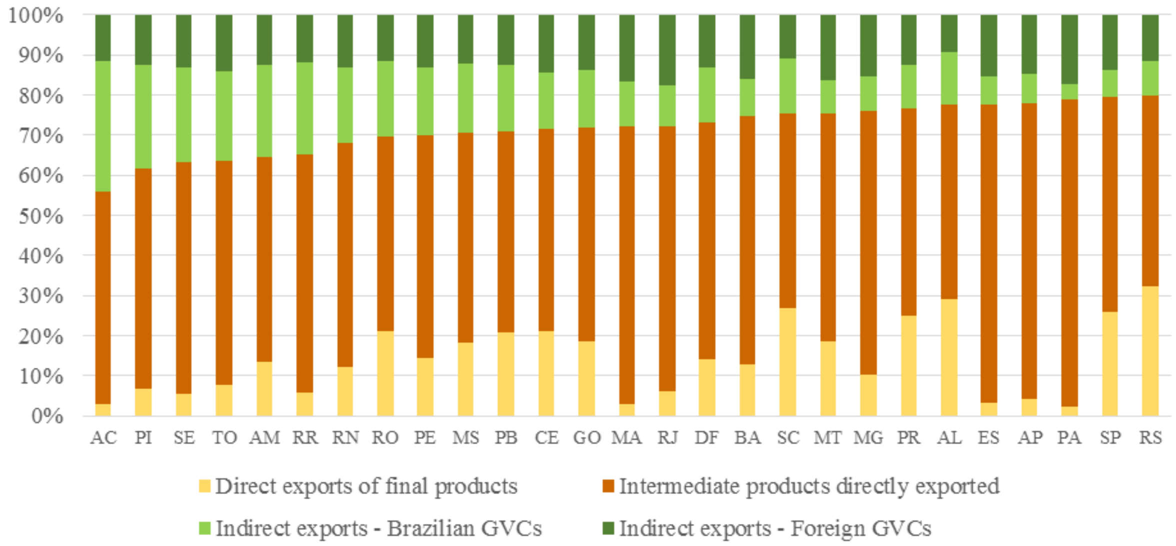


Figure 2.6 – Decomposition of multilateral value-added exports: direct, intermediate and indirect exports (%)

To understand how GVCs are extended within Brazil, we analyze the incoming value-added flows from foreign countries. Figure 2.7 illustrates the results for the decomposition applied to states' value-added imports, i.e. taking E as a foreign country, and R as a Brazilian state. Apart from Amazonas and São Paulo, in all states the indirect component is greater for value-added imports than for value-added exports. Thus, domestic value chains within Brazil are relevant for spreading foreign value added throughout the country. On average, 20% of states' value-added imports are embodied in final products that are produced by other states. The relevance of indirect value-added imports via other states' GVCs is reduced for São Paulo and to a lesser extent for other states in the South and Southeast regions (except Espírito Santo). This is not surprising because the manufacturing industries are concentrated in these states, which process intermediate imports to produce final products for their own consumption and consumption in other states. This result is an indication that such states inter-link final consumption within Brazil and the generation of value added abroad. The next section further analyzes this point.

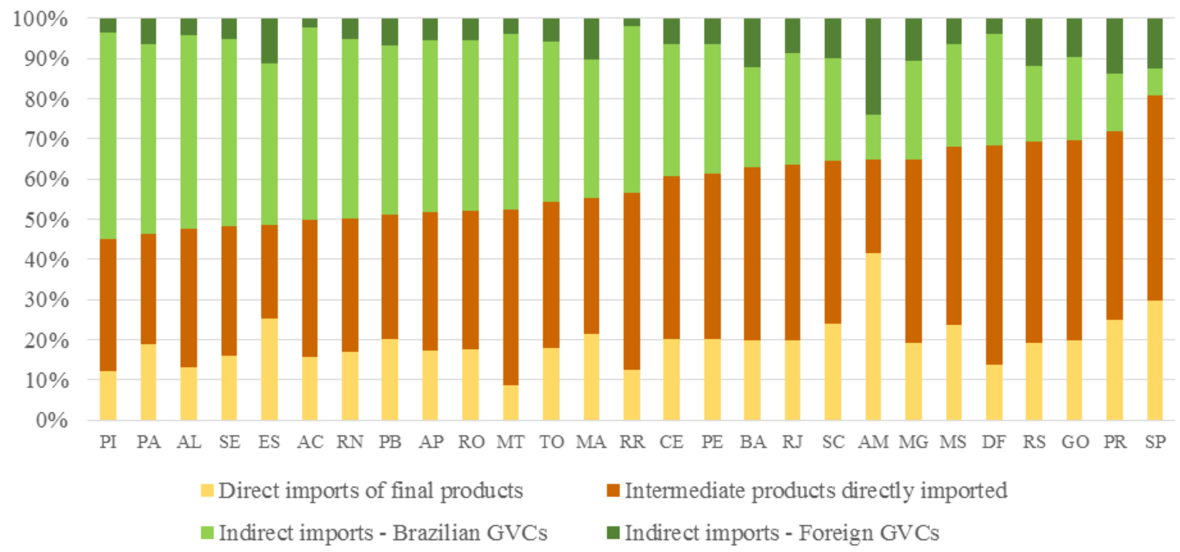


Figure 2.7 – Decomposition of multilateral value-added imports: direct, intermediate and indirect imports (%)

2.4.5 Destination of regional outflows and exports

To investigate the structure of regional exports, we calculate the share of each destination in outflows/exports of each Brazilian state for both gross trade and TiVA.[26] Here, we break down by destination the results of subsection 2.4.1. Figure 2.8 summarizes our findings aggregating the states by regions as both trade sources and destinations and foreign countries as trade destinations. The green arrow shows the share of other Brazilian states as destinations of gross trade or TiVA while the red arrow shows the share of foreign countries.

A comparison of the destinations' shares in gross trade and TiVA shows that for every Brazilian state, the share corresponding to other states as destinations of outflows is larger for gross trade than TiVA, and especially the shares of the Southeast and the South region decline in value-added terms. For each state, the share corresponding to its respective region as trade destination also declines. For example, for Rio Grande do Norte in the Northeast region, the share of trade that is directed to other states in the Northeast region, in the Southeast region, and in the South region declines in TiVA relative to gross trade in 5 percentage points (pp), 6 pp, and 3 pp, respectively.

[26] We distinguish between inflows/outflows for trade between domestic states and imports/exports for trade between states and foreign countries or between foreign countries.

The results reinforce that all Brazilian states amplify their contribution to international trade by indirectly exporting. The states provide intermediate inputs mainly to states in the Southeast region, the South region, and their respective region, thereby exporting more value added abroad.

The participation of states or foreign countries as sources of inflows/imports purchased by each Brazilian state shows similar results as those presented in Figure 2.8. Thus, the implications are analogous: for every Brazilian state, the share of its incoming flows that originate in the Southeast region, in the South region, and in its respective region is larger for gross trade than TiVA. These regions embody foreign inputs in their products that are ultimately consumed by other states, which indirectly imports value added from abroad.

These two simultaneous movements explain the findings shown in Figure 2.5 concerning regional participation in the multilateral trade and value-added balances. Certain regions act as links between GVCs and Brazilian domestic value chains. The following subsection analyzes where the gross bilateral trade flows are ultimately consumed.

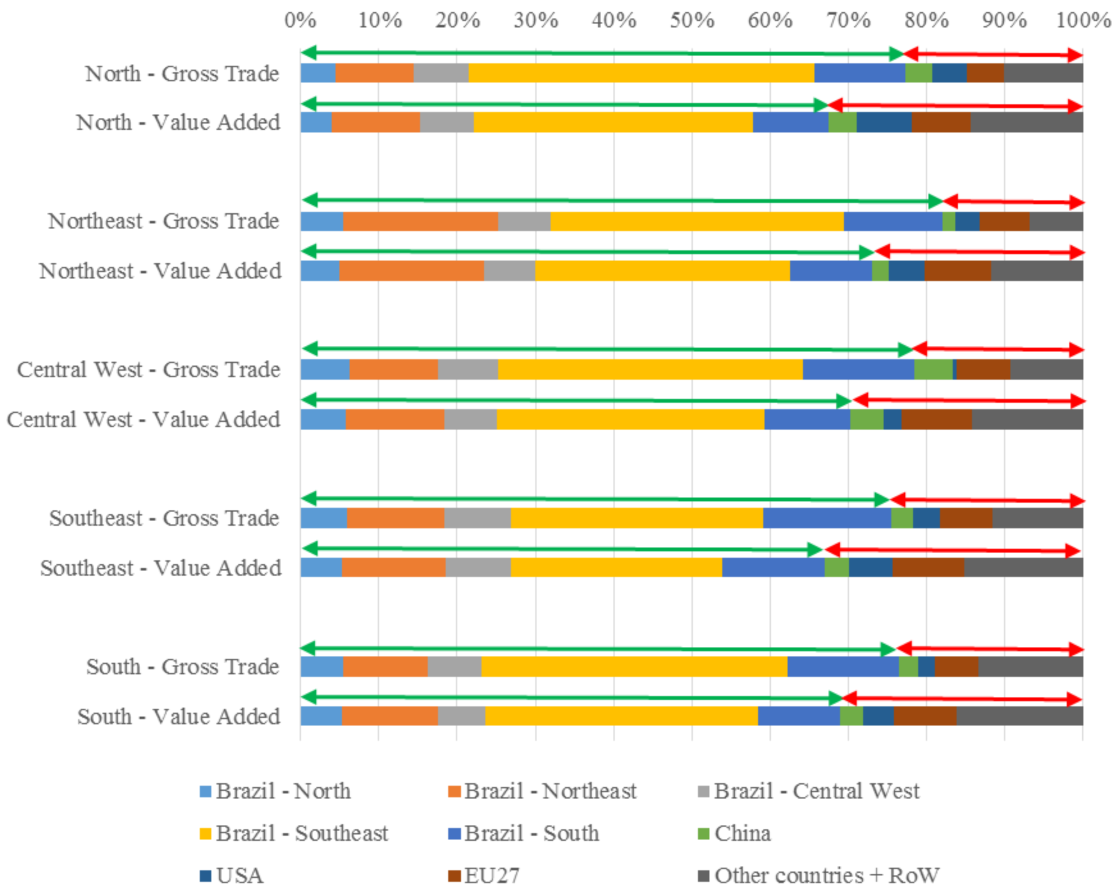


Figure 2.8 – Regional outflows/exports in gross and value-added terms by region/country of destination

2.4.6 Decomposition of Brazilian states' gross trade flows

To analyze output circulation within cross-border production chains, we apply the decomposition proposed by Johnson and Noguera (2012a), which splits gross bilateral trade flows according to whether they are absorbed, reflected, or redirected to their ultimate destination. Considering the gross bilateral outflows/exports from region *E* to region *W*, composed of both final products and intermediates, the decomposition is given by

$$\begin{aligned}\mathbf{u}'\mathbf{e}^{EW} &= \mathbf{u}'(\mathbf{c}^{EW} + \mathbf{A}^{EW}\mathbf{x}^{W}) \\ &= \mathbf{u}'(\mathbf{c}^{EW} + \mathbf{A}^{EW}\mathbf{x}^{WW}) + \mathbf{u}'\mathbf{A}^{EW}\mathbf{x}^{WE} + \textstyle\sum_{k\neq E,W}\mathbf{u}'\mathbf{A}^{EW}\mathbf{x}^{Wk} \qquad (2.7)\end{aligned}$$

where $\mathbf{x}^{ij}$ is the vector of gross outputs in region *i* caused by the final demand of region *j*. The first term on the right side of equation (2.7) is the portion of bilateral exports absorbed and consumed in destination *W*. The second term is the component reflected back and ultimately consumed in region *E*. The third term is the redirection of region *E*'s intermediates to third destinations embodied in region *W*'s products.[27] Here, we split the redirection to Brazilian states and the redirection to foreign countries.

This decomposition is complementary to that in subsection 2.4.3. Here, we are interested in the redistribution that bilateral trade partner *W* implements to the gross trade flows it receives from region *E*: either to its own final consumption, back to region *E*, or to a third region's final consumption. In this latter case, there is embodiment of region *E*'s value added in the final use of a third region, that is, indirect exports of region *E*'s value added. However, the value added of other regions might also be embodied in this redirection because we are analyzing gross trade flows. Therefore, for a thorough assessment of indirect value-added exports, we apply the decomposition in subsection 2.4.3. The decomposition proposed by Johnson and Noguera (2012a) is applied in the present subsection to explore the mechanism of Brazilian states' indirect participation in domestic and international trade through their bilateral trade relationships.

First, the decomposition of bilateral inflows of Brazilian states is informative concerning the cross-border production-sharing relationships, indicating links between GVCs and domestic value chains. Figure 2.9 summarizes the results from the decomposition of inflows aggregating the source states (Table A.2.8 in Appendix A.2.2 presents the monetary figures). For example, Amazonas absorbs approximately 44% of the inflows it receives from other Brazilian states, reflects back approximately 8%, and redirects the remainder either to other states' (40%) or foreign countries' (7%) final consumption.

Thus, the results in Figure 2.9 allow us to evaluate the states as links connecting bilateral trade partners to other markets. We observe that the share of the inflows for a given state that is redirected to foreign countries ranges more widely, from 1% in Distrito Federal to 21% in Mato Grosso. In addition to Southeast and South region states and Bahia in the Northeast region, Mato Grosso is an important link for Brazilian outputs to foreign markets. These results are consistent with studies on the economic interdependence of Brazilian regions, for example, Perobelli and Haddad (2006), who apply a computable general equilibrium model

[27] The authors indicate that the decomposition is only approximate because the output split used in equation (2.7) is influenced by the entire structure of cross-border linkages. Even so, the decomposition provides shares that are consistent with the zero order and first round effects of the Leontief matrix inversion describing how final goods absorbed in each destination are produced (JOHNSON; NOGUERA, 2012a).

calibrated for the year 1996. The authors verified that, for manufacturing industries, the regional export flows were mainly directed to the aforementioned states.

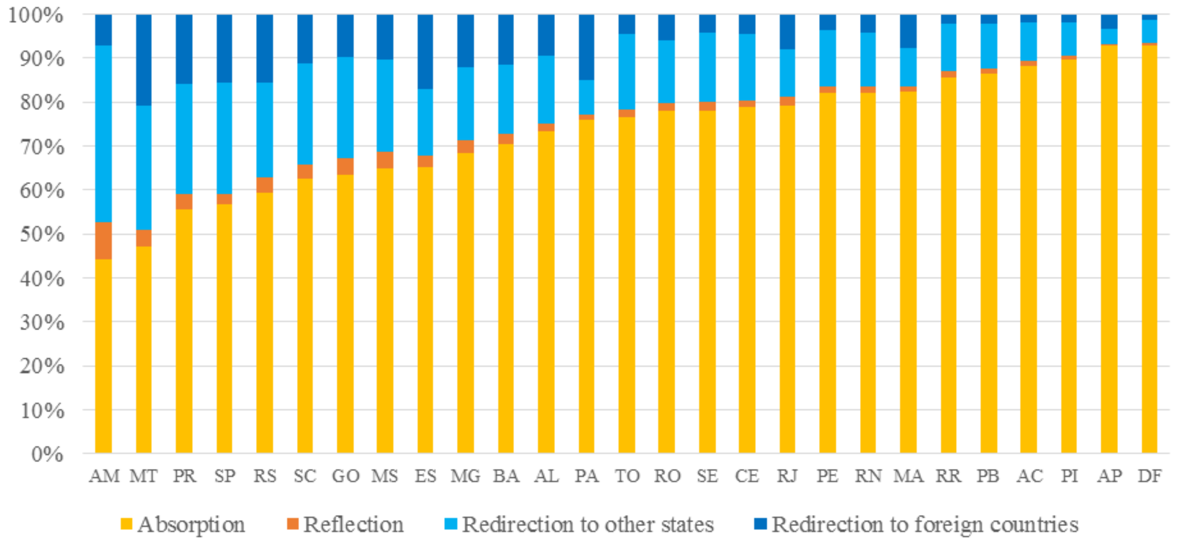


Figure 2.9 – Decomposition of Brazilian states' inflows, aggregation over sources (%)

Table 2.6 reports the results of the decomposition for informative state pairs. For the selected bilateral pairs, the entries in the table correspond to the approximate outflow share that is ultimately consumed in each of the top five final destinations.

For Rio de Janeiro, we analyze the bilateral outflows to its main gross trade partners, that is, São Paulo and Minas Gerais. A relatively small share of Rio de Janeiro's outflows to both São Paulo and Minas Gerais is absorbed in these same states. This indicates significant bilateral Rio de Janeiro-São Paulo and Rio de Janeiro-Minas Gerais production sharing. These two states redirect approximately 20% of Rio de Janeiro's bilateral outflows to foreign countries and an even larger share to other states (28% in the case of São Paulo; 25% in the case of Minas Gerais). Thus, by sharing production processes with main bilateral trade partners, a substantial share of Rio de Janeiro's outflows and embodied value added are redirected, which amplifies the state's participation in value-added exports relative to gross exports.

In comparison to Rio de Janeiro, a larger share of São Paulo's outflows is absorbed by the bilateral pairs; aggregating over destinations, the absorption component corresponds to 72% of outflows. However, the circulation of São Paulo's output varies significantly across state partners. For example, nearly half of São Paulo's outflows to Mato Grosso are reflected back or redirected, which is evidence of a bilateral production-sharing relationship with São Paulo as a supplier of intermediates. Comparing São Paulo's trade with Mato Grosso with São Paulo's trade with Pará, São Paulo's outflows to Pará are largely absorbed by Pará indicating weaker bilateral production sharing.

More important is the extent to which São Paulo provides indirect participation to other Brazilian states acting as a link to other markets. Aggregating by source, São Paulo reflects or redirects approximately 43% of its inflows (see Figure 2.9). This indicates that the average state in Brazil has a strong bilateral production-sharing relationship with São Paulo as a supplier of intermediates to São Paulo's goods and services that are ultimately consumed elsewhere.

This role of São Paulo as a link between its state partners and domestic and foreign markets is exemplified by bilateral Amazonas-São Paulo production sharing. For Amazonas as a source of outflows, this redirection component is particular to its relationship with São Paulo; Amazonas' outflows are nearly exclusively absorbed by its other bilateral state partners. This is exemplified by minimal production sharing with Rio de Janeiro, shown in Table 2.6.

Within regions, Amazonas in the North region provides a link between regional value chains and the markets in other Brazilian regions while Pará has influence connecting them to GVCs. In the Northeast region, Bahia is the main link for bilateral partners and domestic and foreign markets. Table 2.6 shows that Rio Grande do Norte is engaged in triangular trade with São Paulo and other destinations via Bahia. In contrast, Rio Grande do Norte's outflows to Pernambuco, which is also an important bilateral trade partner in the Northeast region, are mostly absorbed there, indicating a weak bilateral production-sharing relationship.

Table 2.6 – Decomposition of states' outflows, informative pairs

Rio de Janeiro's outflows to:				São Paulo's outflows to:			
São Paulo		Minas Gerais		Mato Grosso		Pará	
São Paulo	47%	Minas Gerais	55%	Mato Grosso	52%	Pará	77%
RoW	9%	São Paulo	7%	RoW	7%	USA	3%
Minas Gerais	5%	RoW	5%	São Paulo	6%	RoW	3%
Rio de Janeiro	5%	Rio de Janeiro	4%	Rio de Janeiro	3%	São Paulo	2%
USA	4%	USA	3%	China	3%	China	2%
Amazonas' outflows to:				**Rio Grande do Norte's outflows to:**			
Rio de Janeiro		São Paulo		Bahia		Pernambuco	
Rio de Janeiro	90%	São Paulo	64%	Bahia	37%	Pernambuco	84%
São Paulo	2%	RoW	5%	São Paulo	8%	São Paulo	2%
RoW	1%	Rio de Janeiro	4%	RoW	7%	Bahia	1%
Minas Gerais	1%	Minas Gerais	3%	USA	6%	RoW	1%
China	1%	USA	2%	Minas Gerais	4%	Rio de Janeiro	1%

Note: shares do not sum one because only the top five destination are included for each bilateral pair.

To understand the integration of Brazilian states in global trade, we analyze the circulation of imports from foreign countries within cross-border production chains. We intend to recognize the mechanisms by which indirect value-added imports occur in the states. We apply the decomposition of equation (2.7) for states' imports from foreign countries, that is, taking E as a foreign country and W as a Brazilian state. Figure 2.10 summarizes the results of this decomposition aggregating country import sources (Table A.2.9 in Appendix A.2.2 presents the monetary figures).

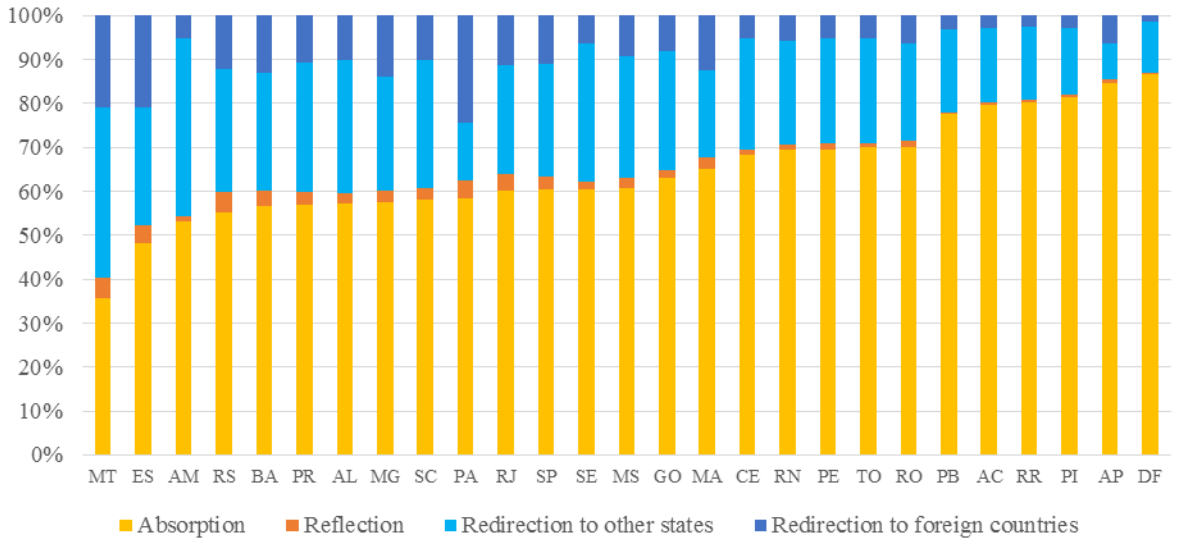


Figure 2.10 – Decomposition of Brazilian states imports, aggregation over sources (%)

As with indirect exports, also with indirect imports São Paulo is the main link for foreign markets and Brazilian states. São Paulo embodies large amounts of imported inputs in (final or intermediate) products and services that are ultimately consumed elsewhere in Brazil. Approximately 40% of the redirection of imports through domestic value chains correspond to São Paulo. The other states in the Southeast and South regions also have important roles embodying imported inputs in domestic value chains, as well as Mato Grosso and Amazonas, because of the Free Trade Zone of Manaus. Notably, the redirection of Bahia's imports was mainly towards other states in the Northeast region.

Figure 2.11 sums up the results concerning the Brazilian states' redirection of inflows to foreign countries and imports to other states. The size of the bubbles is proportional to the sum of both redirections by the state. Thus, Figure 2.11 indicates the weight of the states as they link the outputs of other states to foreign countries and vice versa. We observe that the states of the South and Southeast regions are the main links for the GVCs connecting and extending Brazilian value chains. These states (except Rio de Janeiro) redirected more than the median share of incoming inflows and imports and, in doing so, circulated substantial flows of outputs across its trade partners' borders. Goiás, Mato Grosso, and Mato Grosso do Sul in the Central-West region also redirect a substantial share of their inflows and imports, but their absolute weight is smaller. In the Northeast region, Bahia, and to a lesser extent, Alagoas, act as important links between their region's value chains and international production processes. In the North region, Amazonas and Pará are important links between Brazilian states from all regions and foreign countries, but in different directions. While Amazonas redirects substantial amounts of imports to other states' final consumption, Pará embodies intermediate inputs from elsewhere in the country in its exports.

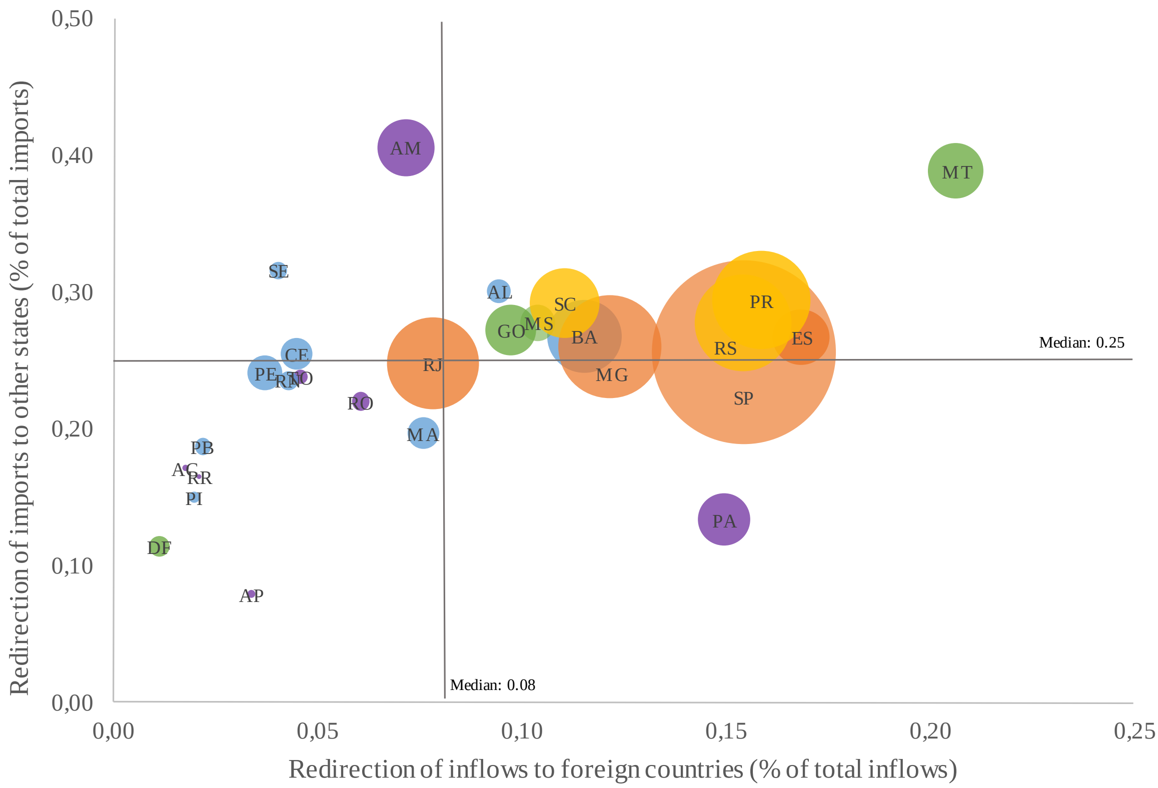


Figure 2.11 – Redirection of outflows and imports by Brazilian states
Notes: the size of the bubbles represent the sum of inflows that are redirected to foreign countries, and imports that are redirected to other states. Dark grey lines indicate the median values in the axes. The colors distinguish the region of the states, as follows: North region – purple; Northeast region – blue; Central-West region – green; Southeast region: orange; South region: yellow.

Finally, we evaluate the circulation of Brazilian states' outputs within GVCs. We apply the decomposition in equation (2.7) for states' exports, that is, taking *E* as a Brazilian state and *W* as a foreign country. Figure 2.12 reports the results by destination countries (Table A.2.10 in Appendix A.2.2 presents the monetary figures).

A comparison of the decomposition of the bilateral Brazilian exports and those sourced by the rest of the world shows that the countries depicted in Figure 2.12 (except India, Russia, Mexico, and the UK) redirect larger shares of gross imports from Brazil.[28] For example, Taiwan redirects approximately 60% of its imports from Brazil and 53% of those from other countries. This is not surprising because most Brazilian exports consist of intermediate inputs.[29] At the state level, Rio de Janeiro and Pará are outstanding because approximately 40% of their exports are processed and redirected by their bilateral country partners. This

[28] The share of imports that these countries redirect from Brazil and from the rest of the world are highly correlated though (0.92).
[29] In 2008, intermediate inputs comprised approximately 72% of Brazil's exports.

finding is consistent with their strong integration in foreign countries' GVCs in terms of value-added exports, as described in subsection 2.4.3.

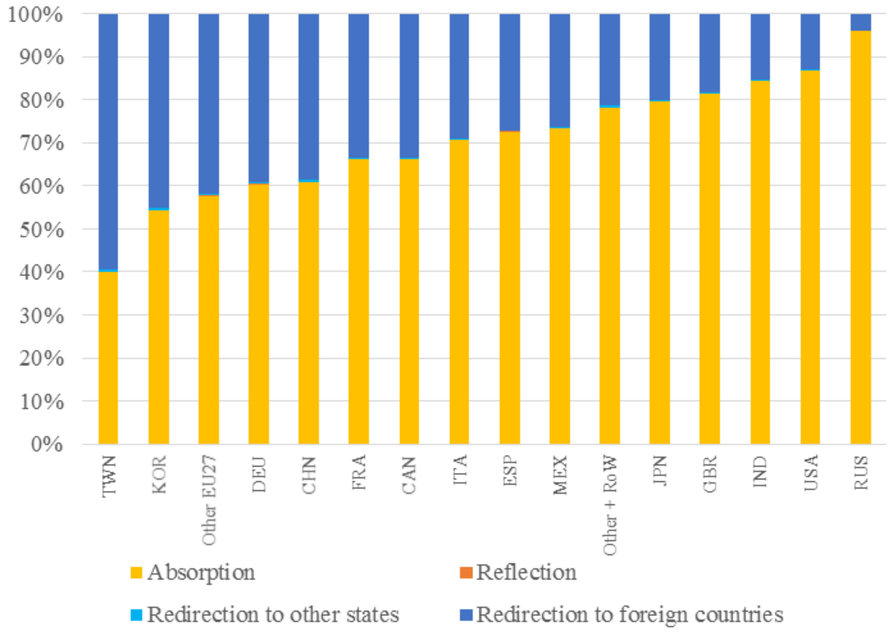


Figure 2.12 – Decomposition of Brazilian exports, by destination country (%)

Table 2.7 shows the results of the decomposition for informative state-country pairs, which is analogous to Table 2.6. We verify that Rio de Janeiro has a strong bilateral production-sharing relationship with both China and Germany. By supplying intermediate inputs that are processed and re-exported by these two countries, Rio de Janeiro is engaged in triangular trade with the USA and other destinations. With Rio de Janeiro's domestic production-sharing relationships, the redirection of its outputs by bilateral partners explains the adjustment of Rio de Janeiro's balance with the USA from a gross trade deficit to a surplus in value-added terms, as seen in Table 2.5.

For all Brazilian states, gross bilateral exports to the USA are largely absorbed and consumed in the USA. The USA is also the main destination of Brazilian state exports that are redirected by Canada, which is evidence of robust bilateral Canada-USA production sharing. Table 2.7 shows this dynamic in the decomposition of Pará's exports to Canada. Approximately one-third of the output is ultimately consumed by the USA.

The absorption component of São Paulo's exports is greater on average than that of Rio de Janeiro or Pará, as approximately 75% of São Paulo's exports are consumed by its bilateral trade partners. This is an indication that large amounts of other Brazilian states' outputs that are processed and re-exported by São Paulo are embodied in products that are less likely to be redirected by the importing country, such as final products. Table 2.7 shows the decomposition of São Paulo's exports to China, which are more intensively absorbed than those sourced by Rio de Janeiro. However, São Paulo does have strong bilateral production-sharing relationships with some specific countries, sourcing them with intermediate inputs that are ultimately consumed elsewhere. This is the case of countries in the EU (Austria, Denmark, Germany, the Netherlands, and Poland, among others) and in emerging Asia (Korea and Taiwan). Table 2.7 indicates that São Paulo is engaged in triangular trade with other Asian countries, the USA, and other destinations via Korea.

The integration of Brazilian states in the cross-border production chains of Europe is exemplified by the decomposition of Mato Grosso's bilateral exports to European countries. The UK absorbs most of Mato Grosso's bilateral exports. For Brazilian states, the absorption share of the UK is approximately 80%. Meanwhile, other countries largely redirect Mato Grosso's bilateral exports. This is the case in Germany and the Netherlands, which are important links for the outputs from Brazilian states to final consumption in other European countries.

Table 2.7 – Decomposition of states' exports, informative pairs

Rio de Janeiro's exports to:				Pará's exports to:			
China		Germany		USA		Canada	
China	53%	Germany	57%	USA	82%	Canada	46%
RoW	13%	RoW	10%	RoW	6%	USA	33%
USA	10%	USA	5%	Canada	2%	RoW	6%
Japan	3%	France	3%	Mexico	2%	China	2%
Germany	2%	China	3%	China	1%	Mexico	2%

São Paulo's exports to:				Mato Grosso's exports to:			
China		Korea		United Kingdom		Netherlands	
China	73%	Korea	57%	United Kingdom	86%	Netherlands	56%
RoW	7%	RoW	12%	RoW	3%	Germany	8%
USA	6%	China	7%	Ireland	1%	RoW	8%
Japan	2%	USA	6%	USA	1%	United Kingdom	5%
Germany	1%	Japan	3%	France	1%	France	4%

Note: shares do not sum one because only the top five destination are included for each bilateral pair.

2.5 Concluding remarks

Our objective was twofold in this chapter. First, we proposed a theoretical framework for the estimation of a combined country-state IO table, using a WIOT and an IRIOT. Our approach is innovative, as we do not take one of the datasets as given and adapt the other accordingly (FENG *et al*, 2013; MENG *et al*, 2013; CHERUBINI; LOS, 2012). Instead, we employ the input coefficients from both datasets (rather than the deliveries themselves). Our approach is especially appropriate in cases where neither dataset presents a higher quality of information. In the proposed framework for the estimation of the country–state table, the domestic intersectoral flows are largely based on the IRIOT, whereas the international transactions are largely based on coefficients from the WIOT.

It is relevant to note that the proposed framework is applicable to various datasets with different geographical details. The estimated IO tables allow us to quantitatively understand the extent to which subnational regions contribute to GVCs. This is significant because trends in regional income and regional employment have become much more dependent on the extent of such contributions (LOS *et al*, 2015). Another possible application lies in the analysis of environmental impacts of production systems, particularly when regional actions result in global effects and the interconnectedness of domestic and foreign economies should be taken into account (e.g. as is the case of regional emissions of greenhouse gases). There has been renewed interest in this regard as subnational governments are spearheading climate change-related mitigation efforts in many countries.[30]

Our second objective was to analyze the integration of Brazilian states in the GVCs. We consider that a better understanding of how regions participate in GVCs can help policy makers to develop more effective responses to the challenges posed by the continuing globalization of production processes. Thus, this empirical study used our proposed framework and obtained a model covering the interdependence of 27 Brazilian states and 40 other countries (considering the rest of the world as a country), with the economic structures arranged across 28 industries. The data refer to 2008, the last reference year for which both the WIOT and the IRIOT were available at the time this study was initiated. Given the problems of double counting based on gross trade, which are particularly serious in the

[30] We develop an empirical application to quantify Brazilian states' carbon dioxide (CO_2) emissions in Chapter 4.

presence of production fragmentation (KOOPMAN *et al*, 2014), our analysis of the integration of Brazilian states in the GVCs was conducted in value-added terms (i.e. TiVA). In this way, we quantified the value added generated in each region (country or state) that is contained in the final use of each of the other regions in our model.

The empirical application proceeded along two lines. First, to assess the importance of the Brazilian states' participation in the GVCs, we quantified the states' international trade in value added. We observed that this trade is highly concentrated in the Southeast and South regions. São Paulo alone accounted for one-third of Brazil's international value-added trade in 2008. In relative terms, value-added exports were found to be particularly important for Espírito Santo, Mato Grosso, and Pará, while value-added imports were significant for Amazonas.

The second line of the application turns to how the states' value-added participation occurs. We verified that the value-added exports to gross exports ratio (VAX ratio) varies widely across Brazilian states, indicating differences in engagement across the GVCs. One possible explanation is that cross-state variation in the VAX ratios is caused by the industry composition of exports, so that states that export predominantly manufacturing products tend to have low aggregate VAX ratios. However, we were unable to affirm that industry composition of exports drives aggregate VAX ratios, as differences within industries across states also account for this finding.

Given this result, we then investigated the differences in Brazilian states' participation in the GVCs. Engagement in international trade, in particular, varies significantly given the interregional fragmentation of production processes. Our quantification of value-added trade indicated that while some states export value added mostly directly or indirectly via their own industries (e.g. São Paulo and Pará), for the other states (e.g. Amazonas and Rio de Janeiro), the indirect engagement in international trade (by providing inputs to other states) is relatively more important.

Finally, we elucidated the mechanism of indirect participation in value-added trade by decomposing gross bilateral trade flows according to whether they are absorbed, reflected, or redirected to their ultimate destination. We identified the states that act as links within the GVCs that connect with and extend Brazilian value chains. The states of the Southeast and

South regions are the main links, as they redirect more than the median share of incoming inflows and imports, and in doing so, circulate substantial flows of outputs across their trade partners' borders. Amazonas, Bahia, Mato Grosso, and Pará are also important links between Brazilian states' value chains and international production processes.

In terms of policy, an important implication of the TiVA analysis is that a more coherent view of trade is needed at the national level, as indicated by OECD (2013), since success in international markets today depends as much on the capacity to process imported inputs as on the capacity to export. Hence, the emergence of GVCs clarifies that the mercantilist approach of "imports bad, exports good" trade is an anachronism that is potentially counterproductive to economic growth and competitiveness. Thus, policies such as "Industrialization by Substitution of Imports", prevalent in former decades in Brazil, do not seem suitable in a scenario where international production fragmentation is widespread. Re-evaluating the connections between value-adding activities in the country and final demand worldwide is even more pressing with slow growth of domestic consumption.

In the same sense, the emergence of GVCs breathed new life into regional development policies. The international experience shows that benefiting from the fragmentation of production processes does not require building entire value chains. As globalization allows the transfer of comparative advantages in certain fragments across the world, regions can increasingly join global production processes by producing the fragments of these processes (JONES; KIERZKOWSKI, 2005). Take the rising economies in Asia as an example; they maintain tight production fragmentation relationships with the rest of the world, making them progressively competitive and enabling them to produce larger shares of value added in GVCs.

Countries also benefit by producing tasks in different regions, that is, by exploring regional comparative advantages. As we have seen, production sharing is important for the integration of Brazilian states in international trade. Thus, in order to benefit from global consumption, a state does not need to be directly connected to foreign markets as long as it joins the production processes of other states within the country. A possible strategy for improving regional participation in global production networks is enhancing the complementarity of tasks in different states, taking into account their interdependencies. We explore this point in more detail in the next chapter.

3 BRAZILIAN STATES IN GLOBAL VALUE CHAINS: SPATIAL PRODUCTION SYSTEMS INTERPRETED BY FEEDBACK LOOP ANALYSIS

3.1 Introduction

Over the last few decades, the fragmentation of production processes has redefined comparative advantages at the global level, inducing great changes in the spatial location and organization of economic activity. Simultaneously, the reorganization of value chains generated a complex system of interdependent flows linking regions all over the world. As the process of fragmentation continues, interregional dependency will assume even greater importance in explaining the growth and path of development of economies (HEWINGS; OOSTERHAVEN, 2015). Therefore, it is increasingly relevant to study the spatial organization of production systems, a topic that has not received sufficient attention in the literature.

For studying production fragmentation across space, the interregional IO methodology constitutes a natural and important analytical framework. In this paper, our objective is to elucidate the geographical structure of the flows of GVCs using hierarchical feedback loop analysis. In essence, this methodology offers a detailed view of economic interactions by first identifying paths of influence across regions and then proposing a hierarchical extraction method to recognize the paths in terms of their economic importance (POLENSKE; HEWINGS, 2004).

The hierarchical feedback loop methodology has already been applied for analyzing the spatial structure of gross trade flows within Europe (SONIS *et al*, 1993), Asia (SONIS *et al*, 1995), and the Midwest region in the USA (SEO *et al*, 2002). It has also been employed for identifying the economic interactions among industries within the Chicago region (LIU; HEWINGS, 2014). Our paper not only focuses on the supply chain dependencies of the 27 Brazilian states but also considers their linkages with producers abroad. This is relevant as international and interstate fragmentation are fundamentally interconnected and trends in local income have recently become much more dependent on the extent of the contribution of subnational regions to GVCs (LOS *et al*, 2015). In this way, our analysis distinguishes 67 regions comprising the global economy in the year 2008. Another differential is that instead of gross trade analysis, which suffers from serious double counting in the presence of production fragmentation (KOOPMAN *et al*, 2014), we consider the value-added flows involved in the global production processes.

The remainder of this paper is organized as follows. The rest of this section provides a background on how the fragmentation of production processes leads to the spatial reorganization of economic activities around the globe and within countries. The hierarchical feedback loop methodology is explored in section 3.2. Section 3.3 presents our results, first exploring the relevance of spatial fragmentation for each region considered in the model, and then identifying the spatial structure of the main supply chains' flows at the global level. Greater sectoral detail is also provided. Section 3.4 concludes.

3.1.1 Fragmentation and spatial reorganization of production systems

According to Krugman (2009), the world's economic history can be staged as a play in three acts, collectively referred to as, "the fall and rise of comparative advantage". In Act I, which takes place before World War I, trade primarily took place between countries with very different resources exporting very different products. Thus, this trade fitted the comparative advantage paradigm well. Act II, which refers to the recovery of international flows after World War II, mainly included trade between similar countries. The increasing intra-industry trade was explained as a consequence of the advantages of specialization due to increasing returns. However, comparative advantage staged a comeback in Act III, which started in the 1990s: world trade increasingly occurred (and continues to occur) between countries at different levels of development, having disparate resources, factor prices, and technologies.

The role of technological improvement of connecting services for the development of global fragmentation is emphasized by Jones and Kierzkowski (2005). The authors indicate that the new comparative advantages came into play in world production systems on account of the lowering of costs of service link activities such as communication and transportation. In their pioneer general framework used for analyzing fragmentation (JONES; KIERZKOWSKI, 1990), the authors highlight how production processes are being split into subsequent production blocks undertaken separately in the space and how they need to be connected by service links. Unlike the literature on new economic geography (NEG), their fragmentation paradigm indicates that (internal) increasing returns are presented by the service links and not the firm. This leads to an important reversal of the view often expressed in the NEG literature that increased levels of economic activity lead to spatial agglomeration of such activity. Under the fragmentation framework, increases in the scale of production might encourage its fragmentation.

In the simplified version of the model, Jones and Kierzkowski (2005) assume that the service links exhibit increasing returns associated with fixed costs invariant to the scale of the output.[31]

For a given degree of fragmentation of the production process, the nature of service links leads to average costs that are decreasing with total output. Further increases in output encourages a finer degree of fragmentation in order to reduce production costs if the extra cost of the service links is more than balanced by the lower marginal costs obtained by a closer match between factor intensities and net factor productivities. In the aggregate, average costs of production decrease with output for a given degree of fragmentation, and marginal costs decrease discontinuously at the point the degree of fragmentation increases. Thus, lowering the costs of service links promotes greater spatial separation of production processes for any output level. Increases in the scale of production might also encourage the dis-agglomeration of economic activity, with consequential increased trade of intermediate inputs at both international and interregional levels.

Therefore, the fragmentation process leads each production block to be implemented in the best possible location. Differences in productivities and factor prices then become very relevant for the determination of the geographical pattern of production (JONES; KIERZKOWSKI, 2005). As indicated by Romero *et al* (2009), multinational corporations are always reconsidering where to locate their plants, based on regional characteristics such as the cost of production factors, size of internal markets, and regulatory issues. Therefore, globalization is radically transforming international and interregional division of labour, thus altering the geography of production around the world.

We might ask, however, to what extent are production systems being spatially reorganized? Baldwin (2006) indicates that the fundamental forces that have fostered international fragmentation of production – reduction in costs of moving ideas, products, and people, that

[31] According to the authors, this assumption is more reasonable to communications, but transportation costs are also declining with quantities transported.

is, the service links of Jones and Kierzkowski (2005) – might result in regionalized fragmentation. According to the author, because the reduction in the cost of moving ideas (due to large technological advancements in communications) has greatly surpassed the reduction in the cost of shipping products, and even more that of passenger transport (given the increasing opportunity cost of the time of skilled staff), regionalizing offshoring is one way to save the costs of trade. In this context, the literature discusses whether the international fragmentation of production processes involving geographically distant countries is actually global or mainly regional, given that it occurs between neighbouring countries or within regional trade blocks. As indicated by Los *et al* (2014), this has important implications for trade policy. If fragmentation is a truly global phenomenon, extensive multilateral trade agreements are required to enhance the production benefits from the supply chain trade; if not, regional trade arrangements might be sufficient.

The empirical evidence on this matter is mixed. Johnson and Noguera (2012b), based on their series of global IO tables for 1970-2009, find that value added to exports (VAX) ratios are lower and falling more rapidly over time among countries within geographical regions, which suggests regionalization of production processes to be more important than their globalization.[32] In the same sense, Baldwin and Lopez-Gonzalez (2014, p. 14) claim that the "supply chain trade is not global – it is regional. 'Global value chains' is a great buzzword but it is inaccurate in aggregate". Such a claim is based on the observation that international gross trade flows within regions are much larger than those across regions, as depicted by the data from the World Input-Output Database (WIOD) project. On the other hand, using the WIOD project data, Los *et al* (2014) argue that while trends toward regional fragmentation might have been dominant in the 1980s and early 1990s, true global fragmentation assumed more importance in the 2000s. The authors find that in almost all product chains, the share of value added outside the country-of-completion has risen since 1995, which indicates increasing international fragmentation. Moreover, they find that this share is mainly added outside the region to which the country-of-completion belongs, suggesting that value chains are truly global.

[32] See Johnson and Noguera (2012c) for a detailed discussion on the dataset. The authors combine data from several sources, including the OECD IO Database, the IDE–JETRO Asian Input–Output Tables, and the UN Trade Database, and construct the global IO tables. The dataset is organized for four composite industries and covers 42 countries.

In our analysis of the spatial organization of GVCs, we assess the fragmentation of production processes both within and across blocks of countries (here, the North American Free Trade Agreement (NAFTA) block, the EU27, and East Asia) in the year 2008. Using the feedback loop approach, we evaluate the bilateral supply linkages hierarchically at the global level.

3.1.2 Interregional trade under the fragmentation paradigm

In our application, we are especially interested in fragmentation within countries, that is, production sharing between subnational regions. According to Krugman (2015), within the USA the ability to slice up the value chain is not going to lead to a significant rise in interregional trade. Thus, the explosion in international trade is not matched by comparable growth in interregional trade. According to the author, as the regions in the USA are homogenizing, they have less reason to trade with each other than they once did, "to the extent that Americans are doing pretty much the same thing everywhere, the rationale for specialization and interregional trade is reduced" (KRUGMAN, 2015, p. 33). However, if contrary to Friedman, the world is not flat (KRUGMAN, 2015), then the world within nations is not flat either, but it is rather uneven (HEWINGS; OOSTERHAVEN, 2015). This is especially valid for Brazil, the country of focus in our empirical study, which is heterogeneous in several aspects.

Jones and Kierzkowski (2005) note that international trade allows a greater degree of concentration of productive activity in the national arena, often in urban areas, as it cuts the dependence of local consumption on a corresponding range of local production, thereby decreasing the importance of the distance to the market. Alternatively, while the possibilities to fragment production processes allow more countries to join supply chains at the international level, leading to dispersal of productive activity, increased international trade may encourage national agglomeration.

Thus, under the fragmentation paradigm, when the benefits of agglomeration exceed those of spatial fragmentation (due to a closer match elsewhere between factor intensities and net factor productivities), firms find it more profitable to locate close to each other. However, if significant differences in productivities and factor prices occur at the regional level, according to Parr *et al* (2002), agglomeration economies are supplemented, and perhaps replaced, by less spatially constrained advantages.

The authors emphasize the significant role played by changes in firms (with most plants now being part of multiregional enterprises) in conditioning location decisions. In the single-establishment firm, economies of scale, scope, and complexity, if realizable, would only be available at a particular geographic location, and any one of these would form the basis for an agglomeration economy. However, the changing relationship between the establishment and the firm has resulted in economies of scope and complexity being realized at the level of the firm, while specific products' economies of scale are exploited within individual establishments with the best possible location. Thus, the ties that once bound establishments in close spatial proximity seem to be unravelling in favour of spatial association at the multi-state level (PARR *et al*, 2002).

The schematic process is illustrated in Figure 3.1. High costs of transportation (i.e. Jones and Kierzkowski's (2005) service links) limited market areas, and thus, the ability to explore scale economies are spatially circumscribed. As a result, each establishment often produces more than one product in a given location. Declining transportation costs and changes in firms brought about intra-establishment specialization, causing drastic transformation in the spatial structure of production. The value chain now involves more interstate movements. With the boost in interstate trade flows, the main implication of these changes is an increase in interregional spillover and feedback effects (HEWINGS; OOSTERHAVEN, 2015).

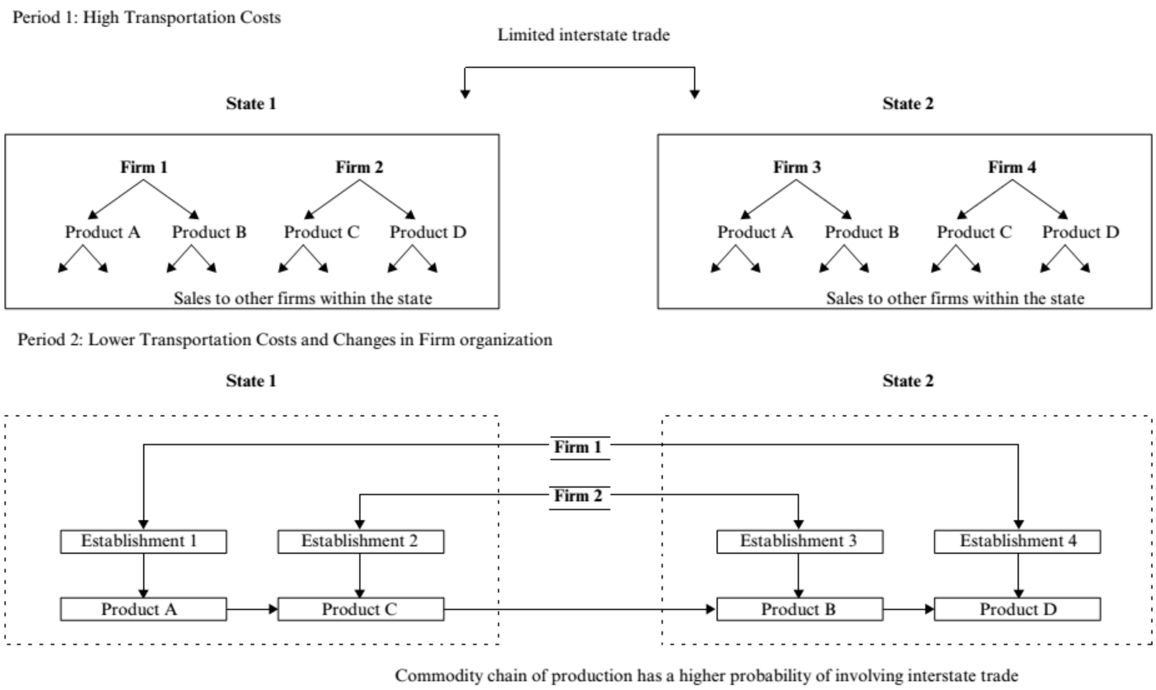


Figure 3.1 – Changing spatial organization of firms
Source: Hewings and Oosterhaven (2015).

Therefore, regions are becoming both more competitive and interdependent over time, so that understanding the spatial structure of production across subnational regions and countries is increasingly relevant. In our empirical application, we analyze the spatial organization of value chains across Brazilian states. Brazil's geographical heterogeneity results in diverse regional competitive advantages, many of them resulting from natural endowments. This also adds to the complexity of interregional dependency. Here, we are not interested so much in the factors generating regional interdependency as we are in recognizing its spatial pattern as of 2008.

3.2 Methodology

In this paper, we focus on the spatial organization of production processes. Note that in contrast to trade in value added (TiVA) studies, we are not interested in a country's contribution to final consumption but in its contribution to the output value of a given consumption good. Several methodologies can be employed for analyzing interregional and intersectoral dependencies. In this paper, we address the identification and interpretation of the global economic structure using the hierarchical feedback loop analysis of value-added flows within GVCs.

In essence, this approach offers a more detailed view of economic interactions by first identifying the paths of influence across regions and then proposing a hierarchical extraction method to identify the paths in terms of their economic importance (POLENSKE; HEWINGS, 2004). First, we analyze the macro-level structure (where all transactions are aggregated into one industry) of the feedback loops. Then, aiming to understand the combination of interregional and intersectoral interdependencies, we proceed to a more detailed sectoral analysis.

We apply the full country-state IO table that was estimated for the year 2008 for our empirical analysis, following the procedure described in Chapter 2. In the following subsection, we explain the estimations of the flows of value added that comprise the production processes of the final products. Next, we explain the hierarchical feedback loop methodology, by focusing on the macro and sectoral levels in that order.

3.2.1 Value-added flows of supply chains

Using the basic Leontief model allows us to express the total output of an economy as the sum of intermediate consumption and final consumption (MILLER; BLAIR, 2009):

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \tag{3.1}$$

$$(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{B} \tag{3.2}$$

$$\mathbf{x} = \mathbf{By} \tag{3.3}$$

where $\mathbf{x}$ is the $n \times 1$ total output vector (n is the number of industries in the system), $\mathbf{A}$ is the $n \times n$ direct input coefficients matrix, $\mathbf{y}$ is the $n \times 1$ final demand vector, and $\mathbf{B}$ is the Leontief inverse matrix.

Considering $\mathbf{G}$ as the $n \times n$ diagonal matrix of value-added coefficients, we can describe the related value-added IO model as

$$\mathbf{w} = \mathbf{Gx} \tag{3.4}$$

From (3.3):

$$\mathbf{w} = \mathbf{GBy} \tag{3.5}$$

where $\mathbf{w}$ is the $n \times 1$ value-added vector.

We apply a country-state IO model in our empirical analysis. Therefore, the dimensions of the above matrices and vectors become: a) $\mathbf{x}$, $\mathbf{y}$, and $\mathbf{w}$, size $[(r.n) \times 1]$; and b) $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{G}$, size $[(r.n) \times (r.n)]$.

Bearing in mind the definition of a GVC of a final good according to Timmer *et al* (2015) (the set of value-adding activities needed in its production and identified by the country–industry in which the last stage of production happens), we are interested in the spatial structure of value-added flows from each region to each GVC in the world economy. In order to estimate these flows, we construct the $\mathbf{E}$ $(r.n) \times (r.n)$ diagonal matrix of final demand, whose elements correspond to the sum of a given industry's final demand across destination regions (either domestic or foreign). Then, we compute

$$\mathbf{W} = \mathbf{GBE} \tag{3.6}$$

where $\mathbf{W}$ is the $(r.n) \times (r.n)$ matrix of the supply chain's value-added flows.

Figure 3.2 illustrates the framework for the supply chain's value-added flows as represented in matrix $\mathbf{W}$:

			Global value chain							Value added
			Region 1			...	Region r			
			Industry 1	...	Industry n	...	Industry 1	...	Industry n	
Value added from region - industries	Region 1	Industry 1	w_{11}^{11}	...	w_{1n}^{11}	...	w_{11}^{1r}	...	w_{1n}^{1r}	$\sum_t \sum_j w_{1t}^{1j}$
		...	...	...	...	...	...	...	...	...
		Industry n	w_{n1}^{11}	...	w_{nn}^{11}	...	w_{n1}^{1r}	...	w_{nn}^{1r}	$\sum_t \sum_j w_{nt}^{1j}$
	...	...	...	...	...	...	...	...	...	...
	Region r	Industry 1	w_{11}^{r1}	...	w_{1n}^{r1}	...	w_{11}^{rr}	...	w_{1n}^{rr}	$\sum_t \sum_j w_{1t}^{rj}$
		...	...	...	...	...	...	...	...	...
		Industry n	w_{n1}^{r1}	...	w_{nn}^{r1}	...	w_{n1}^{rr}	...	w_{nn}^{rr}	$\sum_t \sum_j w_{nt}^{rj}$
Total final output			$\sum_s \sum_i w_{s1}^{i1}$	...	$\sum_s \sum_i w_{sn}^{i1}$	...	$\sum_s \sum_i w_{s1}^{ir}$	...	$\sum_s \sum_i w_{sn}^{ir}$	World GDP

Figure 3.2 – Framework for supply chain's value added flows (matrix W)

Source: prepared by the author based on Timmer *et al* (2015).

Note: cell values represent the value added generated in the region-industry in the row within the GVC corresponding to the region-industry of completion in the column.

For the value chain of the final product *t* completed in region *j*, we define the foreign value added as all value added outside the region of completion *j*:

$$FVA_t^j = \sum_s \sum_{i \neq j} w_{st}^{ij} \tag{3.7}$$

Here, w_{st}^{ij} is the value added generated directly and indirectly in industry *s* of region *i* for the production of final products by industry *j* of region *t*, that is, in the GVC of industry *j* of region *t*. There is one column for each GVC, characterized by the region–industry of completion, with the cells showing the origin of value added. The sum across all industries participating in a GVC is equal to the gross output value of the final product, given by the bottom row. Since final output values equal global expenditure on the product, the summation of the final output across columns equals the world GDP measured from the expenditure side. A given row in Figure 3.2 represents the value added by a given region–industry for all GVCs. Thus, the summation across the row, depicted in the final column, equals the value added in an industry. Summed across all industries, this equals world GDP measured from the production side (TIMMER *et al*, 2015).

3.2.2 Hierarchical feedback loop analysis

In our empirical application, we apply the hierarchical feedback loop approach developed by Sonis and Hewings (1988, 1991) to facilitate the identification of the spatial structure of the GVCs.[33]

We consider the *(r.n)* × *(r.n)* block matrix **W** of the supply chain's value-added flows:

$$\mathbf{W} = \begin{pmatrix} \mathbf{W}_{11} & \mathbf{W}_{12} & \cdots & \mathbf{W}_{1r} \\ \mathbf{W}_{21} & \mathbf{W}_{22} & \cdots & \mathbf{W}_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{W}_{r1} & \mathbf{W}_{r2} & \cdots & \mathbf{W}_{rr} \end{pmatrix} \tag{3.7}$$

where each block

$$\mathbf{W}_{ij} = \left\| w_{st}^{ij} \right\| \tag{3.8}$$

represents the value added from sectors in region *i* to the GVCs of region *j*. We define

$$t_{ij} = \textstyle\sum_{st} w_{st}^{ij} \tag{3.9}$$

as the sum of flows between all industries within each submatrix $\mathbf{W}_{ij}$. Hence, the *r* × *r* matrix of aggregate flows is defined as

$$\mathbf{T} = \left\| t_{ij} \right\| \tag{3.10}$$

The major focus of our empirical application in this paper is the identification of feedback loops that reveal the economic influence of each region. A series of aggregate transactions is specified such that each region is allowed precisely one transaction flow entering it and one flow leaving it. Such a series of transactions is called "feedback loop", since each and every region influences itself at the end of the loop. A feedback loop is complete if it includes all regions. A complete feedback loop is either closed or can be decomposed into a set of closed subloops. If the entering flow and the leaving flow for the same region are identical, the smallest possible closed subloop can be identified, that is, the influence that a region directly exerts on itself, namely, its domestic self-influence.

Economically, a series of transactions represents a chain of bilateral influences which are based on either backward or forward linkages. Thus, in economic terms, a feedback loop indicates how strongly (at each hierarchical level) each region is connected to all other regions included in the loop. By focusing on complete loops, one can evaluate the place and position of each region relative to all others.

[33] This section draws on Sonis *et al* (1995).

For a set of n regions, the number of all complete feedback loops is equal to $n!$. One method for dealing with this large number of complete feedback loops is to derive a hierarchical structure. Essentially, the hierarchical feedback loop approach proposed by Sonis and Hewings (1988) extracts complete feedback loops that successively account for the largest possible sum of transaction flows at each stage of the selection process. This procedure continues until all transaction flows have been included.

A complete feedback loop is presented by a submatrix $\mathbf{T}_x$ of flows extracted from the matrix $\mathbf{T} = \|t_{ij}\|$ of aggregate transaction flows. $\mathbf{T}_x$ must include precisely one non-zero entry from the matrix $\mathbf{T}$ in each row and in each column and zeros elsewhere. Replacing all the non-zero entries of $\mathbf{T}_x$ by units gives us a so-called permutation matrix $\mathbf{P}_x$, corresponding to a permutation of the sequence of numbers 1, 2, …, r. This permutation (of regions) represents the structure of the flows in the corresponding feedback loop. Hence, the submatrix $\mathbf{T}_x$ is referred to as a quasi-permutation matrix. Moreover, the flow intensity of a complete feedback loop (V_x) is defined as the sum of all transaction flows of $\mathbf{T}_x$.

Within the hierarchical feedback loop approach, the hierarchy of complete feedback loops is defined as the sequence of quasi-permutation submatrices $\mathbf{T}_x$ chosen according to the rank-size of their flow intensities V_x. Thus, the complete feedback loop with maximal flow intensity is located at the top of the hierarchy. The procedure is summarized in the following steps.

Step 1: For the matrix $\mathbf{T} = \|t_{ij}\|$ of aggregate transaction flows, find the quasi-permutation submatrix $\mathbf{T}_1$ (and the corresponding permutation matrix $\mathbf{P}_1$) associated with the complete feedback loop with maximal flow intensity (V_1). This loops stands on the top of the hierarchy.

Step 2: Replace in $\mathbf{T}$ the flows from $\mathbf{T}_1$ using arbitrary large negative numbers. For this new matrix $\mathbf{T}'$, find the quasi-permutation submatrix $\mathbf{T}_2$ (and the corresponding permutation matrix $\mathbf{P}_2$) associated with the complete feedback loop with maximal flow intensity (V_2). Since the flows from the top feedback loop have been replaced by arbitrary large negative numbers in $\mathbf{T}'$, they will not be included in this hierarchically subsequent loop.

Step 3 through r - 1: Repeat step 2 for the matrix $\mathbf{T}'$.

After r - 1 steps, one obtains a sequence of r complete feedback loops, ordered according to the decreasing size of their flow intensities.

3.2.3 The Matrioshka approach

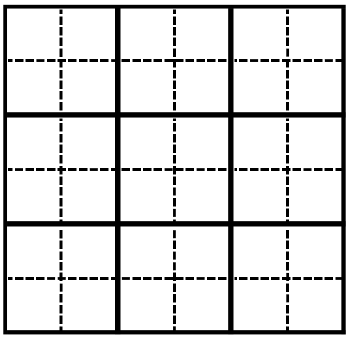
In order to simultaneously analyze intersectoral and interregional interdependencies, we apply an extension of the previous subsection's procedure at the sectoral level, as proposed by Sonis and Hewings (1991). As indicated by Sonis *et al* (1995), with this extension, the hierarchy of the feedback loops reflects the spatially intertwined intersectoral interdependencies, enabling us to distinguish the spatial extent of interregional industrial processes.[34]

To this aim, the matrix **T** of aggregate transaction flows needs to be replaced by the detailed original matrix $\mathbf{W}$. The hierarchical feedback loop procedure operates at successive levels of the system, but the approach at each stage is the same. This top–down decomposition is analogous to the construction of Matrioshka dolls, in which successively smaller dolls of the same shape and style are nested within larger dolls. Thus, the Matrioshka approach examines the domestic and interregional transactions at the industry level in terms of the hierarchical structure of feedback effects.

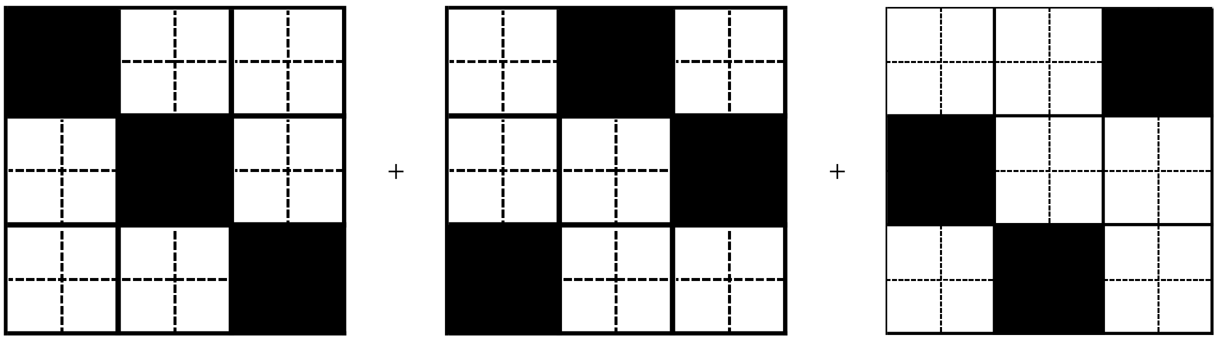
In simple terms, given a quasi-permutation submatrix $\mathbf{T}_1$ corresponding to the complete feedback loop on top of the hierarchy at the regional scale, we apply the hierarchical feedback loop procedure to the blocks of cells in matrix **W** that correspond to the regional flows from $\mathbf{T}_1$. Thus, for these regional blocks in matrix **W**, we obtain a nested hierarchy of n complete feedback loops according to the rank-size of their industry flow intensities. The procedure is then applied to the regional blocks defined by the quasi-permutation submatrix $\mathbf{T}_2$, and so on, within a structure of nested feedback loop hierarchies.

Considering, as an example, a three-region / two-industries matrix **W** of supply chain's value added flows of the following form:

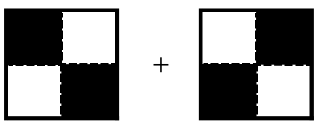
[34] This section also draws on Sonis *et al* (1995).

$\mathbf{W} =$ 

At the regional spatial scale (i.e. where interest is in merely focused on the aggregate flows rather than the intersectoral flows), suppose the following hierarchical feedback loop structure is identified:

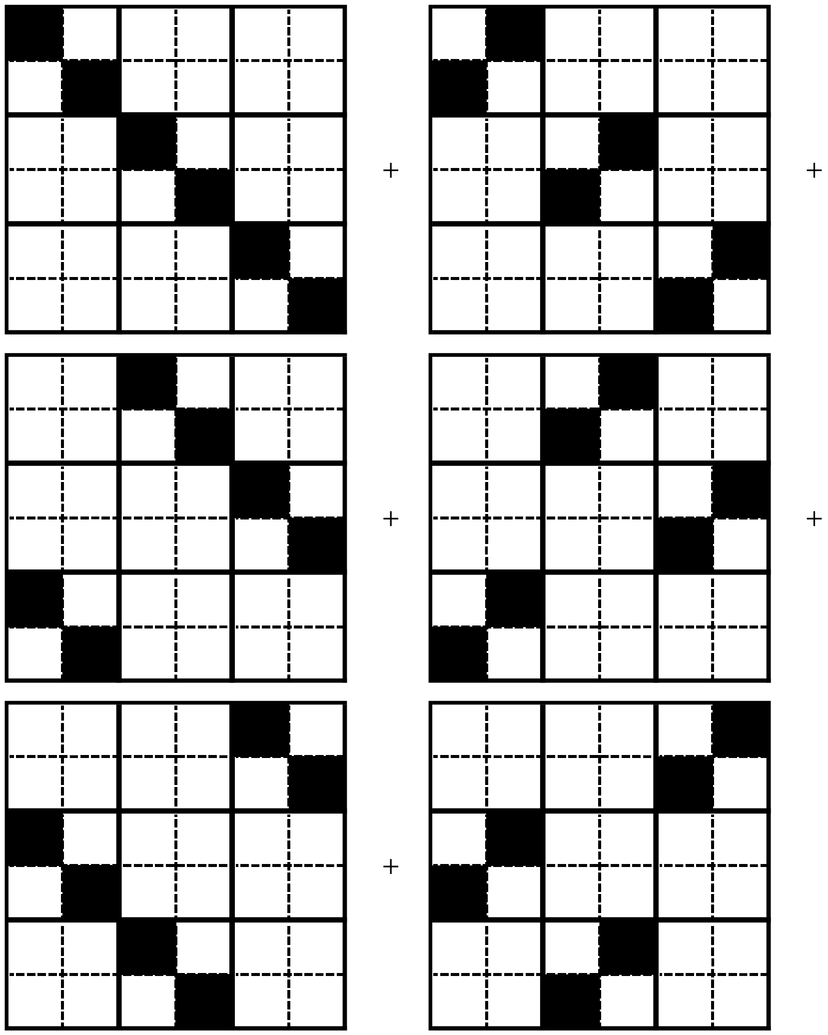


At the sectoral level, a simple decomposition necessarily holds distinguishing intra-sectoral and intersectoral flows. Suppose that, regardless of the regions involved, the flow intensity within industries is larger than between industries, so that the following hierarchical feedback loop structure holds at sectoral level:



Thus, the nested hierarchical decomposition satisfies the Matrioshka principle:

$\mathbf{W} =$



A similar structure of nested feedback loop hierarchies can be extracted for the general case of an IO system comprising *r* regions/*n* industries. A Matlab program is compiled to find the hierarchical sequence of *r* complete feedback loops at the regional scale (with a nested hierarchy of *n* complete loops at the sectoral level in each of them).

3.3 Results

In order to understand the spatial configuration of global production processes, we first focus on individual elements at the national/state level, identifying where each region sources the intermediate inputs required for its final production. This provides an indication of each region's dependency on the international supply networks. Next, we take the global perspective and apply the feedback loop methodology to our inter-country IO table, so as to hierarchically identify the myriad of economic interactions in the GVCs.

3.3.1 Supply chain interdependency

Table 3.1 presents the foreign value-added shares in total final output of the set of value chains for each country in our model. The countries of origin are grouped into five blocks: Brazil (i.e. Brazilian states), the NAFTA block, EU27, East Asia, and "Others and RoW", the latter referring to the rest of the global economy. In this way, we intend to assess each country's dependency on sourcing of intermediates inputs from abroad and to distinguish their geographical origin.

The degree of fragmentation within the NAFTA block is the lowest. On average, only 2.3% of its final production's total output corresponds to value added from other NAFTA members. This result is due the USA's self-sufficiency in intermediates and particularly the low reliance its value chains place on other NAFTA countries. Moreover, because of USA's self-sufficiency, the NAFTA block is the least integrated block (to global networks). The largest foreign value-added share belongs to "Others and RoW", which includes important energy and food producers in the world (e.g. the Organization of the Petroleum Exporting Countries or OPEC). For both the Mexican and the Canadian value chains, fragmentation within the block is more important, that is, their dependency on the USA's intermediates is larger than the other way around.

Within the EU27, we find much tighter production sharing relationships. Here, 8.1% of the total output of the average value chain corresponds to the value added produced by other EU27 members. The reliance on intermediates sourced within the block is especially important for the Eastern European countries. Alongside Ireland and the Benelux countries, the largest shares of foreign value added sourced within the block correspond to the newer EU27 members' sets of value chains, especially Hungary, the Slovak Republic, the Czech Republic, Slovenia, Bulgaria, and Estonia. Thus, like Los *et al* (2014), we observe that many value chains in the EU27 block are predominantly fragmented within the block. For 17 of the EU27 countries, the shares of foreign value added sourced within the block were larger than shares from elsewhere in the world. However, it is very important to note that the major EU27 countries comprise most of the exceptions, as their value chains are significantly globalized and rely more strongly on upstream activities outside the EU27.

Table 3.1 shows that the contribution of "Others and RoW" toward final production is especially relevant for the Eastern European countries. This is because of their noteworthy production sharing with Russia (especially for Bulgaria and Lithuania), and to a lesser extent with Turkey (especially for Bulgaria and Romania). In fact, the interdependency seems to work both ways with Turkey, as sourcing of intermediates from the EU27 as a whole is relatively significant for this country's value chains. Russia is largely self-sufficient in intermediates, and thus, the foreign content in its value chains is quite small. However, Russia's largest foreign value-added share is, in fact, produced in the EU27 block.

As for East Asia, production sharing within the block is more expressive than NAFTA's but quite timid compared to the EU27's. Value chains in Japan are especially self-sufficient in intermediates, so much so that only 1.5% of its total output corresponds to value added from elsewhere in East Asia. The relatively small East Asian share in the foreign value added of China's final production also seems to be at odds with the suggestion of a highly integrated production network with other countries in the block that provide intermediates for further processing in China. As indicated by Los *et al* (2014), East Asia's small share does not contradict this suggestion but reflects that the highly integrated Asian production system contributes to a relatively small part of final output in China (e.g. electronics production). At the global level and considering the absolute values, the interdependency among East Asian countries is quite important, as we observe in the next subsection. The value chains of both Korea and Taiwan rely more (than those of Japan and China) on upstream activities in East Asia. These activities are also important for the value chains of Australia, Indonesia, and India, which are included in the block "Others and RoW". Of all the blocks specified in Table 3.1, East Asia is the main source of foreign value added for final production in these three countries.

Table 3.1 –Foreign value-added shares in output of GVCs, by country of completion (%)

	Brazil	**NAFTA**	**EU27**	**East Asia**	**Other + RoW**	**Total**
Brazilian states	*15.3*	*1.4*	*2.4*	*1.2*	*3.2*	***23.5***
Nafta						
USA	0.1	1.6	1.7	1.6	3.1	**8.1**
Mexico	0.3	6.2	2.3	2.6	2.2	**13.6**
Canada	0.2	6.5	2.7	2.4	2.6	**14.3**
Nafta region	*0.2*	*2.3*	*1.8*	*1.7*	*3.0*	***8.9***
EU27						
Austria	0.2	1.2	12.8	1.7	4.6	**20.4**
Belgium	0.3	2.3	16.8	2.3	5.7	**27.3**
Bulgaria	0.3	1.5	13.5	2.6	12.8	**30.6**
Cyprus	0.2	1.6	9.9	4.0	3.7	**19.5**
Czech Republic	0.2	1.7	16.5	3.8	7.1	**29.2**
Germany	0.3	1.5	7.6	1.9	4.3	**15.6**
Denmark	0.3	2.3	11.9	1.9	4.4	**20.7**
Spain	0.2	1.5	6.9	1.8	4.3	**14.8**
Estonia	0.2	1.3	13.4	2.7	7.4	**25.0**
Finland	0.2	1.6	8.9	2.2	6.7	**19.5**
France	0.2	1.2	5.9	1.3	3.9	**12.4**
United Kingdom	0.1	2.1	5.6	1.5	3.9	**13.3**
Greece	0.1	1.4	7.1	1.3	6.2	**16.2**
Hungary	0.2	2.4	18.4	3.9	7.0	**31.9**
Ireland	0.2	7.8	16.6	2.6	5.2	**32.4**
Italy	0.2	1.1	6.2	1.4	5.5	**14.3**
Lithuania	0.1	0.8	10.3	1.3	12.0	**24.6**
Luxembourg	0.2	3.5	29.5	3.6	3.2	**40.0**
Latvia	0.1	1.0	11.9	1.1	6.5	**20.6**
Malta	0.2	1.6	16.4	3.5	7.6	**29.3**
Netherlands	0.4	2.7	10.2	2.6	7.1	**23.0**
Poland	0.1	1.2	10.8	2.2	5.5	**19.8**
Portugal	0.7	1.1	9.6	1.2	5.5	**18.1**
Romania	0.2	1.1	10.9	1.6	6.3	**20.0**
Slovak Republic	0.2	1.5	17.3	3.8	8.3	**31.0**
Slovenia	0.3	1.5	15.1	2.1	6.7	**25.6**
Sweden	0.6	1.9	10.8	2.2	4.5	**20.1**
EU27 region	*0.2*	*1.7*	*8.1*	*1.8*	*4.8*	***16.6***
East Asia						
China	0.4	3.0	4.6	4.3	8.8	**21.1**
Japan	0.1	1.2	1.0	1.5	5.4	**9.3**
Korea	0.3	3.1	3.4	6.6	10.3	**23.6**
Taiwan	0.3	3.3	3.7	6.3	8.9	**22.6**
East Asia region	*0.3*	*2.3*	*2.9*	*3.3*	*7.4*	***16.1***
Others + RoW						
Australia	0.1	1.6	2.2	2.6	3.5	**10.0**
Indonesia	0.2	1.7	2.8	4.8	6.6	**16.1**
India	0.1	1.5	2.4	2.6	6.7	**13.2**
Turkey	0.1	1.0	4.8	1.6	6.9	**14.5**
Russia	0.1	0.7	3.6	2.0	1.8	**8.1**
RoW	0.5	5.0	9.0	6.4	2.6	**23.6**
Others + RoW	*0.3*	*3.6*	*6.8*	*5.0*	*3.4*	***19.2***

From Table 3.1, we observe that Brazil, as a whole, is mostly self-sufficient in intermediates. Of all the countries in our model, the foreign content in the set of Brazil's value chains is larger only than the USA's and Russia's. However, there is a great degree of fragmentation among Brazilian states. For the average value chain, 15.3% of the value of its final output is added in a state other than where the final output is completed. This is larger than the share observed for the EU27, indicating even tighter production sharing relationships. Focusing on the supply chain network within Brazil, Table 3.2 presents the regional value-added shares in each state's final production. In order to emphasize the spatial characteristics of the Brazilian states' value chains, the states are grouped into five regions, as indicated in Appendix A.1.

In the Brazilian supply network, the dependency of all states' value chains in relation to the Southeast region's intermediates is outstanding. For every state, the largest value-added share in their final production comes from the Southeast region. São Paulo's upstream activities are especially important, on average, for final production anywhere in the country; their value added ranges from at least 4% (in Maranhão) to as much as 12% (in Amazonas) of the final outputs of the other states. To a lesser extent, intermediates from the South region also contribute significantly to all regions' value chains.

Therefore, we observe that for Brazilian value chains, the fragmentation within the regions is considerably less relevant for final production than production sharing with the more developed Southeast and South regions. Besides the Southeast and South regions , interdependency within the region is more relevant for states in the Northeast; however, this is very much surpassed by the supply networks across Brazilian regions.

Table 3.2 also provides information on value-added shares of foreign origin in the states' value chains. Besides Amazonas and Paraná, São Paulo's value chains are more integrated with the rest of the world; almost 10% of the state's final output consists of value added in foreign countries (note, however, that it is quite limited compared to other countries in our model). Intermediates from the block "Others and RoW" contribute the most to São Paulo's final production, followed by intermediates sourced from the EU27. Amazonas is distinguished in terms of the origin of foreign value added as its final production absorbs as many intermediates from East Asia as it does from the block "Others and RoW". This can be attributed to the assembling of electronics in the Free Trade Zone of Manaus, which incorporates large volumes of constituent parts from East Asia.

Table 3.2 – Regional value-added shares in output of GVCs, by state of completion (%)

	North	North-east	Central-West	South-east	South	BRA total	NAFTA	EU27	East Asia	Other + RoW	Foreign total
North region											
Acre	0.6	1.3	0.9	8.0	2.0	**12.8**	0.6	1.0	0.4	1.4	**3.3**
Amapá	0.4	1.0	0.7	8.5	1.6	**12.2**	0.6	1.3	0.4	1.6	**3.9**
Amazonas	0.9	2.2	1.4	17.5	2.8	**24.8**	2.0	3.2	3.9	4.0	**13.1**
Pará	0.5	1.7	0.9	8.8	2.2	**14.1**	0.9	1.4	0.5	2.0	**4.8**
Rondonia	0.7	1.7	1.7	11.9	2.9	**18.9**	0.8	1.4	0.6	2.1	**4.9**
Roraima	0.6	1.1	0.6	6.8	1.7	**10.8**	0.5	1.1	0.3	1.3	**3.3**
Tocantins	0.6	1.9	1.8	11.0	2.6	**17.9**	0.9	1.5	0.6	2.1	**5.1**
North region	*0.7*	*1.8*	*1.3*	*12.5*	*2.5*	***18.7***	*1.2*	*2.1*	*1.8*	*2.7*	***7.8***
Northeast region											
Alagoas	0.7	3.2	1.1	9.0	2.5	**16.5**	0.8	1.1	0.5	1.7	**4.0**
Bahia	0.7	2.4	0.9	12.8	2.4	**19.1**	1.2	1.9	1.1	3.7	**7.9**
Ceará	0.6	2.7	0.8	7.8	2.0	**14.0**	0.9	1.8	0.9	2.5	**6.1**
Maranhão	0.7	1.6	0.5	6.8	1.5	**11.2**	1.0	1.8	0.6	3.0	**6.4**
Paraiba	0.6	3.2	0.9	7.9	1.9	**14.4**	0.8	1.3	0.7	2.0	**4.7**
Pernambuco	0.7	2.4	0.9	8.5	2.1	**14.5**	1.2	1.8	0.7	2.7	**6.5**
Piauí	0.7	3.2	0.8	10.5	2.2	**17.3**	0.7	1.2	0.5	1.7	**4.1**
Sergipe	0.6	2.8	0.9	8.9	2.2	**15.4**	0.8	1.2	0.5	1.8	**4.3**
Rio Grande do Norte	0.6	3.7	0.9	8.5	2.1	**15.7**	0.7	1.2	0.6	1.8	**4.3**
Northeast region	*0.7*	*2.6*	*0.9*	*9.6*	*2.1*	***15.9***	*1.0*	*1.7*	*0.8*	*2.8*	***6.3***
Central-West region											
Distrito Federal	0.8	1.6	0.8	9.8	1.7	**14.6**	0.7	1.7	0.4	1.6	**4.4**
Goiás	0.9	2.0	1.3	14.3	3.2	**21.7**	1.7	2.0	1.1	3.3	**8.1**
Mato Grosso	1.2	2.3	1.6	14.2	4.3	**23.6**	1.2	1.5	0.7	2.8	**6.2**
Mato Grosso do Sul	0.8	2.0	1.4	12.4	3.3	**19.9**	1.3	2.6	1.0	3.7	**8.5**
Central-West region	*0.9*	*1.9*	*1.1*	*12.0*	*2.7*	***18.6***	*1.1*	*1.8*	*0.7*	*2.5*	***6.2***
Southeast region											
Espírito Santo	0.6	1.6	0.9	9.9	2.1	**15.2**	1.0	1.5	0.9	2.1	**5.6**
Minas Gerais	0.7	1.6	1.3	10.7	2.7	**17.0**	1.5	2.3	1.1	2.9	**7.8**
Rio de Janeiro	0.5	1.0	0.7	6.9	1.9	**11.1**	1.3	2.4	0.8	2.9	**7.5**
São Paulo	1.1	1.9	1.1	4.9	3.0	**11.9**	1.7	2.9	1.5	3.6	**9.7**
Southeast region	*0.9*	*1.6*	*1.1*	*6.4*	*2.7*	***12.7***	*1.6*	*2.7*	*1.3*	*3.3*	***8.8***
South region											
Paraná	0.9	1.7	1.4	13.0	3.0	**20.0**	1.7	3.0	1.6	3.8	**10.1**
Santa Catarina	0.7	2.0	1.4	10.2	3.7	**17.9**	1.3	2.1	1.5	3.5	**8.4**
Rio Grande do Sul	0.9	2.1	1.0	12.7	3.0	**19.7**	1.3	2.1	1.0	4.0	**8.4**
South region	*0.9*	*1.9*	*1.2*	*12.2*	*3.2*	***19.4***	*1.4*	*2.4*	*1.4*	*3.8*	***9.0***

3.3.2 Aggregate feedback loops

In the previous subsection, we analyzed the reliance of each region's final production on intermediates produced elsewhere in the world. Now, we consider the global perspective and identify paths in global supply chains in terms of the order of their economic importance using the hierarchical feedback loop approach.

At the first level of analysis, all the supply chains' value-added flows are aggregated into one industry to reveal the macro-level structure of the feedback loops. Table 3.3 summarises the hierarchy of the complete feedback loops, which are ordered according to the decreasing size of their flow intensities. In our analysis, we focus on the top ten feedback loops, which together represent 94.6% of the global supply chains' value-added flows in 2008.

Inspection of the aggregate supply chain's value-added flows shows that, by far, the largest flows are the domestic flows. Thus, Step 1 of the hierarchical procedure produces a diagonal quasi-permutation submatrix $\mathbf{T}_1$. Associated with this set of flows is a corresponding permutation matrix $\mathbf{P}_1 = \mathbf{I}$ and the permutation

$\mathbf{p}_1$ = (AC) (AP) (AM) (PA) (RO) (RR) (TO) (AL) (BA) (CE) (MA) (PB) (PE) (PI) (SE) (RN) (DF) (GO) (MT) (MS) (ES) (MG) (RJ) (SP) (PR) (SC) (RS) (CHN) (IND) (RUS) (USA) (MEX) (CAN) (AUT) (BEL) (BGR) (CYP) (CZE) (DEU) (DNK) (ESP) (EST) (FIN) (FRA) (GBR) (GRC) (HUN) (IRL) (ITA) (LTU) (LUX) (LVA) (MLT) (NLD) (POL) (PRT) (ROM) (SVK) (SVN) (SWE) (JPN) (KOR) (TWN) (AUS) (IDN) (TUR) (RoW)

which corresponds to the domestic flows within each state or country. The flow intensity of this complete feedback loop is worth US$ 50,856,717 million and accounts for 84.9% of the total supply chain's value-added flows. The remaining percentage of the total flows, 15.1%, comprises the interregional flows.

Table 3.3 – Decomposition of supply chain's value-added flows into feedback loops

Rank	Structure of the complete feedback loop	Flow intensity	% total flows	% inter-regional flows
1	(AC) (AP) (AM) (PA) (RO) (RR) (TO) (AL) (BA) (CE) (MA) (PB) (PE) (PI) (SE) (RN) (DF) (GO) (MT) (MS) (ES) (MG) (RJ) (SP) (PR) (SC) (RS) (CHN) (IND) (RUS) **(USA)** (MEX) (CAN) (AUT) (BEL) (BGR) (CYP) (CZE) (DEU) (DNK) (ESP) (EST) (FIN) (FRA) (GBR) (GRC) (HUN) (IRL) (ITA) (LTU) (LUX) (LVA) (MLT) (NLD) (POL) (PRT) (ROM) (SVK) (SVN) (SWE) (JPN) (KOR) (TWN) (AUS) (IDN) (TUR) (RoW)	50,856,717	84.9%	
2	(AC TO AP RR) (AM PA ES BA PE PB CE RN RO) (AL SE) (MA PI) (DF GO) (MT MS) (MG RJ SP) (PR RS SC) (CHN KOR IDN IND TWN AUS JPN) (RUS TUR) **(USA RoW)** (MEX CAN) (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK) (BEL NLD) (DEU FRA ITA ESP PRT LUX IRL GBR) (DNK SWE) (LTU LVA)	1,180,642	2.0%	13.1%
3	(AC SE BA GO MT RO) (AP MLT RR) (AM DF TO MS ES) (PA MA) (AL PE CE PI) (PB RN) (MG SP RJ) (PR SC RS) **(CHN RoW)** (IND AUS) (RUS POL) (USA CAN) (MEX DNK IRL TWN IDN JPN KOR) (AUT SVN HUN SVK CZE) (BEL GBR NLD DEU ITA FRA ESP) (BGR CYP GRC) (EST LVA) (FIN SWE) (LTU LUX PRT) (ROM TUR)	1,088,000	1.8%	12.1%
4	(AC RR MLT AP) (AM RO SE ES PA RN CE PB PE BA DF) (TO MA MT SC RJ PR SP RS MG GO MS AL PI) (CHN USA) (IND CAN) **(RUS DEU RoW JPN TWN MEX IDN AUS KOR)** (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) (BEL FRA) (CYP LVA LUX) (DNK FIN) (EST LTU)	832,397	1.4%	9.2%
5	(AC AP RN PI) (AM MT GO TO PB SE MA CE PE AL MS RO ES RJ RS SP PR MG BA SC DF PA) **(RR EST LUX FIN RUS NLD DNK PRT SVK POL IRL BEL SWE IND IDN KOR CHN JPN RoW ITA TUR GRC SVN BGR LVA CYP MLT LTU)** (USA MEX) (CAN AUS TWN) (AUT ROM) (CZE HUN) (DEU GBR ESP FRA)	662,774	1.1%	7.4%
6	(AC RO RR PI CE MA TO) (AP LVA) (AM PE RN SE MS) (PA DF ES MG RS GO) (AL PB) (BA SP) (MT PR RJ SC) (CHN IND MEX ESP NLD ITA DEU) **(RUS FRA GBR RoW KOR CAN BEL LUX BGR TUR PRT GRC SWE POL DNK AUS IDN TWN CZE)** (USA JPN) (AUT SVK ROM HUN IRL FIN EST MLT CYP LTU SVN)	493,197	0.8%	5.5%
7	(AC PB PI AP LTU) (AM SP DF RO AL TO PA MS SC MG PR MT CE) (RR LUX EST CYP) (BA RS RJ) (MA PE SE RN) (GO ES) **(CHN DEU USA GBR FRA NLD ESP IRL CAN JPN RUS RoW IND FIN HUN SVN CZE ROM GRC PRT SWE BEL DNK MEX AUS)** (AUT ITA POL) (BGR SVK) (LVA MLT) (KOR TWN) (IDN TUR)	439,804	0.7%	4.9%
8	**(AC MLT LUX BEL IND NLD FRA RoW DEU ESP TUR SVK SVN LVA RR CYP EST AP TO AL RO RN ES RS BA PR GO MG AM RJ DF PI SE CE PA MT PE MA MS PB)** (SP SC) (CHN CAN GBR USA KOR JPN IDN GRC ROM CZE FIN AUS MEX PRT IRL SWE RUS ITA AUT POL HUN BGR LTU DNK TWN)	411,490	0.7%	4.6%
9	(AC CYP AP SE PB TO PI RO MLT) (AM MA AL RN PA CE MS PR BA RJ GO RS MT ES SP) **(RR LVA DNK CZE SWE AUS CAN KOR IND TUR HUN FIN NLD POL ROM SVK RUS CHN ESP GBR ITA RoW FRA USA DEU AUT BEL IRL LUX GRC IDN PRT EST)** (PE DF MG SC) (MEX TWN JPN) (BGR SVN LTU)	358,752	0.6%	4.0%
10	(AC RN AL MT RJ AM MS PA RS CE ES PR PE PI RR LTU MLT TO SE RO PB AP EST) (BA MG DF MA SC) (GO SP) (CHN MEX IND USA FRA TUR CZE SVN ROM CYP BGR LUX LVA FIN PRT AUS IRL ITA RUS JPN CAN) (AUT DEU NLD SWE) **(BEL ESP GRC KOR RoW GBR)** (DNK IDN) (HUN POL SVK TWN)	331,029	0.6%	3.7%
11 to 67		3,212,047	5.4%	35.6%

Note: for each complete feedback loop, the dominant subloop is in bold text.

Next, we consider the direction and magnitude of the complete interregional feedback loops. Step 2 of the hierarchical procedure results in the quasi-permutation submatrix $\mathbf{T}_2$. The flow intensity of this complete feedback loop is V_2, which amounts to US$ 1,180,642 million and accounts for 13.1% of the total interregional supply chain's value-added flows. Associated with these flows is a permutation matrix $\mathbf{P}_2$, which corresponds to the permutation

$\mathbf{p}_2$ = (AC TO AP RR) (AM PA ES BA PE PB CE RN RO) (AL SE) (MA PI) (DF GO) (MT MS) (MG RJ SP) (PR RS SC) (CHN KOR IDN IND TWN AUS JPN) (RUS TUR) (USA RoW) (MEX CAN) (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK) (BEL NLD) (DEU FRA ITA ESP PRT LUX IRL GBR) (DNK SWE) (LTU LVA)

The loop is broken down into 17 independent closed subloops. The dominant subloop, that is, the subloop with the largest flow intensity, (USA RoW), corresponds to the pair-wise exchange between the USA and RoW. It accounts for 62.4% of the flow intensity represented in the complete loop. The second most important subloop in terms of intensity, (CHN KOR IDN IND TWN AUS JPN), corresponds to countries in Oceania and Asia in our model. The supply chain's value-added flows go from China to Korea and then onward to Indonesia, India, Taiwan, Australia, Japan, and back to China. The flow intensity of this subloop is 15.7% of V_2. The third most important subloop, (DEU FRA ITA ESP PRT LUX IRL GBR), includes the central economies of the EU27, comprising the flows starting in Germany and then going back to Germany via France, Italy, Spain, Portugal, Luxembourg, Ireland, and Great Britain. Its flow intensity represents 12.0% of V_2. The other subloops also have a clear geographical definition: (RUS TUR) for the Eurasian countries, (MEX CAN) for North American countries other than the USA, (AUT HUN ROM BGR GRC CYP SVN MLT EST FIN POL CZE SVK) (the southern and eastern countries of the EU27) for the EU27, (BEL NLD) for the Benelux countries other than Luxembourg, (DNK SWE) for the Nordic countries other than Finland, and (LTU LVA) for the Baltic countries other than Estonia.

The remaining value-added flows of the supply chain in this feedback loop correspond to eight closed subloops within Brazil. The dominant subloop within Brazil, (MG RJ SP), corresponds to the most developed states in the Southeast region, including the flows going from Minas Gerais to Rio de Janeiro, São Paulo, and back to Minas Gerais. Its flow intensity is 2.1% of V_2. Excluding the subloop (AM PA ES BA PE PB CE RN RO), which comprises states from the North, Northeast, and Southeast regions, each of the other six subloops include states from exclusively one Brazilian region.

Figure 3.3 provides a graphical presentation of the second complete feedback loop.[35] The spatial nature of the top-ranked interregional feedback loop is readily apparent. The supply chain network described by this loop is geographically concentrated within blocks of countries. However, we must remember that the dominant subloop, which accounts for 62.4% of the flow intensity in the loop, corresponds to production sharing relationships across blocks (between the USA and the composite region RoW). In order to correctly evaluate the importance of fragmentation within blocks as opposed to global fragmentation, we must analyze the subsequent complete feedback loops.

As for Brazil, the top-ranked interregional feedback loop singles out supply chain networks within great regions. However, the apparent importance of fragmentation within each Brazilian region should be considered in line with the adopted hierarchical procedure. In each step, we search for the complete feedback loop with maximal flow intensity, with the constraint that each region is allowed precisely one transaction flow entering it and one flow leaving it. Thus, the presence of the Southeast states' subloop precludes others states from displaying flows with this great region in the same loop. Then, the procedure identifies the South region's subloop as part of the complete feedback loop with maximal flow intensity. Given the preclusion of flows entering in (and leaving from) both the Southeast and the South regions, the maximal flow intensities for the other states are found majorly within the great regions' flows.

[35] For better visualization, we omit the regions' names in the figures. States are aggregated into the five great Brazilian regions and are sorted as in Table 3.2. Countries are aggregated into the following blocks: the NAFTA, the EU27, East Asia, and "Others and RoW". They are sorted as in Table 3.1.

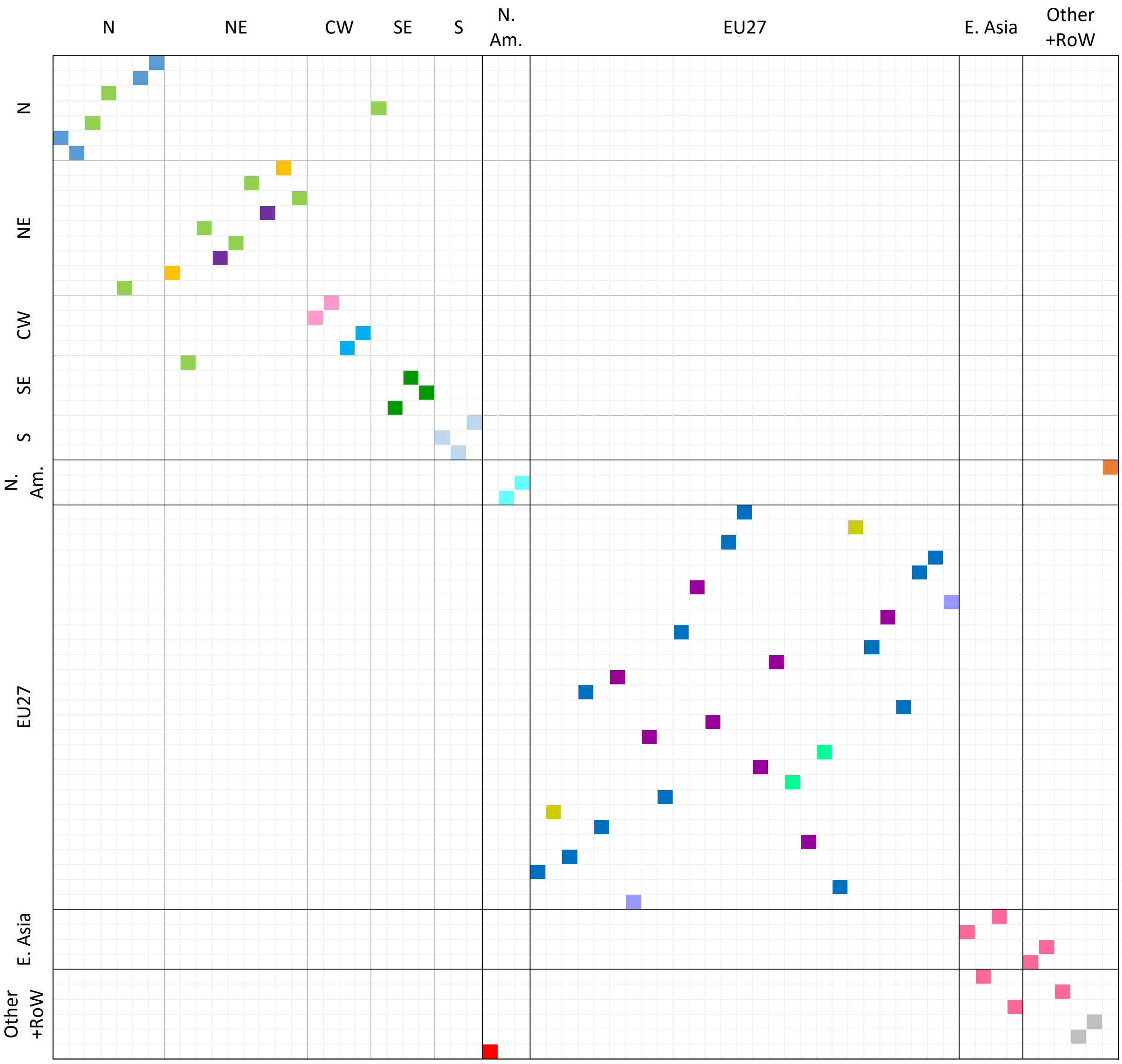


Figure 3.3 – Second aggregate feedback loop
Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop. Different colours indicate different subloops.

Step 3 of the hierarchical procedure gives the next complete feedback loop. All the flows identified in the first two steps are now eliminated from further consideration. The resulting quasi-permutation submatrix $\mathbf{T}_3$ has flow intensity V_3 worth US$ 1,088,000 million (12.1% of the total interregional supply chain's value-added flows). From the permutation matrix $\mathbf{P}_3$, we identify the following permutation:

$\mathbf{p}_3$ = (AC SE BA GO MT RO) (AP MLT RR) (AM DF TO MS ES) (PA MA) (AL PE CE PI) (PB RN) (MG SP RJ) (PR SC RS) (CHN RoW) (IND AUS) (RUS POL) (USA CAN) (MEX DNK IRL TWN IDN JPN KOR) (AUT SVN HUN SVK CZE) (BEL GBR NLD DEU ITA FRA ESP) (BGR CYP GRC) (EST LVA) (FIN SWE) (LTU LUX PRT) (ROM TUR)

Figure 3.4 graphically presents the third complete feedback loop. This loop is divided into twenty closed subloops. The dominant subloop is now (CHN RoW), which corresponds to the pair-wise exchange between China and RoW. It accounts for 55.1% of the flow intensity of V_3. The subloop (USA CAN) of cross-border exchanges between the USA and Canada is important in terms of intensity, as it corresponds to 21.4% of V_3. Accounting for 13.3% of V_3 is the subloop (BEL GBR NLD DEU ITA FRA ESP), which comprises the central economies in the EU27, including the flows from Belgium to Great Britain, the Netherlands, Germany, Italy, France, Spain, and back to Belgium. As in the previous step, the EU27 countries are interconnected within this loop. The exceptions are Romania in the (ROM TUR) loop for the pair-wise exchange with Turkey; Poland, which is connected to Russia in (RUS POL); Denmark and Ireland, which are part of the more complex subloop (MEX DNK IRL TWN IDN JPN KOR), which also includes countries from Americas and Asia; and Malta in the subloop (AP MLT RR), with states from the North region of Brazil.

The result of Malta being connected to states from the North region of Brazil in a major feedback loop should not be interpreted as an indication of strong economic linkage; instead, we need to keep the adopted hierarchical procedure in mind. In each step, the solution determines a series of transactions with maximal flow intensity, such that each region is allowed precisely one transaction flow entering it and one leaving it. For small economies such as Malta and these states, a likely result is that their main partners are already connected to other regions within the major feedback loops, and thus, they end up being connected to other small economies.

The Brazilian states in this third feedback loop join closed subloops comprising exclusively domestic flows (with the exception of Malta). Once again, the states in the Southeast region compose the dominant subloop within Brazil (MG SP RJ), now corresponding to flows starting from Minas Gerais and going via São Paulo and Rio de Janeiro back to Minas Gerais. The flow intensity of this subloop corresponds to 1.9% of V_3. We still observe a closed subloop comprising the states in the South region, but for the other regions in the country, the transaction flows become more spatially spread out.

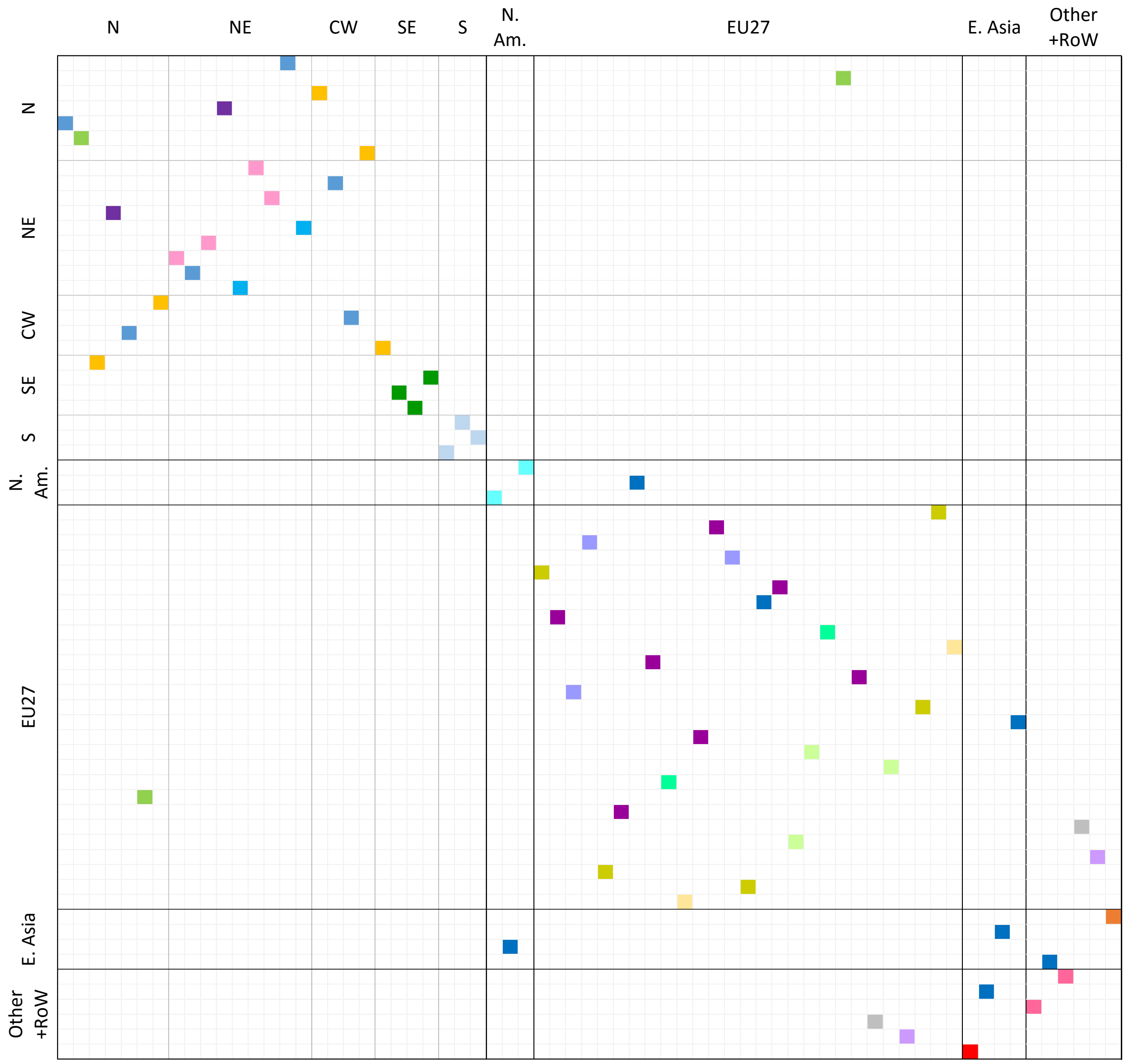


Figure 3.4 – Third aggregate feedback loop
Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop. Different colours indicate different subloops.

Proceeding with the hierarchical procedure, in step 4, we obtain the quasi-permutation submatrix $\mathbf{T}_4$ with flow intensity V_4 amounting to US$832,397 million (9.2% of the total interregional supply chain's value-added flows). Associated with these flows is a permutation matrix $\mathbf{P}_4$ representing the following permutation:

$\mathbf{p}_4$ = (AC RR MLT AP) (AM RO SE ES PA RN CE PB PE BA DF) (TO MA MT SC RJ PR SP RS MG GO MS AL PI) (CHN USA) (IND CAN) (RUS DEU RoW JPN TWN MEX IDN AUS KOR) (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) (BEL FRA) (CYP LVA LUX) (DNK FIN) (EST LTU)

Figure 3.5 shows a graphical presentation of the fourth complete feedback loop. It is composed of eleven independent closed subloops. Unlike the previous loops, the dominant subloop in this case does not correspond to exchanges between two regions but to a sequence of transactions centered on RoW and including countries from Asia, Europe, Oceania, and Americas. In this subloop (RUS DEU RoW JPN TWN MEX IDN AUS KOR), the supply chain's value-added flows go from Russia to Germany, RoW, Japan, Taiwan, Mexico, Indonesia, Australia, Korea, and back to Russia. The flow intensity of this subloop is 52.7% of V_4. The second most important subloop in terms of intensity is (CHN USA), corresponding to the pair-wise exchange between China and the USA. It accounts for 31.4% of the flow intensity represented in the complete loop. Also, importantly, we find a subloop of transactions connecting older and newer members of the EU27 (plus Turkey). This subloop (AUT CZE POL SWE NLD GBR IRL PRT ESP ITA GRC TUR BGR ROM SVN SVK HUN) accounts for 9.0% of V_4.

The Brazilian states continue to be connected among themselves in this loop (excepting Roraima and Amapá, which are connected to Malta in (AC RR MLT AP)). The dominant subloop within the country, (TO MA MT SC RJ PR SP RS MG GO MS AL PI), comprises states from all Brazilian regions and is centered on São Paulo, which is connected to states from the South region. The flow intensity of this subloop is 2.6% of V_4.

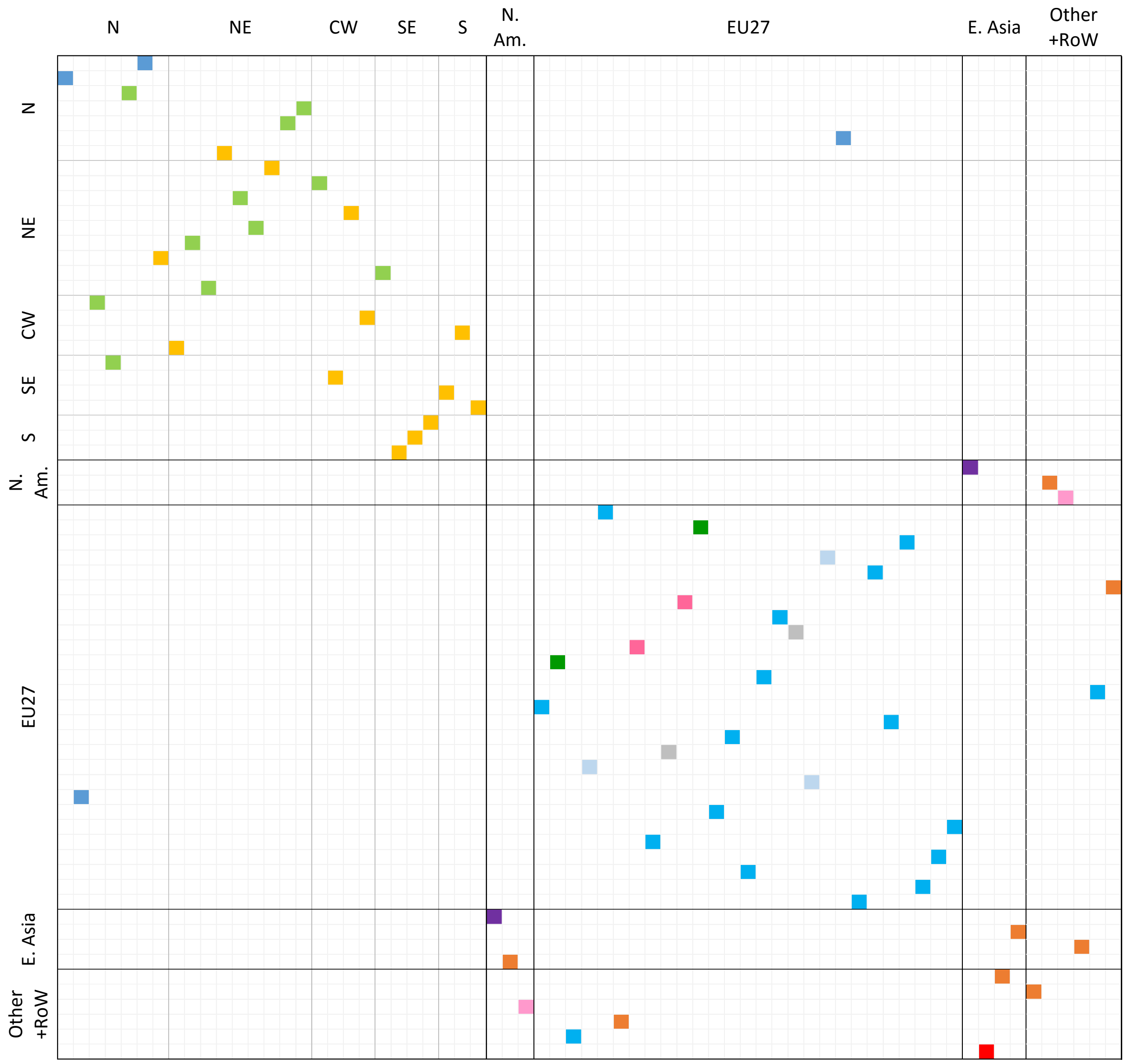


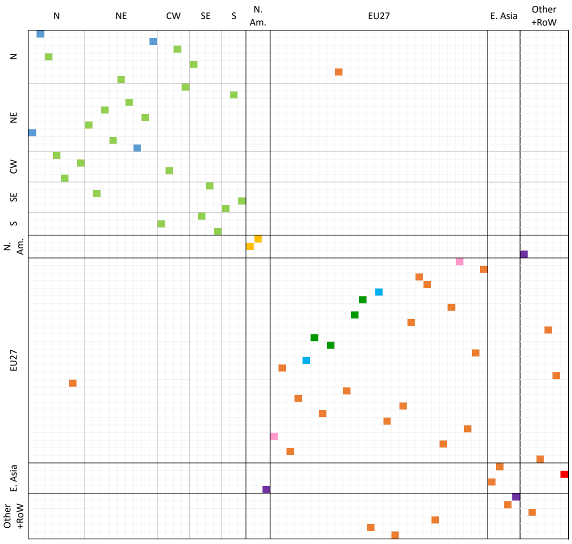
Figure 3.5 – Forth aggregate feedback loop
Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop. Different colours indicate different subloops.

The fifth to the tenth complete feedback loops are represented graphically in Figure 3.6. In each of these loops, the largest flow involves the composite region RoW (incoming flows in the fifth and sixth loop from Japan and Great Britain, respectively, and outgoing flows directed to India, Germany, France, and Great Britain from the seventh to the tenth loop, respectively).

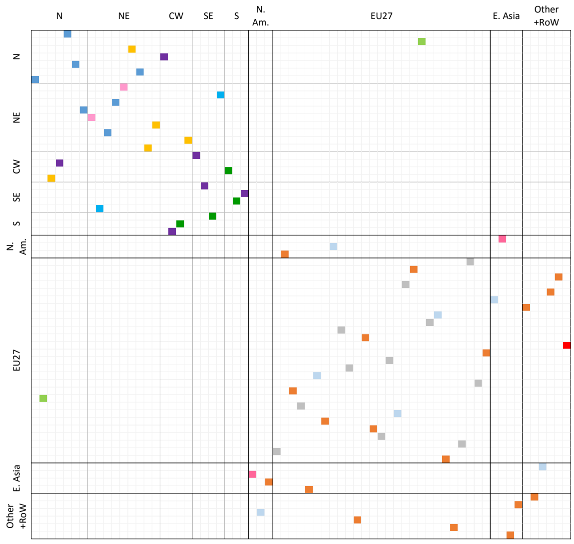
The fifth complete feedback loop still presents a supply chain network that is geographically concentrated within blocks of countries: it includes the flow-intensive subloops of (USA MEX) and (DEU GBR ESP FRA), besides the chain of value-added flows going through Korea, China, and Japan in the dominant subloop. We do not observe such a clear spatial pattern for supply chain networks in the sixth loop. Although these loops still present many links between countries within the EU27, the major economies in the block also connect to countries outside the block (e.g. Germany is linked to China in the sixth and seventh loops, Great Britain is connected to the USA in the seventh and eighth loops, and France links with the USA in the ninth and tenth loops).

As for the Brazilian states, with the exception of minor flows involving small EU27 countries, they continue being linked exclusively among themselves in the loops depicted in Figure 3.5. In fact, it is only in the 13th feedback loop that an expressive supply chain flow takes place between a Brazilian state and a foreign country (with flows of value added from Espírito Santo to Indonesia's value chains). Within Brazil, we observe that the subloops increasingly spread out geographically, depicting supply networks across great regions. In each of the loops, the dominant subloop is centered on São Paulo.

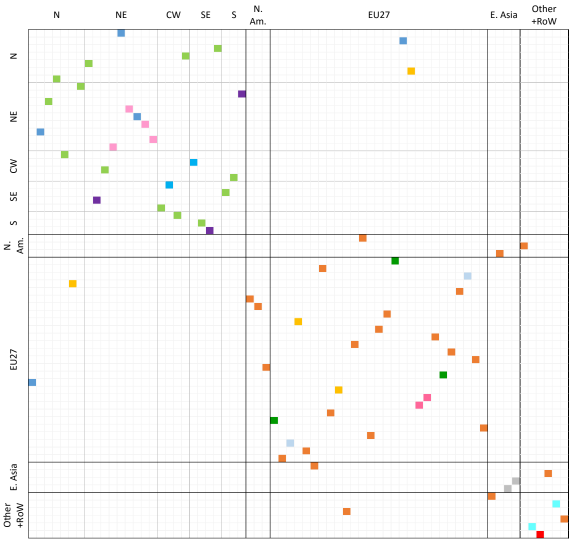
Accordingly, Table 3.4 presents the pairwise interactions of São Paulo's supply chains, sorted in decreasing order of the bilateral flow's intensity. The fact that the hierarchy of feedback loops reflects the rank-size of São Paulo's links with the other Brazilian states is evidence of the polarizing role of São Paulo in production fragmentation within Brazil. On the other hand, we observe this does not hold for São Paulo's foreign supply chain interactions. The pairwise interaction with the composite region RoW, which bilateral flow intensity is smaller only than the intra-regional flow intensity for São Paulo, is depicted quite late, in the 21st and 28th feedback loops (value-added flows going from São Paulo to RoW's value chains, and the other way around, respectively). This shows that even though production sharing with foreign countries is important for the state itself, at global level, its supply chain flows are relatively small.



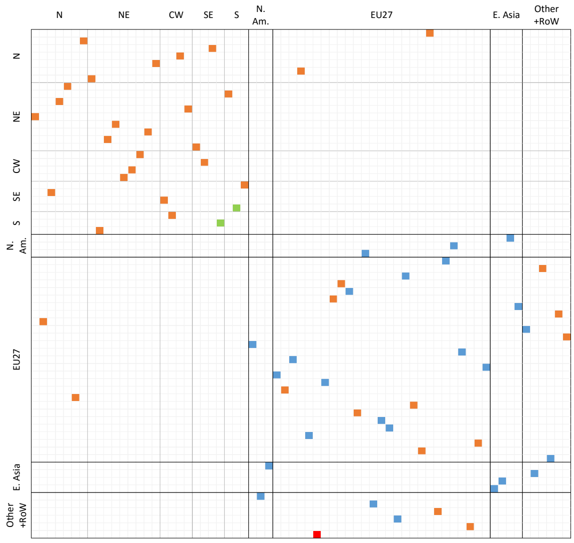
5th feedback loop



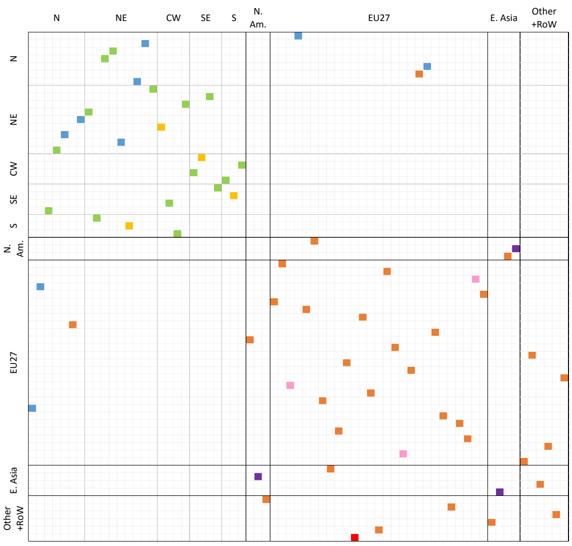
6th feedback loop



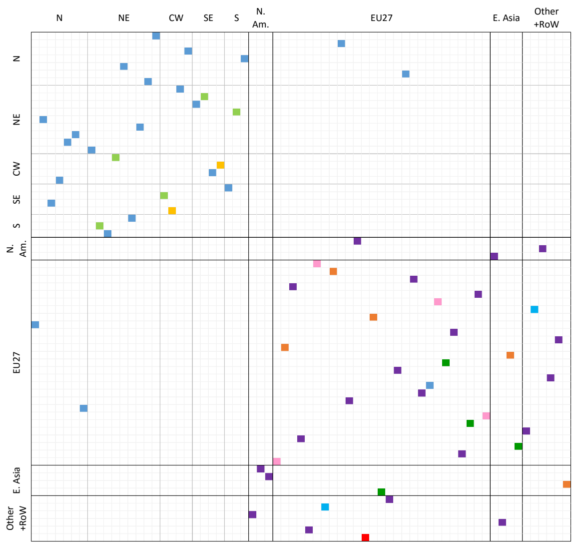
7th feedback loop



8th feedback loop



9th feedback loop



10th feedback loop

Figure 3.6 – 5th to 10th aggregate feedback loop

Note: the red cell indicates the largest flow in the loop; orange cells, the dominant subloop. Different colours indicate different subloops.

Table 3.4 – Pairwise interactions of São Paulo's supply chains

Rank	Partial permutations	Aggregate flow	Place in hierarchy	Rank	Partial permutations	Aggregate flow	Place in hierarchy
1	(SP)	393,148	1	35	(SP SE)	1,162	26 / 19
2	(SP RoW)	29,100	28 / 21	36	(SP RO)	1,136	20 / 24
3	(SP RJ)	20,484	3 / 2	37	(SP PB)	972	21 / 38
4	(SP MG)	19,846	2 / 3	38	(SP AL)	943	25 / 29
5	(SP PR)	14,246	5 / 4	39	(SP IND)	906	43 / 40
6	(SP RS)	14,164	4 / 5	40	(SP FIN)	880	53 / 28
7	(SP USA)	11,689	22 / 23	41	(SP PI)	830	24 / 44
8	(SP BA)	8,950	6	42	(SP AUS)	767	47 / 42
9	(SP DEU)	8,367	30 / 31	43	(SP TWN)	762	51 / 25
10	(SP CHN)	8,015	27 / 26	44	(SP TO)	736	35 / 41
11	(SP SC)	7,667	8	45	(SP AUT)	709	45 / 46
12	(SP AM)	6,954	9 / 7	46	(SP PRT)	686	44 / 47
13	(SP GO)	5,789	10	47	(SP IDN)	585	52 / 45
14	(SP DF)	5,275	7 / 20	48	(SP DNK)	569	46 / 51
15	(SP ES)	4,338	16 / 9	49	(SP POL)	500	50 / 49
16	(SP MT)	3,968	11	50	(SP TUR)	405	49 / 55
17	(SP FRA)	3,365	31 / 30	51	(SP IRL)	296	54 / 53
18	(SP ITA)	3,311	33	52	(SP AC)	295	42 / 48
19	(SP PE)	3,242	12 / 13	53	(SP AP)	275	40 / 50
20	(SP JPN)	3,005	32 / 22	54	(SP CZE)	272	56 / 54
21	(SP CAN)	2,766	37 / 15	55	(SP GRC)	252	59 / 55
22	(SP GBR)	2,761	34 / 32	56	(SP HUN)	192	57 / 58
23	(SP MS)	2,738	13 / 12	57	(SP ROM)	184	58 / 60
24	(SP PA)	2,478	15 / 16	58	(SP RR)	172	48 / 52
25	(SP CE)	2,446	14 / 17	59	(SP SVK)	102	63
26	(SP SWE)	2,206	18 / 39	60	(SP SVN)	90	61 / 67
27	(SP NLD)	2,180	29 / 34	61	(SP LUX)	75	66 / 65
28	(SP MA)	1,817	19 / 14	62	(SP BGR)	69	67 / 64
29	(SP RUS)	1,631	41 / 35	63	(SP LTU)	32	64 / 66
30	(SP ESP)	1,569	36 / 37	64	(SP CYP)	31	62 / 57
31	(SP MEX)	1,560	17 / 43	65	(SP EST)	27	65 / 61
32	(SP BEL)	1,392	38 / 36	66	(SP LVA)	21	60 / 62
33	(SP RN)	1,384	23 / 18	67	(SP MLT)	14	59 / 56
34	(SP KOR)	1,336	39 / 27				

In summary, the top ten feedback loops reveal a spatial structure for the global supply chains' networks where the flows linking major economies across trade blocks are dominant. The fact that the supply chains are well-defined within trade blocks is only secondary to this structure. Combined with the results for supply chain interdependency for individual countries (see subsection 3.3.1), we observe that production fragmentation is truly global and not merely circumscribed to trade blocks.

Therefore, our findings agree with the results of Los *et al* (2014) but seem to be at odds with those of Baldwin and Lopez-Gonzalez (2014) and Johnson and Noguera (2012b). We find no evidence for the statement of Baldwin and Lopez-Gonzalez (p. 37, 2014) that, "international supply chains are mostly regional. Most supply-chain trade happens within what have been called Factory Asia, Factory Europe and Factory America". In fact, less than one-fourth of the supply chain's international value-added flows take place within these blocks (4%, 16%, and 4% of the world total, respectively, within East Asia, the EU27, and the NAFTA block).

What may explain the divergence in the studies' conclusions? As indicated by Los *et al* (2014), even though the findings of Baldwin and Lopez-Gonzalez (2014) are also based on the WIOD data, there is a crucial difference in that they focus on an analysis of trade in intermediates rather than in value added, as Los *et al* (2014) and we do. The literature indicates that gross trade analysis suffers from double counting problems (e.g. Koopman *et al*, 2014), as the gross value of products in the downstream stages of production also includes the value added from upstream activities. For the analysis of the spatial structure of value chains, it is crucial to note that if trading within a trade block is more concentrated in downstream intermediates than trading outside the block, within-block trade will be overestimated (in comparison with outside-block trade). We indicate this also affects the findings of Johnson and Noguera (2012b) for the ratio of value-added exports to gross exports (i.e. the VAX ratio). With an overestimated denominator, logically, the VAX ratio among partners within blocks will be undervalued; interpreting this indicator may then lead to an overstatement of production sharing within trade blocks.

As for the spatial structure of supply chains' networks within Brazil, the main feature is the dominance of the Southeast region's states, especially São Paulo. That is, not only do these states wield major weight as suppliers of intermediates to other regions' value chains (as seen in subsection 3.3.1), but in absolute terms, they also play a central role in Brazilian value chains. Fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadow production sharing with neighbouring states. Focusing on supply chain interdependency and applying the hierarchical feedback loop methodology, our findings concerning the spatial structure of Brazilian states' interdependency are in line with those of other studies analyzing interregional linkages in the country, such as Perobelli *et al* (2006).[36]

[36] Perobelli *et al* (2006) evaluate the interregional linkages based on an IO table for Brazilian regions, for the year 1996, applying the extraction method by Dietzenbacher *et al* (2003).

3.3.3 Sectoral feedback loop hierarchy

Alongside interregional linkages, we analyze the GVC's intersectoral dependencies by applying the hierarchical feedback loop procedure at the sectoral level, as in subsection 3.2.3. Here, we focus on the main links of the USA, China, and Germany (countries with the largest supply chain flows in the world) alongside that of São Paulo (dominant in the Brazilian supply chain network). Because of computational limitations, the 28 industries in our model are aggregated into seven composite industries, as indicated in Appendix A.3.

Figure 3.7 presents the first intra/intersectoral transactions loop nested within the USA's supply chain links in the top ten aggregate feedback loops. Focusing on the first intra/intersectoral loop, we intend to identify the predominant industries (in terms of flow intensity) in the USA's foreign links in supply chain networks. We observe that USA's participation in major foreign value chains takes place predominantly by the (direct and indirect) generation of value added in the services industry for the final output of the service industry's value chains or the manufacturing industry's value chains (in the case of China). The value added of upstream manufacturing activities is secondary, except for the USA's participation in Mexico's manufacturing value chains. The value added from the USA's agriculture industry is revealed to be relevant for East Asia's final production in the agribusiness sector.

The primary importance of the service industry's upstream activities and the secondary importance of upstream manufacturing activities are also observed for foreign countries contributing to the USA's value chains. However, among the USA's macro-level links presented in Figure 3.7, the participation of RoW and the other NAFTA countries show quite different sectoral patterns, as a great weight corresponds to the value added by upstream mining activities in the USA's final production in the manufacturing sector.

China's participation in foreign value chains takes place predominantly by means of the value added generated in upstream manufacturing activities within all the macro-level links presented in Figure 3.8. Conversely, the value added by the manufacturing industry in foreign countries plays a significant role in China's value chains. The exceptions are RoW, Australia, Russia, and Canada, wherein mining activities outperform other activities as sources of value added for China's final production in the manufacturing sector.

Nested within the major macro-level loops, Germany's value-added flows are predominantly intra-sectoral (i.e. originating from an industry in Germany and contributing to the value chain of the corresponding industry in another country), as illustrated in Figure 3.9. In this aspect, the contribution of Germany's manufacturing activities to the GVCs is outstanding. Similar to China, the participation of foreign countries in Germany's value chains takes place mainly by means of value added by upstream manufacturing activities (except in the case of Russia and RoW, where upstream mining activities are predominant).

Finally, Figure 3.10 presents the main intra/intersectoral transactions loop nested within São Paulo's supply chain links in the major aggregate feedback loops. We observe that most of São Paulo's value added incorporated in the final production of other states or countries is generated in its upstream activities in the manufacturing or services industries. On the other hand, the participation of other Brazilian states in São Paulo's value chains is highly diversified at the sectoral level. The major value-added flows for São Paulo's final production may be generated in upstream mining activities (Rio de Janeiro and also the composite foreign region, RoW), the metallurgy industry (the other states in the Southeast region, Minas Gerais and Espírito Santo), agriculture (states in the South region and Goiás), or manufacturing activities (Bahia and Amazonas, as well as the USA, China, and Germany).

Even though it is not our intent to investigate the factors generating regional interdependency, these results elucidate the nature of interregional trade for Brazil's main manufacturing core, São Paulo. We observe that this state's final production mainly affects agricultural activities in the South region and Goiás, which can be interpreted in terms of the core–periphery model. Concerning the other main state partners, supply chain trade seems to be primarily based not only on comparative advantages that originated from deliberate policies (the Camaçari Petrochemical Complex in Bahia and the Free Trade Zone of Manaus in Amazonas) but also from natural endowments (mineral resources in Minas Gerais and Espírito Santo and oil explorations in Rio de Janeiro).

These results also shed light on the limited integration of other states in Brazil's value chains, especially those which comparative advantages are related to natural resources with restricted mobility. This is the case for Pará, a state located in the North region, for which the important production of mineral and metallurgical intermediates is integrated mostly in foreign value chains. Pará's link as a supplier of inputs to São Paulo's value chains is depicted only in the

16th complete feedback loop (ordered by the rank-size of the intensity of global flows). Attention must be paid to the cost of transportation, which, being a service link, is a fundamental force in the fragmentation paradigm (as seen in subsection 3.1.1). As indicated by Vassallo (2015), in the presence of heterogeneous spatial distribution of production activities and comparative advantages, the transportation cost acts as an impedance factor, limiting interregional trade and reducing its potential welfare benefits. In fact, using a computable general equilibrium application for the Brazilian states, the author observed that reducing costs of rail transportation from Pará to the Southeast region has a relevant positive effect on this state's value added. Pará's interregional trade, notably its provision of iron ore to metallurgic plants in Minas Gerais and automotive industries in São Paulo (as opposed to the prevailing exports), is greatly encouraged by lower transportation costs.

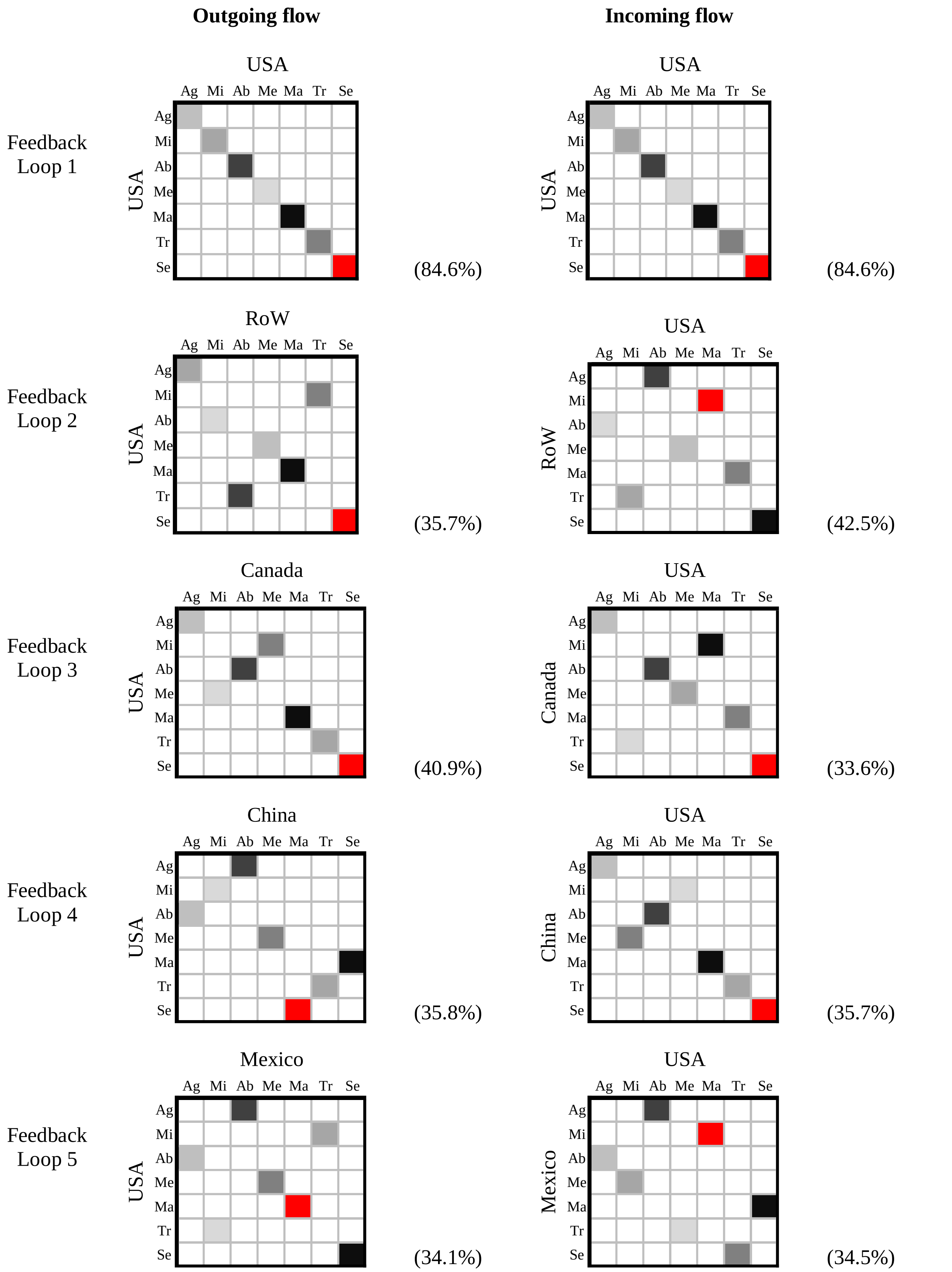


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Figure 3.7 – First intra / intersectoral transactions loop within USA's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

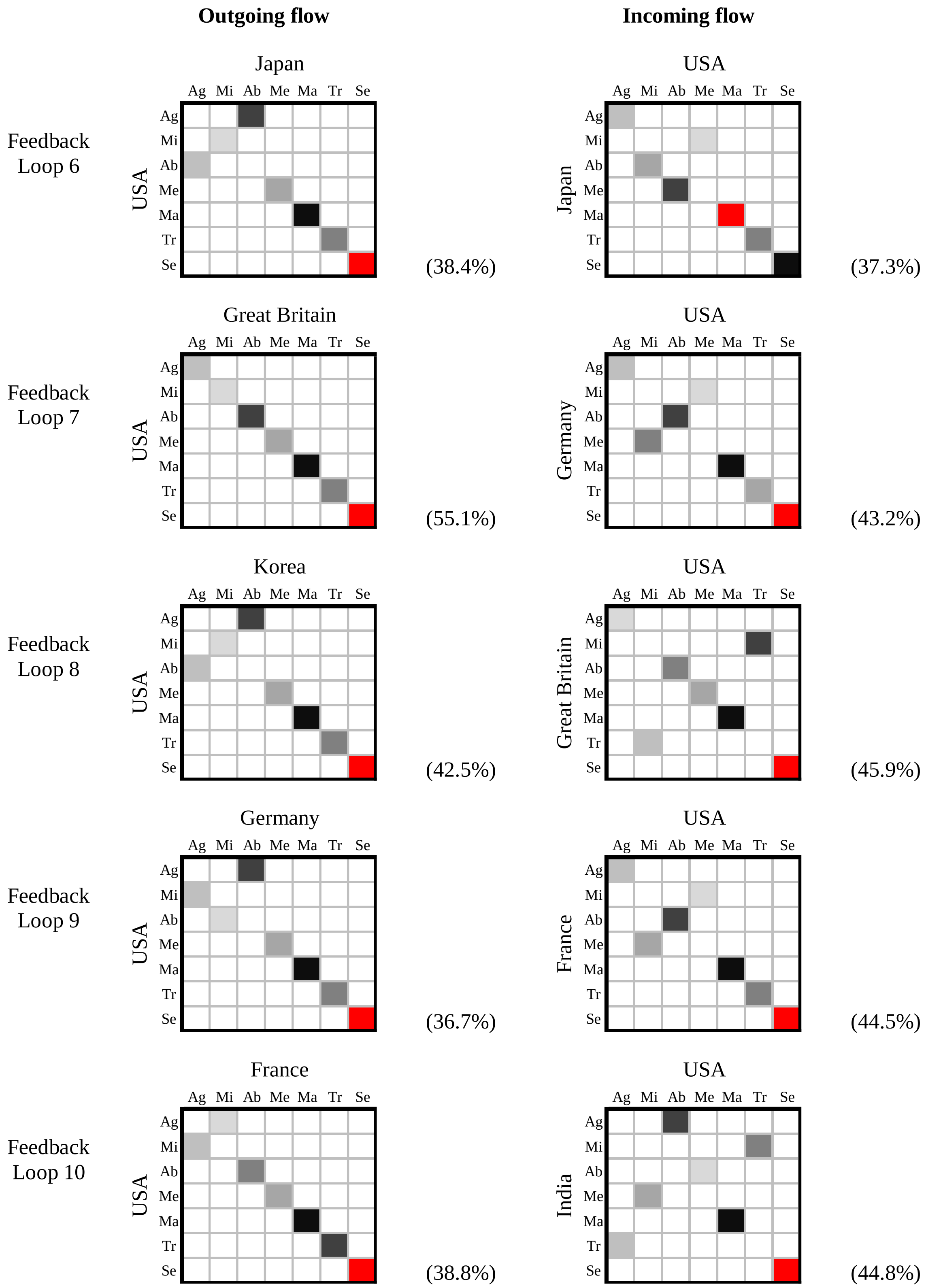

Figure 3.7 (continued) – First intra / intersectoral transactions loop within USA's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

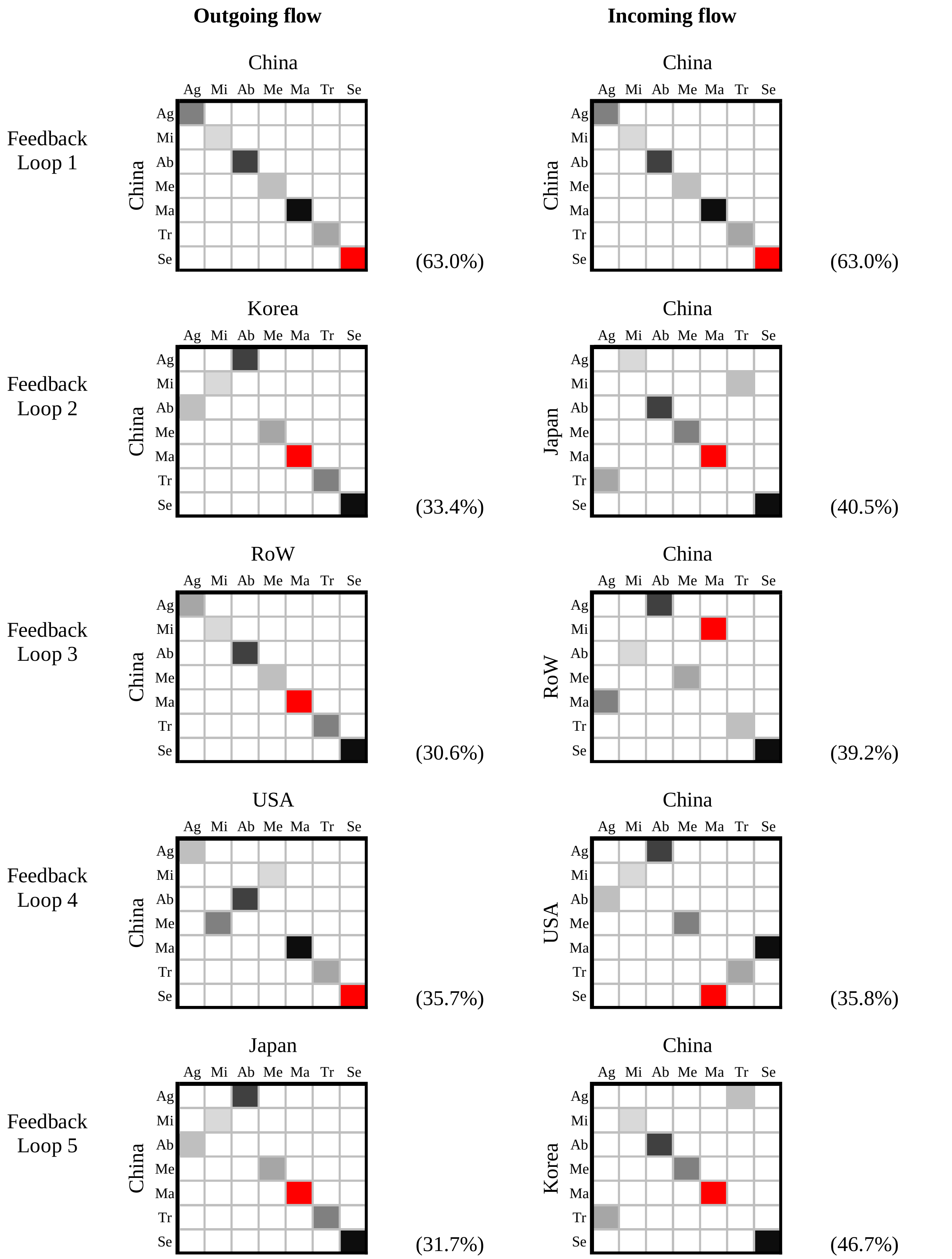

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Figure 3.8 – First intra / intersectoral transactions loop within China's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

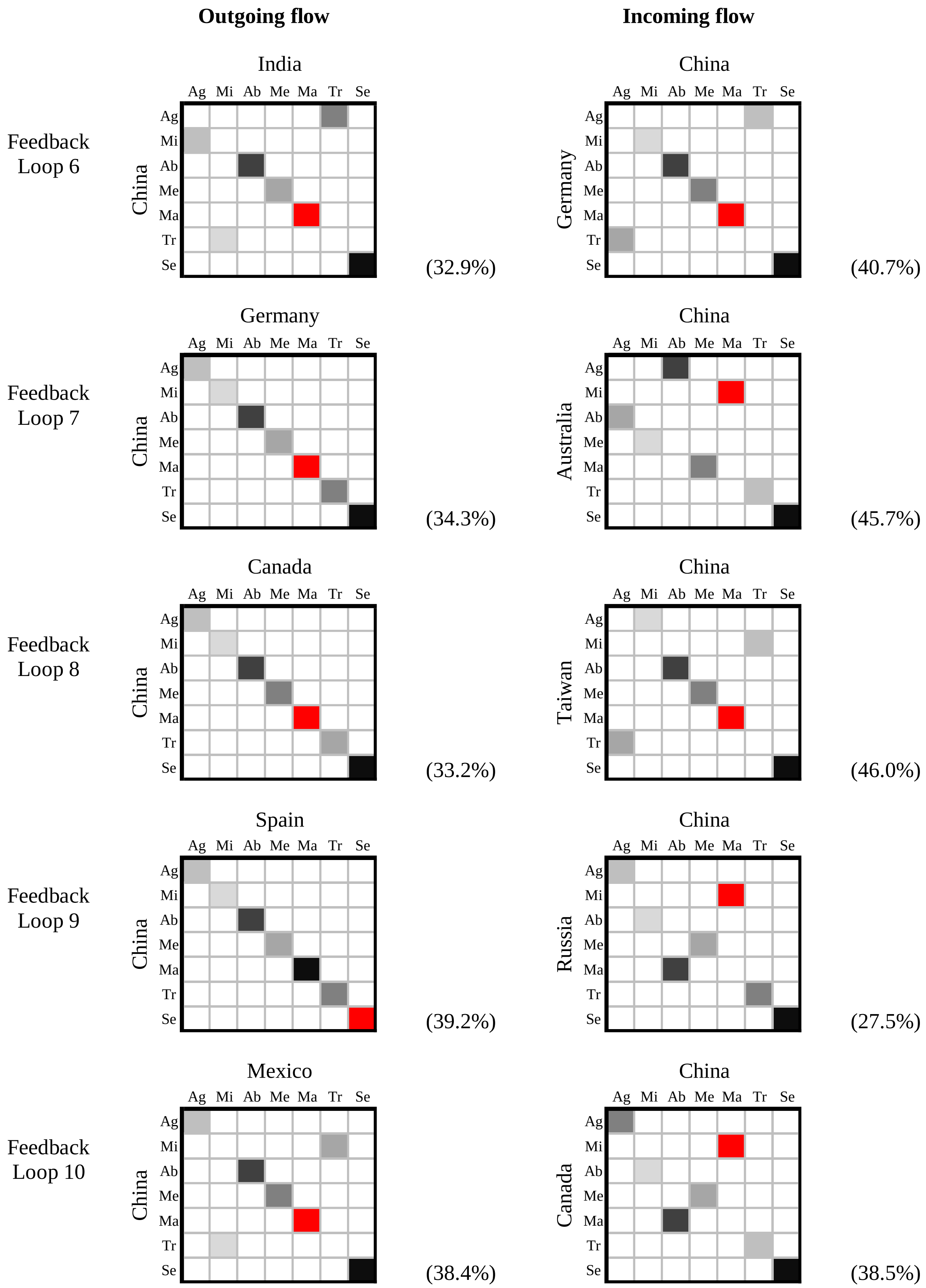

Figure 3.8 (continued) – First intra / intersectoral transactions loop within China's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

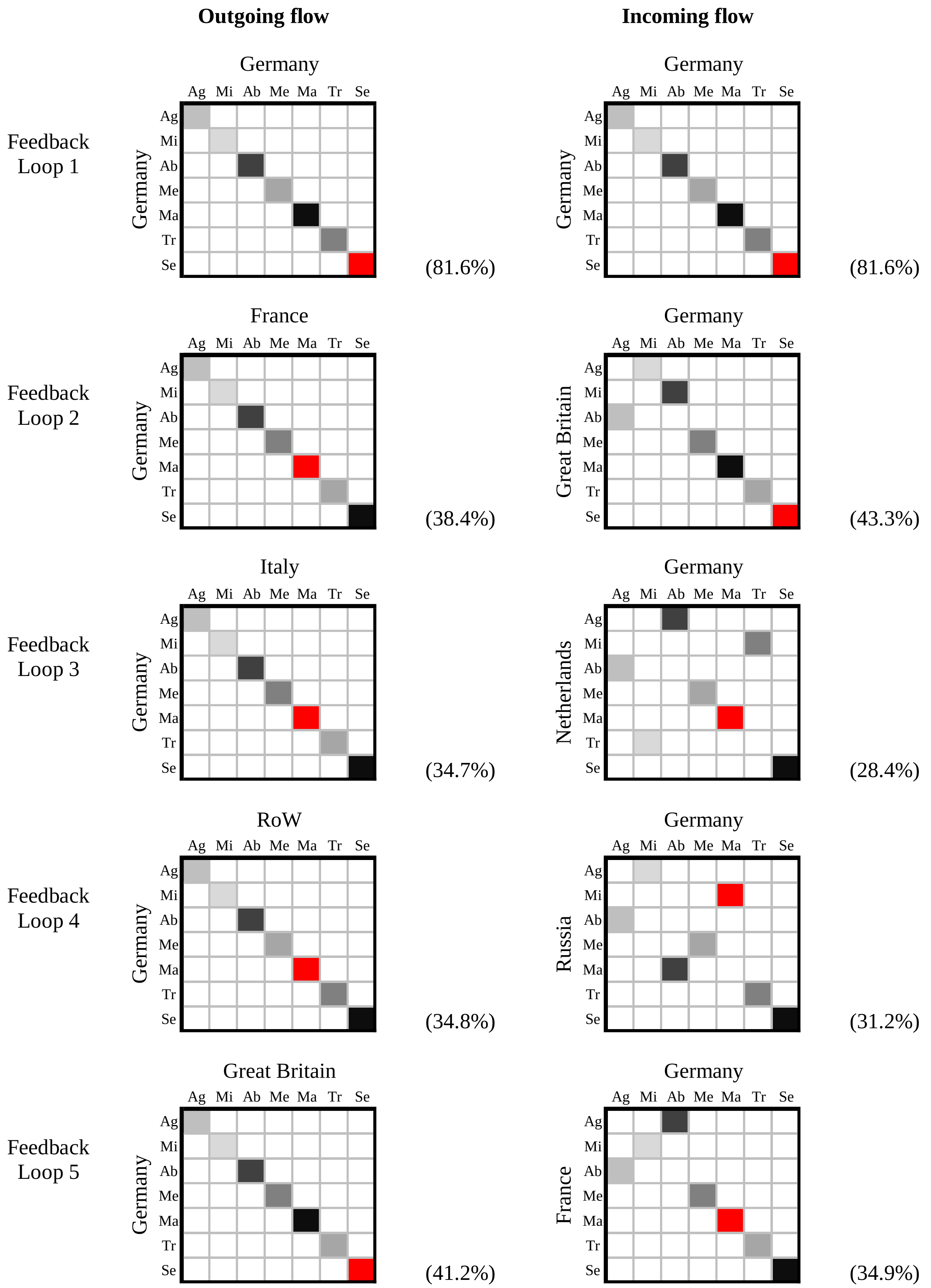

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Figure 3.9 – First intra / intersectoral transactions loop within Germany's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

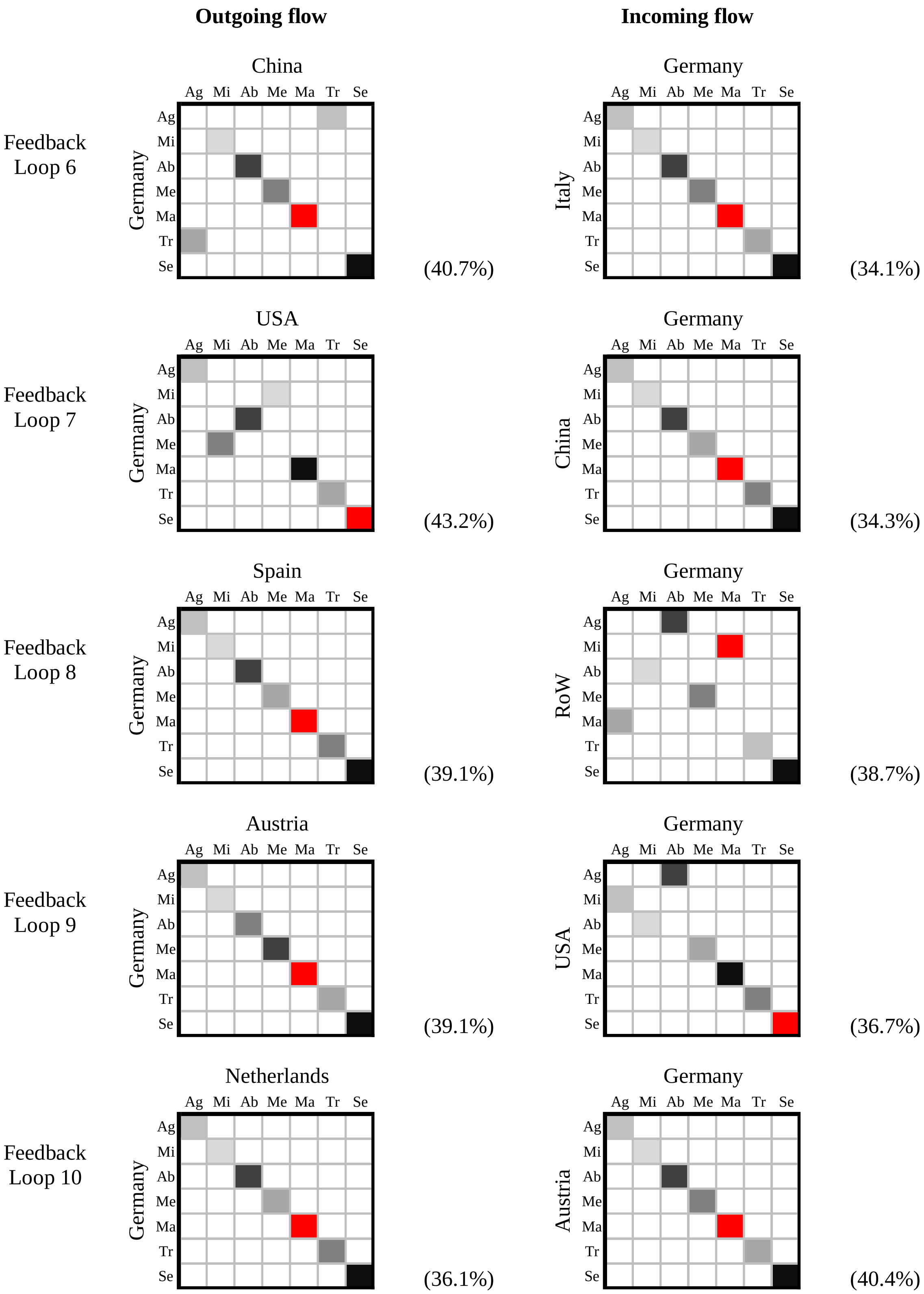

Figure 3.9 (continued) – First intra / intersectoral transactions loop within Germany's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

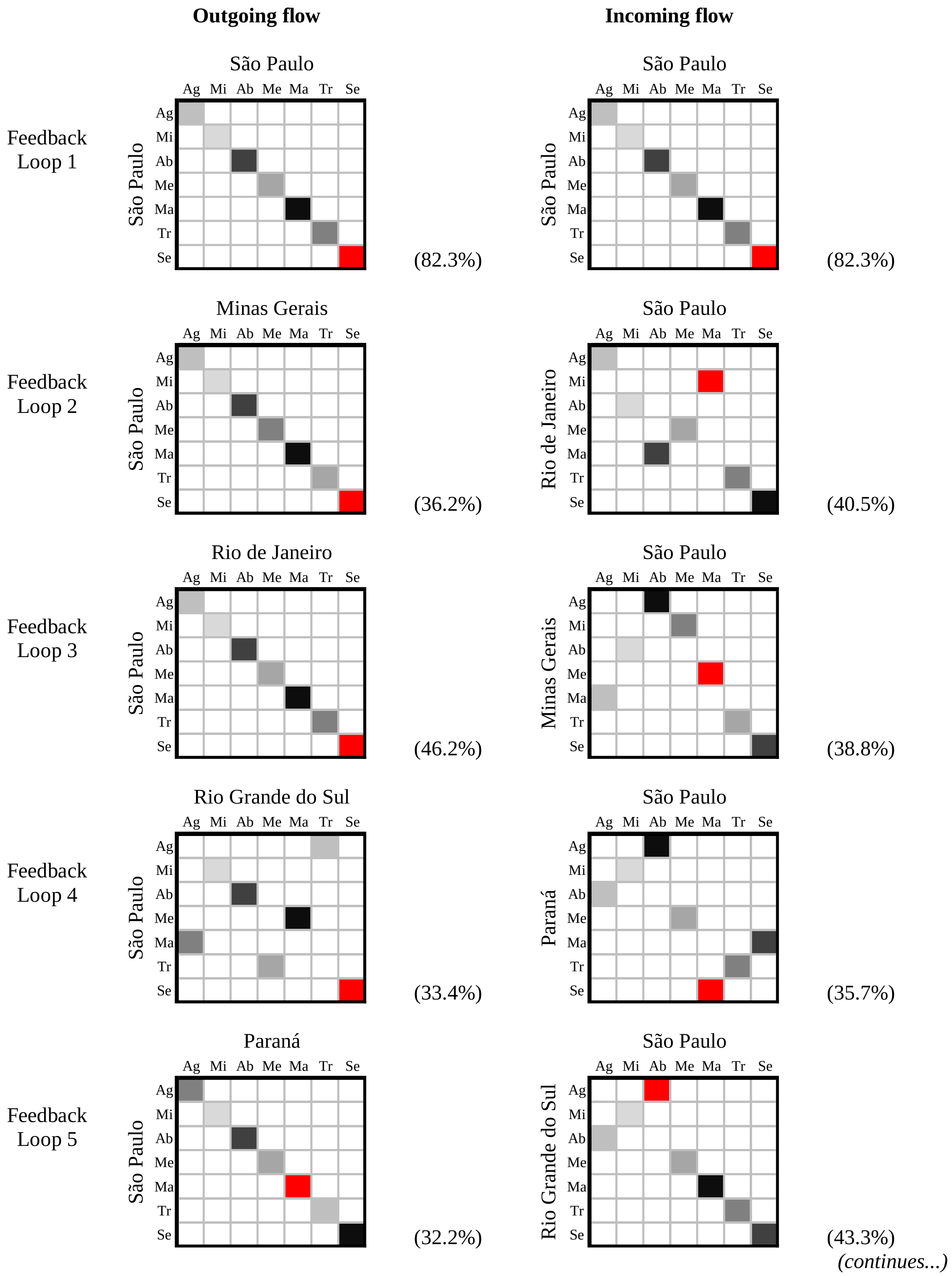

Figure 3.10 – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

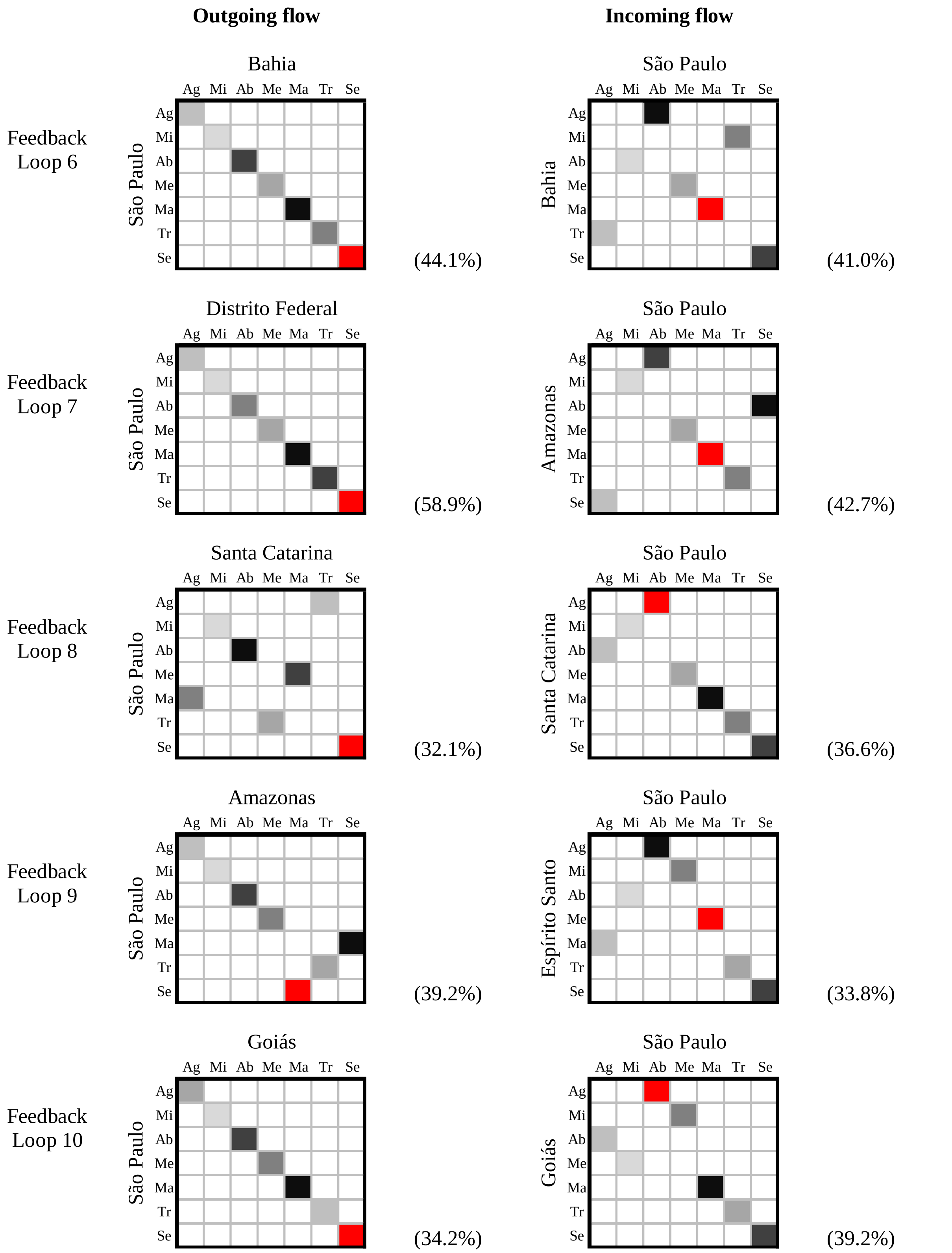

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Figure 3.10 (continued) – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

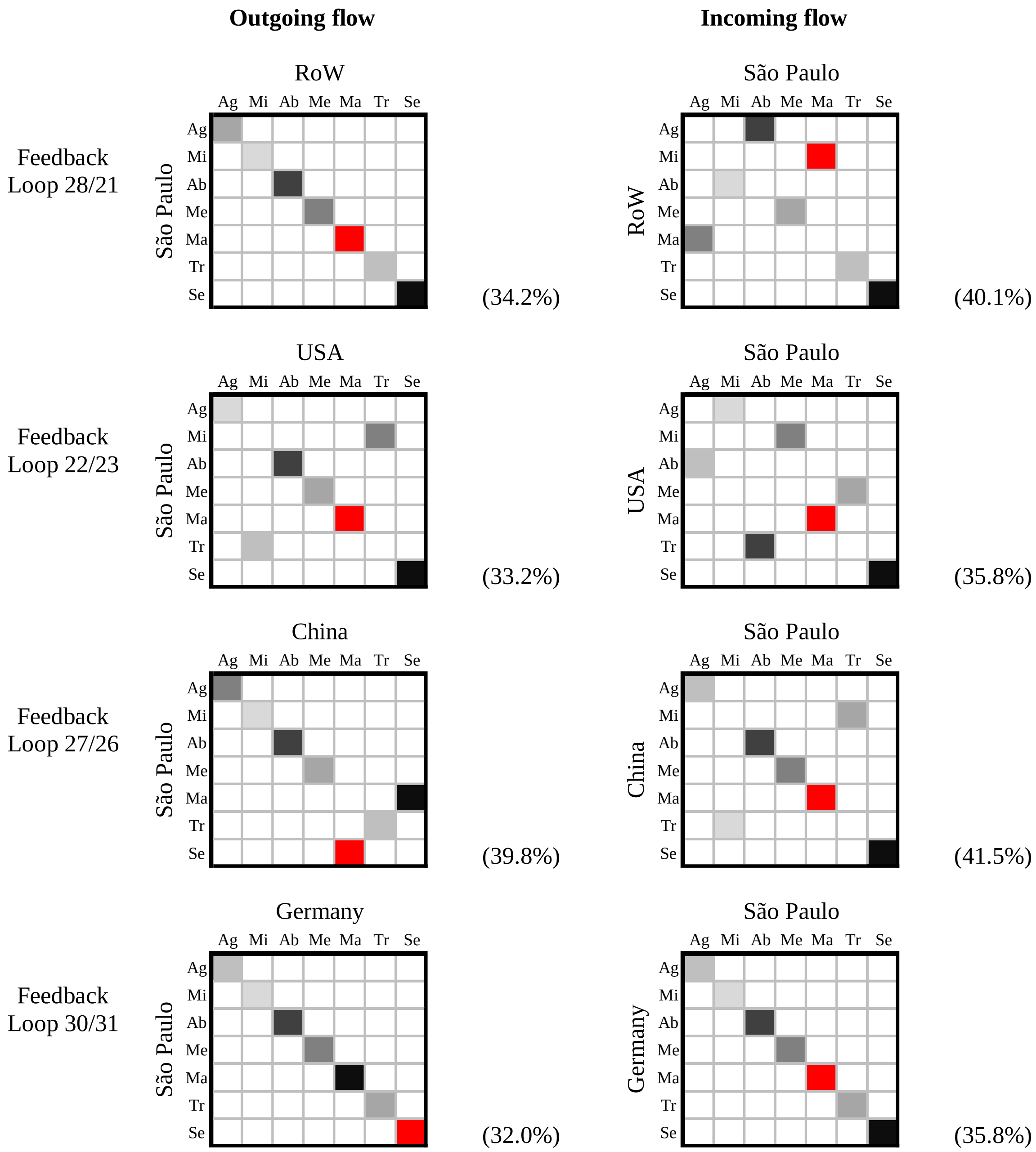

Figure 3.10 (continued) – First intra / intersectoral transactions loop within São Paulo's link in major aggregate feedback loops

Note: the composite industries are Agriculture (Ag), Mining (Mi), Agribusiness (Ab), Metallurgy (Me), Others Manufacturing (Ma), Transports (Tr), and Services (Se). The largest flow is depicted in red; the others are in increasingly lighter shades of gray. The percentage in parenthesis is the share of the link's intensity flow that is comprehended in the depicted first intra / intersectoral transactions loop.

3.4 Concluding remarks

The fragmentation of production processes has induced great changes in the spatial location and organization of economic activity. In this paper, we analyzed the geographical structure of the GVCs' flows using the hierarchical feedback loop methodology. In contrast to other studies that employed this methodology previously, we considered the regional interdependencies as depicted in a country–state IO table comprising the global production system. Our application also differs as we consider value-added flows involved in the supply chains, rather than interregional gross trade.

At the global level, our analysis primarily reveals the spatial structure of the global supply chains' networks, where flows linking major economies across trade blocks are dominant. In fact, more than 75% of the supply chains' international value-added flows link countries in different trade blocks. The fact that supply chains are well defined within blocks is only secondary to this structure. On average, within-block production fragmentation is more intense for countries in the EU27 than in the NAFTA block or East Asia. In the EU27 block, 8.1% of the total output of the average value chain corresponds to value added produced by the other block members. In the NAFTA block and East Asia, only 2.3% and 3.3% respectively of the final output comprises within-block foreign value added. Thus, our results indicate that production fragmentation is a truly global phenomenon and is not merely circumscribed to trade blocks.

For Brazil as a whole, we observed that the country's value chains are mostly self-sufficient in intermediates. Moreover, even for the states where production sharing with foreign countries is relevant, such as Amazonas, Paraná, and São Paulo, at the global level their supply chain flows are relatively small. On the other hand, there is a great degree of fragmentation among Brazilian states. About 15% of the final output in the average value chain corresponds to value-added from another state. This is larger than the share observed for the EU27, indicating even tighter production sharing relationships in Brazilian production networks.

The main feature regarding the spatial structure of supply chains' networks within Brazil is the dominance of the Southeast region's states, especially São Paulo. Not only do these states count as major suppliers of intermediates to other regions' value chains, but in absolute terms (as indicated by the feedback loop analysis) too, they play a central role in Brazilian value chains. Fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadow production sharing with neighbouring states.

Finally, the application of the feedback loop approach at the sectoral level revealed the nature of the interregional dependencies. For São Paulo's value chains, we observed that the state's final production mainly affects agricultural activities in the South region. For the other main state partners, supply chain trade seems primarily based on comparative advantages mostly derived from mineral natural endowments alongside deliberate policies directed at manufacturing centres elsewhere in the country.

Our results focus on the production systems in the year 2008. At the global level, we may wonder about the effects of the financial crisis on the fragmentation of value chains. The aforementioned study of Los *et al* (2014), which uses the WIOD tables for 1995 to 2011, indicates that the steady increases in international fragmentation continued until the onset of the crisis in 2008. The crisis induced a major dip in the participation of foreign value added in final product outputs in 2009, but this appeared to be a short-run effect for virtually all chains. With regard to the effects of the crisis on the geography of value chains, the authors observe that it seems to have propelled the trend toward truly global fragmentation. Contrary to regional fragmentation, global fragmentation of value chains picked up immediately after the crisis and reached the precrisis level again in 2011. China appears to have played an important role in the global relocation of activities in this movement.

It seems unlikely that major changes took place in the spatial organization of value chains within Brazil after 2008. According to the Regional Accounts (IBGE, 2014), between 2008 and 2012, the Southeast and South regions' share in the national value added decreased in favour of other regions, especially the Central-West region. However, this relocation involved only 1% of the country's value added. In fact, the geography of production within Brazil has remained quite similar over the years. For example, Perobelli *et al* (2006) evaluate the interregional linkages based on an IO table for the year 1996 and obtain results similar to ours, indicating the dominance of São Paulo in the Brazilian production structure and the low level of within-region interdependency of the states in the North, Northeast and Central-West regions. These results provide significant pointers in the design of regional development policies. For example, our results indicate that the installation of a manufacturing plant in a state located in the Northeast region, on average, will not impact the value adding activities of its neighbouring states as much as it will impact the developed Southeast region.

The generating factors must be evaluated in the design of eventual policies intending to change the configuration of regional interdependencies. Although, this is not our focus in this paper, our observations of the global fragmentation process show that the lowered costs of service links activities, which brought about profound changes in the spatial structure of economic activities worldwide, may also lead to spatial reorganization within Brazil (with limitations, of course, as many activities cannot be relocated at the regional level). In this regard, investments in transportation infrastructure, which serve to reduce distances across regions (HADDAD, 2004), deserve special attention in development policies.

4 TRACING BRAZILIAN STATES’ CO_2 EMISSIONS IN DOMESTIC AND GLOBAL TRADE

4.1 Introduction

The Brazilian position on climate change was formalized by the National Climate Change Policy (PNMC, in Portuguese – Law nº 12 187, dated December 29, 2009), which provides a legal framework for national actions aimed at mitigation and adaptation. The PNMC defines the country’s national voluntary reduction targets for greenhouse gas (GHG) emissions advancing the policy from merely programmatic (LUCON; GOLDEMBERG, 2010) to a legal commitment with clear environmental objectives that should guide subsequent policymaking. The reduction targets were defined as between 36.1% and 38.9% of projected emissions by 2020. Seroa da Motta (2011) indicated that sectoral mitigation percentages were adopted in the correspondence from Brazil for the Copenhagen Accord in 2010: of the 38.9% national target, deforestation would be responsible for 24.7%, and the remaining 15.2% would be allocated to energy use (7.7%), agriculture and cattle raising (6.1%), and other sectors (0.4%).

Minimal focus is on the distribution of the corresponding mitigation efforts by regions. This is of great concern in a large country such as Brazil with substantial regional variation in economic development, physical geography, production systems, and energy consumption. Brazil’s 1988 Constitution divides the responsibilities for environmental policies and legislation among the three levels of government (PUPPIM DE OLIVEIRA, 2009), and most Brazilian states have established public policies on climate change. According to NESA-USP, as of September 2015, of the 27 states, 16 have established policies and four are underway having initiated draft legislation; three others have implemented local forums to discuss climate change at the state level. Only Roraima in the North region, and Alagoas, Rio Grande do Norte, and Sergipe in the Northeast region do not have climate change forums. Figure 4.1 shows the configuration of climate policies in Brazilian states as of September 2015.

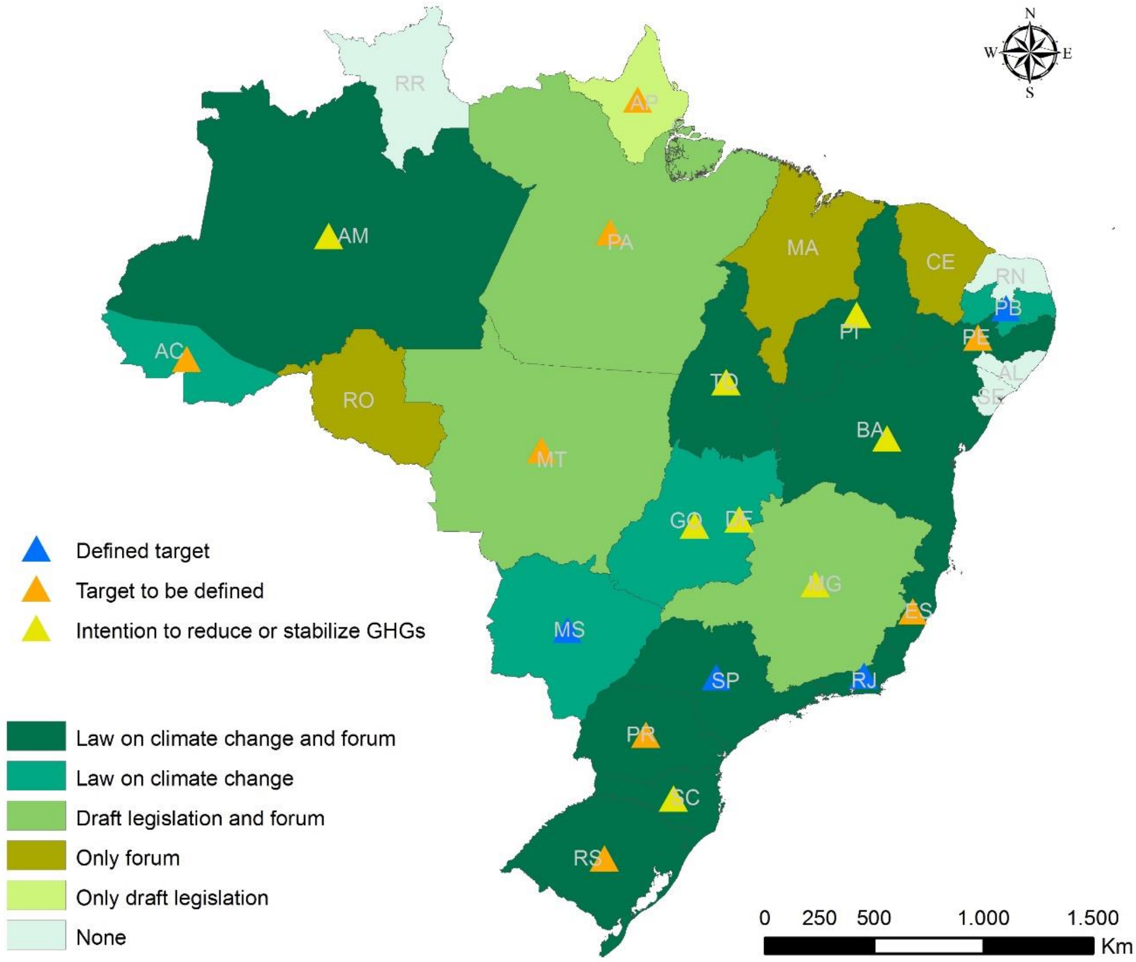

Figure 4.1 – Brazilian states' climate change policies, September 2015
Source: NESA (2015). Prepared by the author.

Four states have mandatory targets for reducing GHG emissions: São Paulo and Rio de Janeiro in the most developed Southeast region; Mato Grosso do Sul in the Central-West region, and Paraíba, in the Northeast region. There are also advancements in municipal climate change policies. The two most populous cities in Brazil, São Paulo and Rio de Janeiro, have established mandatory targets. The chart below summarizes the targets established by federal, state, and municipal laws related to climate change.

Chart 4.1 – Subnational policies with mandatory targets for reducing greenhouse gas emissions

Government level	Policy	Law	Targets	Baseline
Federal	National Policy on Climate Change	nº 12 187 / 2009	36.1% and 38.9%	Projected emissions by 2020
State	State Policy on Climate Change of São Paulo	nº 13 798 / 2009	20% by 2020	Based on the inventory of 2005
	State Policy on Climate Change of Rio de Janeiro	Decreto nº 43 216 / 2011	Reducing emissions intensity (tCO2e / GDP) by 2030	Based on the inventory of 2005
	State Policy on Climate Change of Paraíba	nº 9 336 / 2011	36.1% and 38.9%	Projected emissions by 2020
	State Policy on Climate Change of Mato Grosso do Sul	nº 4.555 / 2014	20% by 2020	Based on the inventory 2005
Municipal	Municipal Policy on Climate Change of São Paulo	nº 14 933 / 2009	30% by 2012	Based on the inventory of 2005
	Municipal Policy on Climate Change of Rio de Janeiro	nº 5.248 / 2011	8% by 2012, 16% by 2016, 20% by 2020	Based on the inventory of 2005

Source: Romeiro; Parente (2011); NESA (2015). Prepared by the author.

The chart shows that the mitigation targets for Brazil's subnational climate change policies differ significantly. This is not a problem in itself and can be echoing the principle of "common but differentiated responsibilities" professed by PNMC at the international level. However, there is no coordination concerning the measurement basis (absolute values or intensities in the case of Rio de Janeiro), and there are incompatibilities in the baselines (different years of reference based on inventories or projected emissions). At the sectoral level, only Rio de Janeiro has stated specific targets.

These characteristics reflect that the subnational policy elaboration processes, which have autonomously emerged, are detached from one other. The incongruity between the targets is problematic for economic agents because the implications of national, state, and municipal policies are unclear (FORUM CLIMA, 2012). Thus, although the subnational policies indicate advances toward a less intensive effect on climate change, the regulatory aspects require improvement. Romeiro and Parente (2011) stated that the lack of convergence in actions increases the difficulty and reduces the effectiveness of the mitigation measures and the respective monitoring.

This criticism is not exclusive to Brazil but is applied to other countries where subnational climate policies have emerged. Literature concerning these policies has flourished in recent years, and subnational governments have led climate change efforts in many countries such as the USA (LUTSEY; SPERLING, 2008; SCHREURS, 2008). Although there are advantages associated with the engagement of subnational governments in climate change policies – such as greater flexibility in implementing new policies (PUPPIM DE OLIVEIRA, 2009) and efficiency gains from the exploitation of local heterogeneities (SOMANATHAN *et al*, 2014) – most literature agrees that the possibility of coordination and complementarity problems exist and questions institutional capacity to take action on such policies. The Intergovernmental Panel on Climate Change's Fifth Assessment Report states that because there are several limiting factors to widespread reliance on subnational levels of government, "a federal structure that provides coordination and enables an easier transmission of climate policies throughout the agents of the economy is likely to increase the effectiveness of actions against climate change" (SOMANATHAN *et al*, 2014, p. 1183).

The coordination of top-down policies is also fundamental in addressing an important aspect of climate change that has been overlooked by policy settings at all levels, which is the driving force of consumption patterns and, consequently, the relationship between trade and GHG emissions. Human-induced climate change is a global externality from production activities (STERN, 2008), and its assessment must consider the connections between economies as trade links for production and consumption in different regions. Peters *et al* (2011) stated that ignoring these connections might result in a misleading analysis of the underlying driving forces of emission trends and lead to suboptimal mitigation policies.

Hoekstra and Wiedmann (2014) indicated that the Kyoto Protocol is an example of a well-intended but ineffective policy. The Protocol adopts a fragmented, two-tier mitigation strategy; it sets reduction targets per Annex B countries with respect to GHG emissions within the territory while the developing countries do not have emission commitments. In this setting, concern for carbon leakage (i.e., increasing CO_2 emissions in countries outside of the agreement's control) arises.[37] Peters *et al* (2011) found that global CO_2 emissions have grown

[37] According to Peters and Hertwich (2008), increased carbon leakage can be caused by two factors. First, in response to mitigation policy, production migrates in the direction of non-participating countries with lax environmental regulations ("strong carbon leakage"). Second, regardless of climate policies, increased consumption in a participating country is met by increased production in a non-participating country ("weak carbon leakage").

39% from 1990 to 2008. While emissions in developed countries have stabilized, emissions in developing countries have doubled. In the same period, the net emission transfers from non-Annex B to Annex B countries has grown 17% per year on average.[38] While it is not clear if these increasing flows are caused by climate policy itself (i.e., whether they represent "strong carbon leakage" or "weak carbon leakage"), given the dynamics of the world economy, the increasing flows are sufficient to cause substantial concern for the effectiveness of climate regimes with limited participation (PETERS; HERTWICH, 2008).

The current framework of subnational climate policies in Brazil suggests concern for carbon leakage within the country because the interrelationships between the states are disregarded. For example, São Paulo, whose industries present low average emission intensities (as we will see in the following), is one of the few states with established mitigation targets. To meet the commitment, the state could shift emissions to other regions in the country so that national emissions might not reduce or increase with regional leakage. Therefore, assessing the interregional flows of CO_2 emissions within the country is, thus, essential for effective mitigation strategies.

Therefore, the questions raised in the literature concerning the emissions embodied in international trade (e.g., VALE *et al*, 2015; DOUGLAS; NISHIOKA, 2012; WIEBE *et al*, 2012; PETERS *et al*, 2011; DAVIS; CALDEIRA, 2010; NAKANO *et al*, 2010; SERRANO; DIETZENBACHER, 2010; PETERS; HERTWICH, 2009), also apply at the regional level. To add to the understanding of the relationship between subnational regional trade and their emissions, this paper quantifies the CO_2 emissions embodied in Brazilian states' trade. We adopt a forward perspective (MENG *et al*, 2015) in the analysis. That is, we aim to quantify emissions embodied in trade, evaluating the amount of emission generated by a state that is for its own final consumption and the amount of emission generated for consumption by other states and foreign countries.

[38] Peter *et al* (2011) adopted the "emissions embodied in bilateral trade (EEBT)" from Peters (2008) and defined net emission transfers as "CO_2 emissions in each country to produce exported goods and services minus the emissions in other countries to produce imported goods and services." In our paper, we apply a methodology close to Peters' (2008) approach based on a multi-regional input-output analysis (MRIO) and define net emission transfers as CO_2 emissions in each country to produce goods and services that are ultimately consumed abroad minus the emissions in other countries to produce goods and services that are ultimately consumed in the country.

Recognizing the significance of intersectoral linkages is fundamental. Thus, the IO methodology is an appropriate tool to investigate environmental impacts considering the links between the various sectors and regions of an economy. Moreover, given the increasing interconnectedness of domestic and global production processes, CO_2 emissions embodied in trade in the context of GVCs are significant even if the focus is on domestic regions (PEI *et al*, 2015). For Brazil, studies that analyze sectoral GHG emissions at the subnational level have been developed by applying either single-region (e.g., CARVALHO *et al*, 2013) or interregional IO models (e.g., IMORI *et al*, 2015; CASTELANI, 2014; CARVALHO; PEROBELLI, 2009; HILGEMBERG; GUILHOTO, 2006). A frequent concern of these studies, the effect of emissions exports, was addressed by impact analysis of exogenous variations in the final demand vectors. Our study goes further by applying a full country-state IO table to comprehend endogenously the world economy using the 27 Brazilian states as distinct regions. Chapter 2 describes the estimation procedure.

Our approach is comparable to Feng *et al* (2013) and Pei *et al* (2015), who studied the CO_2 emissions embodied in trade for Chinese regions. Feng *et al* (2013) used GTAP-MRIO data and split China into 30 sub-regions (26 provinces and four cities) while Pei *et al* (2015) applied the model developed by Meng *et al* (2013), which used WIOD data and split China into four regions. Both studies found a clear pattern for interregional trade in CO_2 emissions: highly developed coastal regions of China are large net takers of CO_2 emissions from less developed inland regions. Concerning the participation in GVCs, Pei *et al* (2015) observed that the inland regions were indirectly involved in GVCs by providing high carbon intensity inputs to downstream and exporting coastal regions. A central implication from the observed trade pattern is that because China's climate policy seeks to address regional differences by setting higher mitigation targets for coastal regions, this may cause additional outsourcing and carbon leakage in the direction of less developed regions. In our study, we analyze if the interdependence of Brazilian states with respect to CO_2 emissions shows a clear pattern similar to that of Chinese provinces.

A major difficulty for subnational climate change policies in Brazil is the limited published official inventories (although state policies typically urge their formulation). At the state level, to the best of our knowledge, only Espírito Santo, Minas Gerais, Paraná, Rio de Janeiro, and

São Paulo have published comprehensive GHG inventories.[39] Inventory periodicity differs, and the adopted methodologies are not entirely consistent. For example, proposals for accounting for emissions from freight originating in the state with an out-of-state destination are inconsistent (FORUM CLIMA, 2012). To address this problem, we quantify CO_2 emissions in each of the 27 Brazilian states for the year 2008. However, we share the limitation of most of the literature that analyzes the relationship between international trade and GHG emissions: we account for CO_2 emissions only from energy use (fossil fuels combustion).[40]

According to the Ministry of Science, Technology and Innovation (MCTI) (2014), energy use in 2008 accounted for approximately 18% of total GHG emissions in Brazil. However, the climate impact of the energy sector is expected to increase in the coming years. As energy use increases, as indicated by Lucon *et al* (2015), in contrast to many other major emerging economies, Brazil's energy mix is becoming more carbon intensive, not less. Figure 4.2 shows the domestic energy supply from renewable and non-renewable sources (in thousand toe) from 2005 to 2014. Although renewable sources still account for a significant share of the energy mix (39.4% in 2014), it decreased 6.2 pp since 2008. Thus, we observe an increased reliance on fossil fuels in Brazil. Additionally, Lucon *et al* (2015) states that the investments foreseen by the federal government in the Ten-Year Energy Expansion Plan – PDE 2013, with more than 70% of R$1.3 trillion directed to fossil fuels, is likely to lock in Brazilian energy infrastructure toward a long-term carbon-intensive pathway.

[39] Other states have published official inventories that comprehend only some emission sectors, namely, Amazonas (electric power sector) and Bahia (energy sector and industrial processes). Although comprehensive, for the energy sector the inventory of Acre covers only electric power generation and emissions from automobiles.

[40] For example, Douglas and Nishoka (2012), Wiebe *et al* (2012), Davis and Caldeira (2010), and Nakano *et al* (2010) account only for CO_2 emissions from fossil fuel combustion, as is the case in our study. Peters *et al* (2011) also consider CO_2 emissions from cement production and gas flaring. Hertwich and Peters (2009) consider GHGs not including the sources and sinks of land use change, which is the same as the WIOD project. In addition to the absence of data on land use change with the necessary detail, the authors indicate that this source of GHGs presents difficulties in allocating emissions to economic activities.

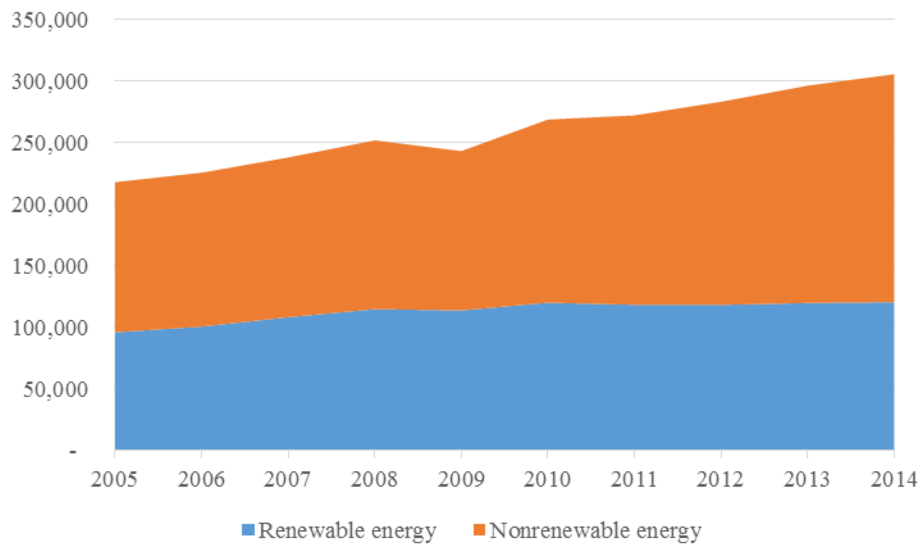

Figure 4.2 – Renewable and nonrenewable sources in domestic energy supply (thousand toe), 2005 to 2014
Source: EPE (2015). Prepared by the author.

Decree nº 7 390, dated December 9, 2010, which regulates PNMC, presents official projections for GHG emissions in Brazil for the year 2020. According to the projections, the GHG emissions from energy use are estimated to be 868,000 Gg in 2020 (about 140% larger than in 2008) amounting to 27% of total projected GHG emissions. Data for recent years show an even more relevant participation of emissions from energy use. In 2012, energy use accounted for approximately 37% of total GHG emissions (MCTI, 2014) given the sharp decline in emissions because of land-use change in the Amazon region since 2009. Given the growing importance of energy use in the Brazilian GHG scenario and the country's central role in global emissions, Brazil's climate impact and the relationship with economic activities are increasingly relevant.

To summarize, the objective of this chapter is to trace CO_2 emissions embodied in Brazilian states' trade both within the country and internationally. The aim is to contribute to climate change policies that account for interrelationships between states in economic and environmental terms. The interrelationships between states are relevant in large and heterogeneous countries such as Brazil, where the regional distributive aspect of mitigation policies is a concern. However, the regional distributive aspects have been neglected by both national policies and subnational climate change policies, and the effectiveness of policies is hampered by deficiencies in top-down coordination.

Recognizing the interconnectedness of domestic and global value chains, we apply a country-state IO table, which explicitly displays the Brazilian states' economic interrelationships and their relations with foreign countries. To extend the model environmentally, we have compiled a novel database reflecting CO_2 emissions from energy use by state and productive industry. This database will be useful subsequently for several applications at the regional level in Brazil for the analysis of various aspects of energy use and CO_2 emissions.

In the empirical analysis, we quantify Brazilian states' trade in CO_2 emissions (i.e., the levels of CO_2 embodied in states' trade). With this, we evaluate the impact of states' interrelationships on CO_2 emissions. Then, we reorganize these results in terms of production-based and consumption-based emissions, which have substantial implications for climate policies. Our analysis does not reveal a clear pattern for CO_2 emissions embodied in states' trade, as we find large variations across trade partners. With the goal of adding to more careful climate policies, we develop our analysis along the following lines. First, we closely examine the flows of trade in CO_2 emissions. Then, we analyze the variations in emission intensities across states. Finally, to illustrate possible climate policy tools, we verify the potential impact of enforcing a "Clean Development Mechanism" among Brazilian states.

Following this introduction, this chapter is organized as follows: section 4.2 presents the methodology used in the empirical analysis and the newly compiled database on energy use and CO_2 emissions for Brazilian states. The results are then analyzed in section 4.3, and the last section presents our concluding remarks.

4.2 Methodology

This section presents our data and our methodological procedure for the empirical analysis. The full country-state IO table that was estimated for the year 2008 is applied following the procedure that was described in Chapter 2.

4.2.1 CO_2 emissions data for Brazilian states

We account for CO_2 emissions from fossil fuels in the economic sectors.[41] Our data also includes the CO_2 emissions that are generated in thermal power plants and from the use of coke in iron and steel mills. Adopting a bottom-up approach, we obtain the levels of CO_2 emissions by industry at the state level in Brazil. For the other countries in our model, we use the CO_2 emissions data from the WIOD project.

First, we depart from the Brazilian Energy Balance (EPE, 2009) and reconcile the data from state energy balances accordingly. For the year 2008, official energy balances are available for the following states: Alagoas, Bahia, Goiás, Minas Gerais, Rio de Janeiro, São Paulo, Paraná, and Rio Grande do Sul. For Ceará and Espírito Santo, we consider participation in the national energy use and sectors' fuel structure from the energy balances of 2007 and 2010, respectively.[42]

Following Montoya *et al* (2014), we reconcile the data on fossil fuel use (in toe) from the energy balances with the industry classification of Brazil's IRIOT. Next, we estimate the corresponding CO_2 emissions by adopting the carbon emission factors and oxidation fractions from the Brazilian Inventory of Anthropogenic Emissions and Removals of Greenhouse Gases (MCTI, 2010).

From this approach, approximately 75% of Brazil's CO_2 emissions from energy use in 2008 were attributed to the ten aforementioned states that publish official energy balances. The differences from the national total by industry are allocated to the other states according to their respective gross output. Therefore, for the other 17 Brazilian states, we assume the same average technology concerning their sectoral CO_2 emissions coefficients.[43]

In our application, we disregard the CO_2 emissions from households' direct use of fossil fuels (approximately 9% of the national emissions). Instead, we focus on the emissions generated

[41] The following fuels were considered: natural gas, steam coal, metallurgical coal, diesel oil, fuel oil, gasoline, LPG, kerosene, gas coke, coal coke, other oil by-products, and coal tar.

[42] The sources for state energy balances are: Alagoas (2012), Bahia (2009), Ceará (2008), Espírito Santo (2013), Goiás (2009), Minas Gerais (2011), Paraná (2011), Rio de Janeiro (2013), Rio Grande do Sul (2010), and São Paulo (2009).

[43] For every industry in our model, we note that the assumed CO_2 coefficient for the rest of Brazil is between the minimum and maximum values of CO_2 coefficients found for the ten states that publish official energy balances.

by the various economic industries in their productive activities. Table A.4.1 in Appendix A.4.1 shows the emissions in Brazilian states by industry.

4.2.2 Trade in CO_2 emissions (TiCE)

To investigate the interregional (and international) spillover of CO_2 emissions, we apply an adaptation of the concept of trade in value added (TiVA) (MENG *et al*, 2013) for our country-state IO system. The adaptation approximates the methodology of Peters (2008) based on multi-regional IO analysis.

From the basic Leontief model, the total output of an economy can be expressed as the sum of intermediate consumption and final consumption (MILLER; BLAIR, 2009)

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \tag{4.1}$$

$$(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{B} \tag{4.2}$$

$$\mathbf{x} = \mathbf{By} \tag{4.3}$$

where $\mathbf{x}$ is the $n \times 1$ total output vector (n is the number of industries in the system), $\mathbf{A}$ is the $n \times n$ direct input coefficients matrix, $\mathbf{y}$ is the $n \times 1$ final demand vector, and $\mathbf{B}$ is the Leontief inverse matrix.

Considering $\mathbf{C}$ as the $n \times n$ diagonal matrix of CO_2 emissions coefficients, we can describe the CO_2 emissions related IO model as:

$$\mathbf{q} = \mathbf{Cx} \tag{4.4}$$

from (3):

$$\mathbf{q} = \mathbf{CBy} \tag{4.5}$$

$$\mathbf{CB} = \mathbf{K} \tag{4.6}$$

$$\mathbf{q} = \mathbf{Ky} \tag{4.7}$$

where $\mathbf{q}$ is the $n \times 1$ CO_2 emissions vector, and $\mathbf{K}$ is the CO_2 emissions-related Leontief inverse.

In our empirical analysis, we apply a state-country IO model. Therefore, the matrix $\mathbf{K}$ above can be decomposed as follows, considering r regions (states or countries):

$$\begin{bmatrix} \mathbf{K}^{11} & \dots & \mathbf{K}^{1r} \\ \vdots & \ddots & \vdots \\ \mathbf{K}^{r1} & \dots & \mathbf{K}^{rr} \end{bmatrix} = \begin{bmatrix} \mathbf{K}^{11} & \dots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \dots & \mathbf{K}^{rr} \end{bmatrix} + \begin{bmatrix} \mathbf{0} & \dots & \mathbf{K}^{1r} \\ \vdots & \ddots & \vdots \\ \mathbf{K}^{r1} & \dots & \mathbf{0} \end{bmatrix} \tag{4.8}$$

In equation (4.8), the elements of the first term of the sum can be considered intra-regional effects, representing impacts on the CO_2 emissions of sectors of a region from exogenous changes in the final demand of the same region. On the other hand, the elements of the second term of the sum can be regarded as spillover effects, representing impacts on the CO_2 emissions of sectors of a region from exogenous changes in the final demand of the other regions.

In our application, we are interested in estimating the contribution of the final demand in each region to the total CO_2 emissions of each region. We construct the **Y** *(r.n)* × *r* final demand matrix by the horizontal concatenation of final demand vectors of each region in our model. Therefore, the dimensions of the above matrices and vectors become: a) **X**, **Y**, and **Q**, size [*(r.n)* × *r*]; b) **A**, **B**, and **K**, size *(r.n)* × *(r.n)*. We rewrite equation (4.7) considering *r* regions in the model

$$\mathbf{Q} = \mathbf{KY} \tag{4.9}$$

and quantify the emissions under a consumption-based accounting principle (see Pei *et al*, 2015; Peters *et al*, 2011; Davis and Caldeira, 2010). Figure 4.3 illustrates the framework for trade in CO_2 emissions (TiCE) as represented in matrix **Q**:

			Final demand			Production-based emissions
			Region 1	...	Region r	
CO_2 from region - industries	Region 1	Industry 1	q_1^{11}	...	q_1^{1r}	$\sum_j q_1^{1j}$
		...	...	...	...	...
		Industry n	q_n^{11}	...	q_n^{1r}	$\sum_j q_n^{1j}$
	...	...	...	...	...	...
	Region r	Industry 1	q_1^{r1}	...	q_1^{rr}	$\sum_j q_1^{rj}$
		...	...	...	...	...
		Industry n	q_n^{r1}	...	q_n^{rr}	$\sum_j q_n^{rj}$
Consumption-based emissions			$\sum_s \sum_i q_s^{i1}$	...	$\sum_s \sum_i q_s^{ir}$	World emissions

Figure 4.3 – Framework for trade in CO_2 emissions (matrix Q)
Note: Cell values represent the CO_2 generated in the region-industry in the row because of the final demand of the region in the column.

Here, q_s^{ij} is the CO_2 emissions generated directly and indirectly in industry *s* of region *i* in response to the final demand of region *j*. For a given region, the sum of CO_2 emissions that its final demand causes across all industries and regions constitutes its consumption-based emissions given in the bottom row of Figure 4.3. On the other hand, for a given industry, the sum of the CO_2 emissions it generates, regardless of the consumer region, equals its production-based emissions given in the last column in Figure 4.3. The summation of consumption-based emissions across all consumer regions and the summation of production-based emissions across all producer region-industries equals world emissions.

In this framework, we define:

a) Emissions in region *E* due to its domestic final demand: $\sum_s q_s^{EE} = \sum_k \mathbf{K}^{Ek}\mathbf{y}^{kE}$ (4.10)

b) Exports of CO_2 of region *E*: $\sum_s \sum_{j \neq E} q_s^{Ej} = \sum_k \sum_{j \neq E} \mathbf{K}^{Ek}\mathbf{y}^{kj}$ (4.11)

c) Imports of CO_2 of region *E*: $\sum_s \sum_{i \neq E} q_s^{iE} = \sum_k \sum_{i \neq E} \mathbf{K}^{ik}\mathbf{y}^{kE}$ (4.12)

d) Production-based emissions of region *E* (sum of (4.10) and (4.11)):

$$\sum_s \sum_j q_s^{Ej} = \sum_k \sum_j \mathbf{K}^{Ek}\mathbf{y}^{kj} \tag{4.13}$$

e) Consumption-based emissions of region *E* (sum of (4.10) and (4.12)):

$$\sum_s \sum_i q_s^{iE} = \sum_k \sum_i \mathbf{K}^{ik}\mathbf{y}^{kE} \tag{4.14}$$

4.3 Results

Our results concern CO_2 emissions solely from energy use in the year 2008. We divide our results into six subsections. First, we present the aggregated results for TiCE for the Brazilian states and countries in our model, assessing the participation of traded components in global emissions. Then, these results are reorganized as production-based and consumption-based emissions, proceeding to the net emission transfers of each region. We further analyze the TiCE results for Brazilian states with respect to trade partners. In the following subsection, we analyze the intensity of both production-based and consumption-based CO_2 emissions, as well as the relationship of consumption-based emissions with final demand expenditures. The last subsection presents the results for an exercise that considers the replication of the best sectoral energy use technologies for all Brazilian states.

4.3.1 Traded components of global CO_2 emissions

Table 4.1 summarizes the results for TiCE. The first column is obtained by properly applying equation (4.10). Taking *j* in equation (4.11) as Brazilian states, we obtain the second column; taking *j* as foreign countries, we obtain the fourth column. Accordingly, we obtain the third and fifth columns considering *i* in equation (4.12) as Brazilian states and foreign countries, respectively.[44]

Table 4.1 shows that, as expected for a country as heterogeneous as Brazil, the values of traded components of CO_2 emissions vary greatly among the states.[45] The states in the Southeast region (Espírito Santo, Minas Gerais, Rio de Janeiro, and São Paulo) present the greatest sums of domestically consumed, interregionally and internationally traded CO_2 emissions. São Paulo's shares were the largest, except for exports of CO_2 emissions to foreign countries for which Minas Gerais led.

Considering the TiCE results in Brazil compared to those of other countries globally, the figures are small. Concerning the relationship of Brazilian states and foreign countries, as shown in the second and third columns of Table 4.1, the largest amounts of exports to and imports from Brazilian states correspond to countries that are not treated individually in our model (i.e., the "rest of the world" region). However, it is notable that China's exports of CO_2 to Brazilian states represent almost 30% of this component.

[44] We distinguish between inflows/outflows for trade between domestic states and imports/exports for trade between states and foreign countries or between foreign countries.

[45] In this section, we aggregate some of the countries in our model as "Other EU27" (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden) and as "Other countries + RoW" (Australia, Indonesia, Turkey, and ROW) for presentation purposes. We aggregate only the final results; all the calculations use the full model composed of 67 distinct regions (27 Brazilian states + 39 countries + RoW).

Table 4.1 – Allocation of global CO_2 emissions separated into domestic, interregionally and internationally traded components (in thousand tons)

	Domestic	Exports (outflows) to Brazilian regions	Imports (inflows) from Brazilian regions	Exports to foreign countries	Imports from foreign countries
Acre	236	135	384	31	160
Amapá	240	72	430	123	226
Amazonas	1,956	4,238	1,800	864	3,580
Pará	2,430	1,956	4,194	5,325	2,111
Rondônia	744	713	1,145	224	611
Roraima	146	83	212	16	95
Tocantins	542	479	769	142	419
Alagoas	773	576	1,114	219	521
Bahia	8,488	6,296	7,050	4,946	5,493
Ceará	2,527	1,069	3,330	317	2,093
Maranhão	1,902	2,613	2,027	2,030	1,819
Paraíba	1,255	820	1,884	137	1,074
Pernambuco	4,372	3,274	3,794	857	2,827
Piauí	908	383	1,410	105	656
Sergipe	968	1,344	1,034	308	579
Rio Grande do Norte	1,070	873	1,726	278	777
Distrito Federal	3,842	1,402	5,012	205	2,669
Goiás	4,369	2,879	3,778	1,444	2,786
Mato Grosso	1,900	3,337	2,005	2,197	1,043
Mato Grosso do Sul	1,651	1,886	1,550	852	1,302
Espírito Santo	1,920	7,826	2,796	9,241	2,134
Minas Gerais	16,478	14,585	11,500	14,110	9,301
Rio de Janeiro	18,909	12,718	16,075	7,590	10,833
São Paulo	34,522	26,581	24,635	13,209	33,255
Paraná	7,867	8,986	6,463	3,586	7,308
Santa Catarina	6,023	7,265	4,995	2,957	5,116
Rio Grande do Sul	7,722	6,212	7,490	3,567	7,194
Brazil	133,759	118,602	118,602	74,880	105,982
China	3,423,810	29,829	6,502	2,037,241	438,670
India	1,021,366	3,279	778	240,880	186,831
Russia	859,049	5,378	1,274	468,338	137,248
USA	3,873,706	9,141	13,725	474,513	1,183,184
Mexico	262,729	630	1,798	60,796	118,411
Canada	243,070	2,861	1,542	150,580	186,898
Germany	383,696	3,737	4,448	242,989	422,677
Spain	167,355	726	1,569	66,901	171,705
France	167,220	809	2,249	78,092	262,037
Great Britain	307,722	1,184	1,862	121,335	270,579
Italy	248,004	1,206	2,143	100,944	225,623
Other EU27	840,613	4,528	6,601	410,874	638,175
Japan	751,063	2,243	2,834	207,223	419,360
Korea	294,521	2,116	1,353	186,160	169,024
Taiwan	127,234	1,757	601	138,882	65,032
Other countries + RoW	3,895,511	36,558	25,600	1,490,581	1,580,873
Foreign countries	16,866,669	105,982	74,880	6,476,329	6,476,329

From the TiCE results we quantify the importance of international trade with respect to global CO_2 emissions, shown in Chart 4.2. In 2008, 29% of global CO_2 emissions, or 6.9 Gt CO_2, were attributed to international trade. This approximates the findings of other authors (Peters *et al* (2011): 26% in 2008; Davis and Caldeira (2010): 23% in 2004). China's exports of CO_2

emissions alone represented 31% of the internationally traded emissions, or 9% of global emissions.

Emissions from the production of interstate traded goods and services in Brazil amounted to 36% of the country's territorial (or production-based) CO_2 emissions. International trade was less relevant for Brazilian emissions than the world average as 23% of Brazil's territorial CO_2 emissions were embodied in its exports to foreign countries.

Interstate and international trade are more relevant to the generation of global and Brazil's CO_2 emissions than for value added, which is emphasized by the comparison with the figures for trade in value added (TiVA) in Chart 4.2. In 2008, 21% of global value added was attributed to international trade (versus 29% for CO_2 emissions). In Brazil, interstate trade accounted for to 27% of the country's value added (versus 36% for CO_2 emissions). The greater relevance of interregional trade for generating CO_2 emissions (in comparison with value added) also holds for every state in Brazil.

Chart 4.2 – Participation of interstate and internationally traded components

Participation of traded components in CO_2 emissions	
Global CO_2 emissions:	23,776,219 kt
Emissions in international trade:	6,919,108 kt → 29% of global emissions
Brazil's production-based CO_2 emissions:	327,240 kt
Emissions in international trade:	74,880 kt → 23% of Brazil's emissions
Emissions in interstate trade:	118,602 kt → 36% of Brazil's emissions
Participation of traded components in value added	
Global value added:	59,869,267 million US$
Value added in international trade:	12,667,732 million US$ → 21% of global VA
Brazil's value added:	1,546,495 million US$
Value added in international trade:	195,610 million US$ → 13% of Brazil's VA
Value added in interstate trade:	420,706 million US$ → 27% of Brazil's VA

4.3.2 Production-based and consumption-based CO_2 emissions

To quantify the emission transfers by means of interregional and international trade, we rearrange the results of TiCE presented in Table 4.1. To compute the production-based emissions, we sum the components "domestic", "exports (outflows) to Brazilian regions", and "exports to foreign countries", as in equation (4.13). For consumption-based emissions, we sum "domestic", "imports (inflows) from Brazilian regions", and "imports from foreign countries" as in equation (4.14). The difference between production-based and consumption-based emissions is defined as “net emission transfer” via trade (PETERS *et al*, 2011). Here, we are considering the transfers via international and interregional trade inside Brazil. Thus, the net emission transfer corresponds to CO_2 emissions in each region (state or country) from goods and services production that are ultimately consumed in a different region minus the emissions in other regions to produce goods and services that are ultimately consumed in the first region. Following the sign convention for an economic balance of trade, net exports are positive and net imports are negative. The results are presented in Table A.4.2 in Appendix A.4.1 and illustrated in Figure 4.4 (Brazilian states).

For the Brazilian states, where emission transfers also happen via interregional trade, of 27 states, seven were sources of net emission transfers to other states or foreign countries. Espírito Santo and Minas Gerais were outstanding net exporters of CO_2 emissions. São Paulo, the greatest emitter in the country of both production and consumption-based emissions, was also the recipient of the largest net emission transfer. These results are analyzed with further detail in subsection 4.3.3.

Considering Brazil as a whole, the country’s consumption-based emissions surpassed its production-based emissions giving the country a net emission transfer via international trade. This is different for the other BRIC countries, which presented positive net emission transfers via international trade, particularly China, with net export emissions amounting to 1.6 Gt CO_2. Concerning the countries included in Annex B of the Kyoto Protocol and that are treated individually in our model, each of them (with the exception of Bulgaria, Denmark, Estonia, Poland, and Russia) received net emission transfers via international trade. This finding adds to the literature concerning the inadequacy of the territorial principle for mitigation targets under a fragmented, two-tier mitigation strategy as in the Kyoto Protocol (PETERS *et al*, 2011).

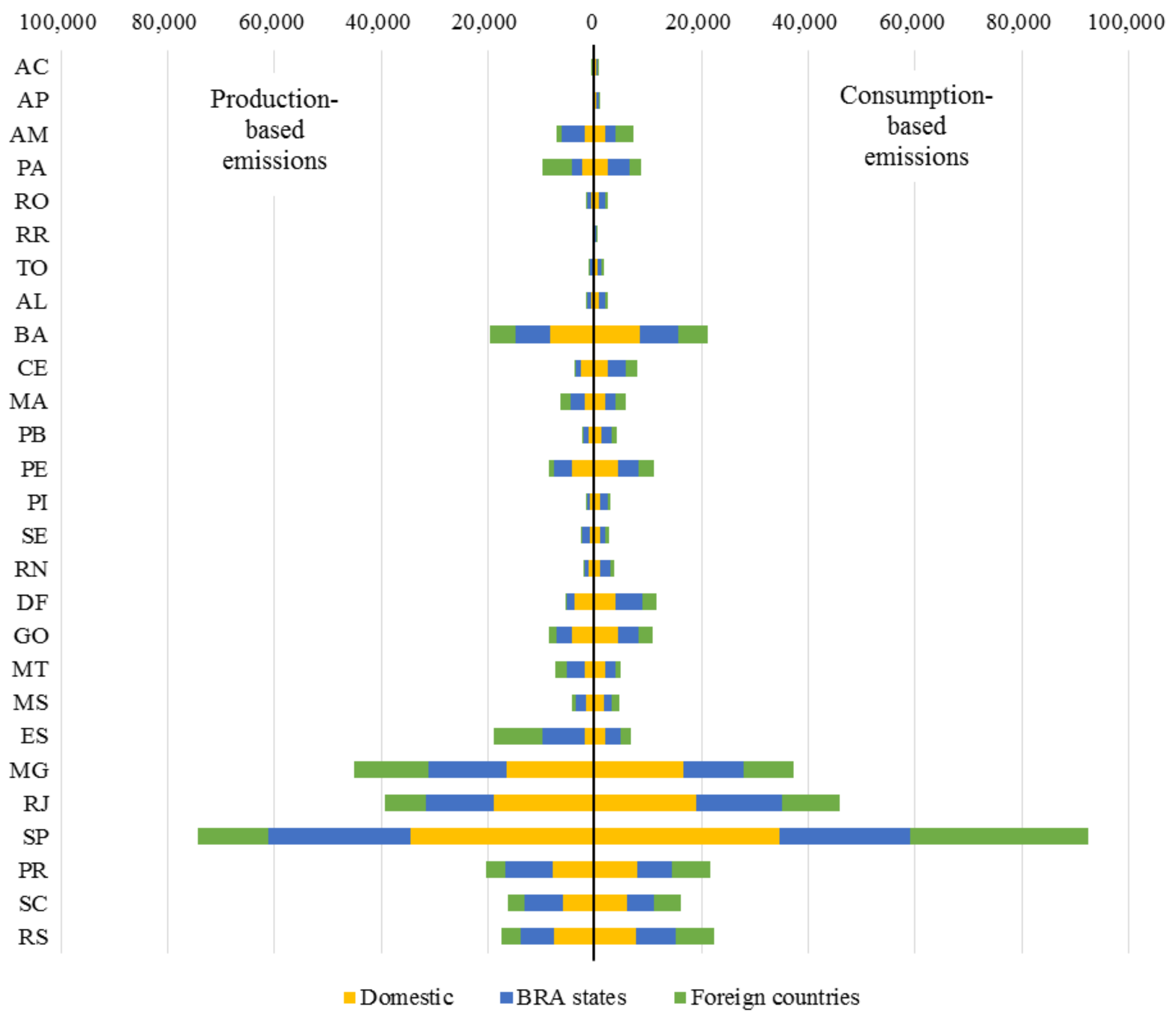

Figure 4.4 – Production-based and consumption-based CO_2 emissions (in thousand tons), Brazilian states

Table A.4.3 in Appendix A.4.1 and Figure 4.5 break down these results by groups of trade partners (domestic, Brazilian states, and foreign countries). The figure shows great variation in the significance of both interregional and international traded components among both Brazilian states and foreign countries.

A total of 36% of the Brazilian production-based CO_2 emissions were attributed to interstate trade. Across the states, this ranges from 17% in Amapá to 60% in Amazonas. The internationally traded component of CO_2 emissions also has great variance among the states corresponding to shares of production-based CO_2 emissions that range from 4% in Distrito Federal to 55% in Pará. The importance of the internationally traded component of CO_2 emissions in Espírito Santo is also outstanding (49% of production-based CO_2 emissions in this state), and only 10% of this state's CO_2 emissions were because of the state's own final demand.

Among the foreign countries, Taiwan is where international trade presented the most important role in production-based CO_2 emissions (52%). Although China was the largest exporter of CO_2 emissions in the world, the internationally traded component was (slightly) less important than in, for example, Germany and Korea given the extent of the Chinese domestic final demand. This observation also applies to the internationally traded component of CO_2 emissions in the USA from the consumption perspective. Although the USA is by far the greatest importer of CO_2 emissions, the internationally traded component is more relevant for the EU countries, for example.

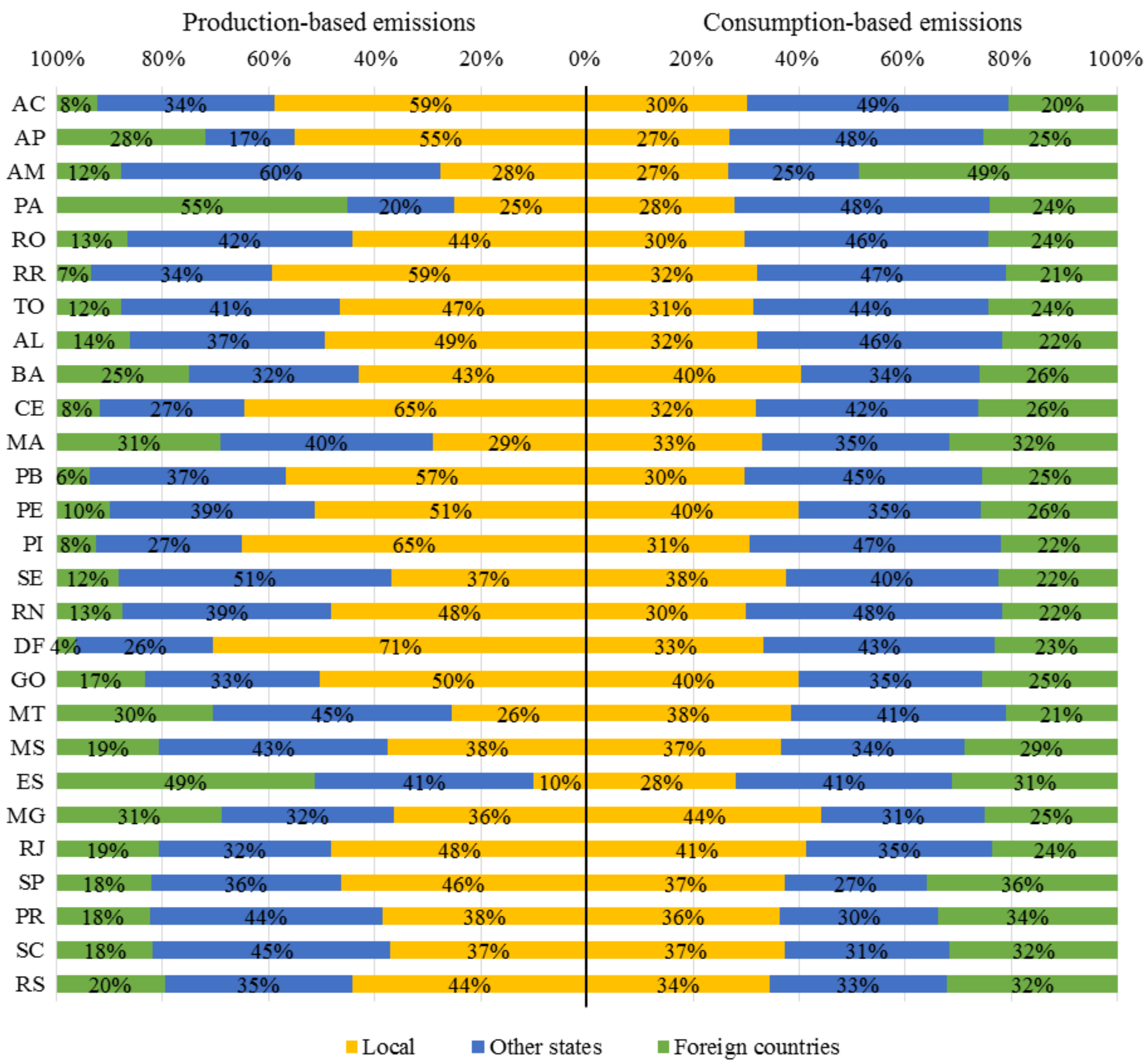

Figure 4.5 – Participation of domestic, Brazilian states, and foreign countries' components in production-based and consumption-based CO_2 emissions (%), Brazilian states

4.3.3 Brazilian states' interregional and international trade in CO_2 emissions

This subsection further details the results for Brazilian states' TiCE. It is relevant for policy purposes to identify and quantify the most important CO_2 emissions flows between each pair of trade partners.

Figure 4.6 illustrates the interregional flows in CO_2 emissions aggregated across the 28 industries in our model. Tables A.4.4 to A.4.7 in Appendix A.4.1 detail the results. In Figure 4.6, the darker cells correspond to larger bilateral flows of CO_2 emissions. TiCE is concentrated in relations with Southeast region states and, to a lesser extent, the states in the South and Central-West regions. Amazonas and Pará, in the North region and Bahia and Pernambuco in the Northeast region have notable trade flows with the Southeast.

A significant share of Brazil's interregional TiCE (23%) occurred among the states in the Southeast region. São Paulo is dominant in interregional trade CO_2 emissions, accounting for 22% of emission outflows and 21% of emission inflows of emissions in Brazil. For all states, São Paulo is the most important source of interregional TiCE and, except for Roraima, Alagoas, and Distrito Federal, it is also the most important destination. São Paulo's leading trade partners (in CO_2 emission terms) are the other states in the Southeast region, from which São Paulo sources 37% of its outflows and acquires 44% of its inflows. The key emission flows from São Paulo to Rio de Janeiro and from Minas Gerais to São Paulo alone amounted to 5% and 4% of Brazil's interregional TiCE, respectively. However, comparing this finding with the results from the TiVA analysis (see Chapter 2) reveals that São Paulo's dominance is less intense in terms of emissions – the state accounts for the larger share of 37% of outflows in value-added terms. This is because São Paulo presents low production-based CO_2 emissions intensity, which will be evaluated in the next subsection. Despite such low intensity, São Paulo's interregional trade flows (in value-added terms) are so large that the state also leads in TiCE.

Espírito Santo and Minas Gerais are more relevant as sources for interregional TiCE (than for TiVA). This is because large amounts of CO_2 emissions are generated in their "mining and quarrying" and "basic metals and fabricated metal" sectors in response to the final demands of other states. For both states, Rio de Janeiro and São Paulo were the most significant destinations for outflows, accounting for more than 46%.

The highest intensity of CO_2 emissions corresponds to the flows from Espírito Santo: on average, for each US$ 1 million of value added caused by other states' final demand, 0.78 thousand tons of CO_2 emissions were produced in Espírito Santo (in the whole interregional system, the average was 0.28 thousand tons of CO_2 emissions/US$ 1 million of value added). Bahia's outflows presented the second highest CO_2 intensity, 0.49 thousand tons of CO_2 emissions/US$1 million of value added, quite below the intensity of Espírito Santo.

Concerning interregional trade (Table A.4.4), we compute the net emission transfers between the states. We focus on the main results. Espírito Santo was a source of net emission transfers for every other state in Brazil. The state's largest surplus was with São Paulo (1,914 thousand tons of CO_2). Surpluses of TiCE were also verified for Amazonas with all trade partners in Brazil (except Espírito Santo). This latter result is mainly because of the Free Trade Zone of Manaus, which represents an industrial hub directed to the demand of the rest of the country. In the case of São Paulo, in contrast to the TiVA observations (see Chapter 2) where the state showed surpluses with all other states (except Amazonas), the sum of the state's deficits (with Espírito Santo and Minas Gerais) more than compensated for its surpluses for interregional trade in CO_2 emissions. This gave a positive net emission transfer to other states amounting to only 3% of São Paulo's production-based CO_2 emissions. On the other hand, the state that received the largest net emission transfer via interregional trade was Distrito Federal, which is comprehensible given the state's limited productive structure and its high final demand expenditures. In 2008, Distrito Federal received 3,610 thousand tons of CO_2 from other states in net terms (corresponding to 66% of its production-based CO_2 emissions).

Therefore, interregional TiCE in Brazil does not present a clear pattern as it does in China (PEI *et al*, 2015; FENG *et al*, 2013) where the highly developed coastal regions receive large net emission transfers from less developed inland regions. The states in the Southeast region, which accounted for 56% of Brazil' value added in 2008, showed both surpluses (Espírito Santo, Minas Gerais, and São Paulo) and deficits (Rio de Janeiro) in interregional TiCE. None of the Brazilian macro-regions presented either surpluses only or deficits only among their states. Thus, interregional TiCE is spatially heterogeneous in Brazil, which should be considered by climate policy makers.

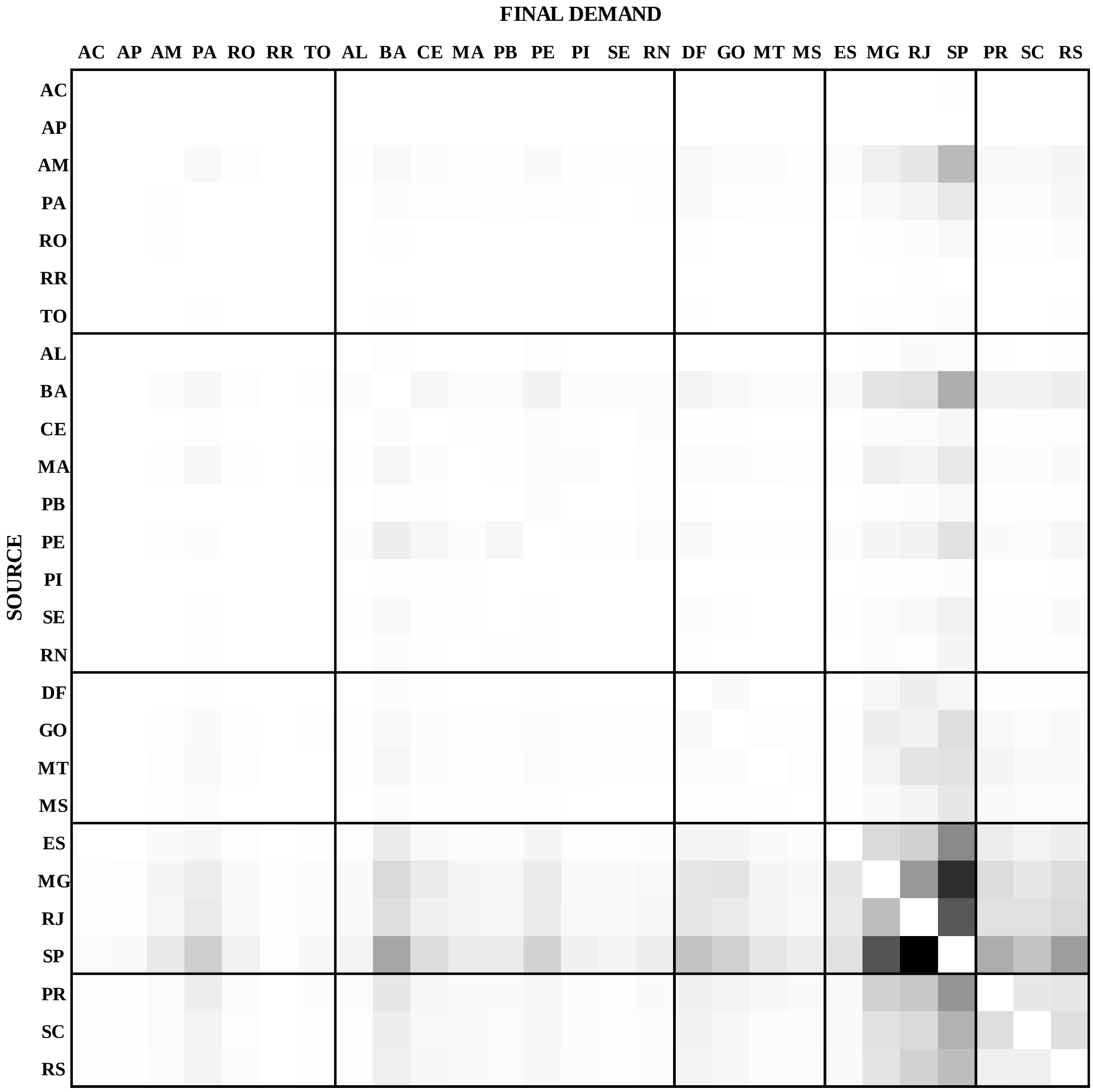

Figure 4.6 – Interregional trade in CO_2 emissions
Note: darker cells correspond to larger bilateral CO_2 flows

Figure 4.7 shows the states' exports in CO_2 emissions by trade partner.[46] The results are detailed in Tables A.4.8 to A.4.10 in Appendix A.4.1. Figure 4.7 shows that the largest export flows of CO_2 are sourced by the states in the Southeast region followed by Pará, in the North Region, Bahia, in the Northeast region, and the states in the South region.

[46] In Figures 4.7 and 4.8, the countries in our model are classified as follows: CHN: China; IND: India, RUS: Russia; USA: the US; MEX: Mexico; CAN: Canada; DEU: Germany; ESP: Spain; FRA: France; GBR: the UK; ITA: Italy; Other EU27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden; JPN: Japan; KOR: Korea; TWN: Taiwan; Other + ROW: Australia, Indonesia, Turkey, and ROW.

According to Table A.4.8, the main exporter of CO_2 emissions was Minas Gerais (almost 19% of national exports), which surpassed São Paulo (approximately 17% of national exports). With approximately 12.5% of national exports of CO_2 emissions, Espírito Santo is also notable. For exports by trade partners, the largest share (34%) was for the group of countries "Other + RoW," followed by the EU27 (25.2%), the USA (18.4%), and China (8.7%). However, this ranking of trade partners does not hold for every state. For Pará and Espírito Santo, the USA is a more important destination of exports of CO_2 than the EU27.

On average, Brazil's exports are more intense in CO_2 emissions than its interregional flows (0.38 thousand ton of CO_2 emissions/US$ 1 million of exported value added versus 0.28 in interregional trade). As observed for total production-based CO_2 emissions and interregional outflows, the intensity of Espírito Santo's exports of CO_2 emissions was the highest in Brazil (1.08 thousand ton of CO_2 emissions/US$ 1 million of exported value added, on average). We observe that the average CO_2 intensity varies with the trade partner. In Brazil as a whole, the USA's final demand generates a higher CO_2/value-added ratio than China's final demand or that of the EU27's (0.44 thousand ton of CO_2 emissions/US$ 1 million of exported value added versus 0.37).

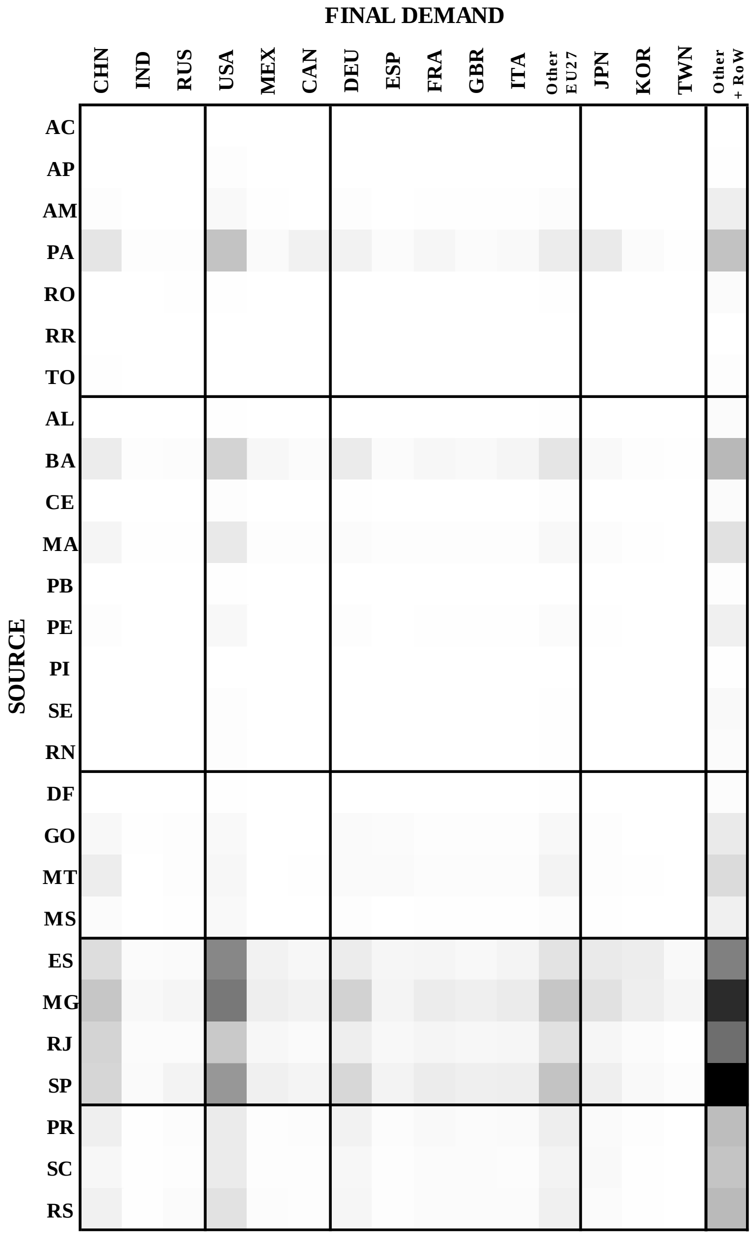

Figure 4.7 – Exports in CO_2 emissions, Brazilian states
Note: darker cells correspond to larger bilateral CO_2 flows

Figure 4.8 shows Brazilian states' imports of CO_2 emissions by trade partner. Tables A.4.11 to A.4.13 in Appendix A.4.1 show the detailed results. São Paulo was largely dominant in CO_2 emissions imports (31% of national imports). Foreign country emission transfers to São Paulo greatly surpassed emission transfers via interregional trade, i.e. the final demand of São Paulo had a greater impact in the CO_2 emissions of foreign countries than in other states in Brazil. Thus, the main source of emission transfer to São Paulo were the group "Other + ROW", China, the EU27, and the USA before even the states in the Brazilian Southeast region. The group "Other + RoW" and China produced the largest amounts of CO_2 emissions in foreign countries in response to Brazilian states' final demand (34% and 28%, respectively) followed by the EU27 (12%) and the USA (9%).

Concerning the CO_2 intensities of Brazilian states' imports of CO_2 emissions, the BRICs' exports to Brazil showed a high CO_2/value-added ratio. In the case of China, for example, each US$ 1 million of exported value added embodied 1.46 thousand ton of CO_2 emissions to Brazil. This reflects the high intensity of the production-based CO_2 emissions in these countries, which is addressed in the following subsection.

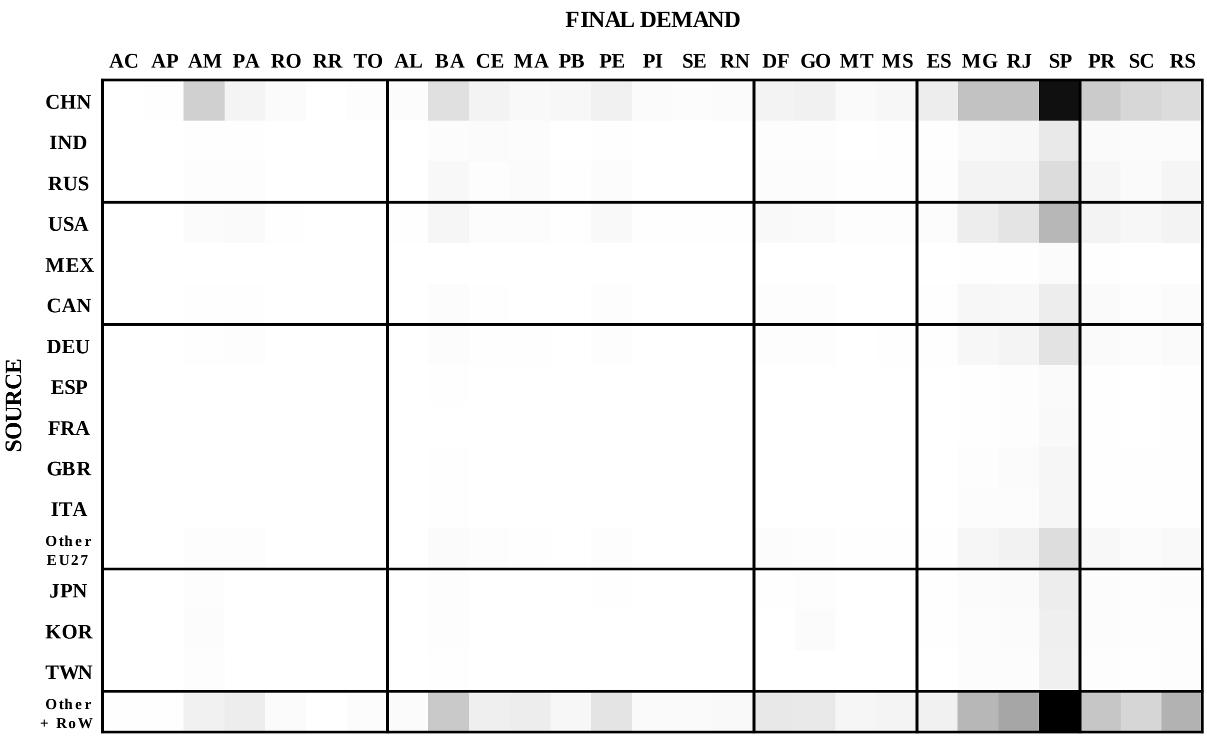

Figure 4.8 – Imports in CO_2 emissions, Brazilian states
Note: darker cells correspond to larger bilateral CO_2 flows

Combining the data in Tables A.4.8 and A.4.11, we obtain the net emission transfers for Brazilian states and foreign countries. Table A.4.14 in Appendix A.4.1 shows the results.

São Paulo received a substantial net emission transfer from foreign countries in 2008 (20,046 thousand tons). Of the countries listed in Tables A.4.8 and A.4.11, São Paulo showed net imports with all (except Mexico, Spain, and France). On the other hand, Espírito Santo, Minas Gerais, and Pará were important net exporters of CO_2 emissions to foreign countries. Espírito Santo was a source of net emission transfers amounting to 7,107 thousand tons of CO_2. In contrast to our results, Carvalho and Perobelli (2009), applying a single-region IO model, found that Minas Gerais was a net exporter of CO_2 emissions to China in 2005 (in our results, Minas Gerais received a net emission transfer of 1,401 thousand tons). We consider this contrasting result reflects a) the increased participation of China in international trade in 2008 and b) methodological differences (the single-region model of Carvalho and Perobelli (2009) does not account for indirect exports and imports; it attributes the lower Minas Gerais' CO_2 coefficients to Chinese industries).

Considering the foreign trade partners, the BRICs and the group "Other + RoW" were sources of net emission transfers for almost every state in Brazil. China stands out, with a total net emission transfer of 23,327 thousand tons to Brazilian states. However, the countries from the EU27 and the USA were net importers of CO_2 emissions in Brazil as a whole.

4.3.4 Intensity of CO_2 emissions

For policy purposes, it is relevant to assess the intensity of emissions in addition to the magnitude of production and consumption-based CO_2 emissions flows. Table 4.2 presents the results for production-based and consumption-based intensities.

For production-based emissions, intensity can be evaluated by the ratio between the total emissions and the total value added in a region. The Brazilian economy was less intensive in production-based CO_2 emissions than the world average (0.21 thousand tons of CO_2/US$ 1 million of value added in 2008; world average: 0.40) and all the developing countries depicted in Table 4.2. The other three BRICs, notably China, presented production-based CO_2 intensities much larger than the world average in 2008.

For the Brazilian states, it is relevant that São Paulo, the main state in economic terms, presented an intensity of production-based CO_2 emissions that was smaller than the national average (0.15 thousand tons of CO_2/US$ 1 million of value added). This reflects the low average energy intensity of São Paulo's industries and the advantage in clean energy production indicated by Abramovay (2010) from the state's hydroelectric plants and the importance of ethanol.[47] The three highest carbon intensities were exhibited by Espírito Santo,

[47] In 2008, the energy intensity of São Paulo corresponded to 0.10 toe (of final energy use, excluding the residential sector)/US$ 1 thousand of value added while, in the rest of Brazil, energy intensity was 0.13 toe/US$

Minas Gerais, and Bahia, in that order. In Espírito Santo, the intensity was 0.56 thousand tons of CO_2/US$ 1 million of value added, thus, above the world average. For these states, a substantial share of their manufacturing production is conducted by polluting industries (e.g., "coke, refined petroleum and nuclear fuel," and "basic metals and fabricated metal"), but they also present above national average technical coefficients for CO_2 emissions.

We assess consumption-based CO_2 emissions in per capita terms. The results are presented in Table 4.2. Among the 40 countries in our model, per capita consumption-based CO_2 emissions vary from 1.03 tons per person per year (py) for India to 16.54 tons/py for the USA. Brazil's emissions (1.89 ton/py) exceeded India's but were below China's (2.88 tons/py) and the world average (3.42 tons/py). Among Brazilian states, the lowest intensity corresponded to Alagoas (0.77 ton/py) while Distrito Federal was at the other extreme (4.51 tons/py, above the world average).

1 thousand. According to the official energy balances, hydroelectricity and biomass were sources of approximately 50% of final energy use in São Paulo and 40% in the remainder of Brazil.

Table 4.2 – Intensity of production-based CO_2 emissions in relation to value added (thousand tons/US$ 1 million) and per capita consumption-based CO_2 emissions (ton per person per year)

	Production-based emissions (kt) / Value added (US$ millions)	Per capita consumption-based CO_2 emissions (ton / py)
Acre	0.12	1.15
Amapá	0.12	1.46
Amazonas	0.27	2.20
Pará	0.32	1.19
Rondônia	0.19	1.67
Roraima	0.10	1.10
Tocantins	0.17	1.35
Alagoas	0.16	0.77
Bahia	0.32	1.45
Ceará	0.13	0.94
Maranhão	0.31	0.91
Paraíba	0.17	1.13
Pernambuco	0.24	1.26
Piauí	0.17	0.95
Sergipe	0.26	1.29
Rio Grande do Norte	0.17	1.15
Distrito Federal	0.09	4.51
Goiás	0.23	1.87
Mato Grosso	0.27	1.67
Mato Grosso do Sul	0.25	1.93
Espírito Santo	0.56	1.98
Minas Gerais	0.32	1.88
Rio de Janeiro	0.22	2.89
São Paulo	0.15	2.25
Paraná	0.22	2.04
Santa Catarina	0.26	2.67
Rio Grande do Sul	0.17	2.06
Brazil	0.21	1.89
China	1.19	2.88
India	0.98	1.03
Russia	0.88	6.94
USA	0.30	16.54
Mexico	0.30	3.33
Canada	0.27	12.93
Germany	0.18	9.72
Spain	0.15	7.53
France	0.09	6.90
Great Britain	0.17	9.46
Italy	0.16	7.95
Other EU27	0.25	7.99
Japan	0.20	9.22
Korea	0.53	9.71
Taiwan	0.68	8.37
Other countries + RoW	0.53	1.87
Global average	0.40	3.42

Hertwich and Peters (2009) observed that per capita consumption-based CO_2 emissions are strongly correlated with per capita final demand expenditures. To examine this point, we used a regression of log-transformed data to derive the cross-country elasticity.[48] For the countries

[48] Because it is an uncontrolled elasticity estimate, the obtained value should be interpreted with caution.

in our model, CO_2 emissions increase with final demand expenditures, as shown in Figure 4.9, with an elasticity $\varepsilon = 0.63$ (standard error 0.04 and $R^2 = 0.84$).[49] Therefore, as a country becomes wealthier, its consumption-based CO_2 emissions increase by 63% for each doubling of per capita final demand expenditure. Because the elasticity is less than one, the intensity of per capita consumption-based CO_2 emissions decreases with final demand expenditures.

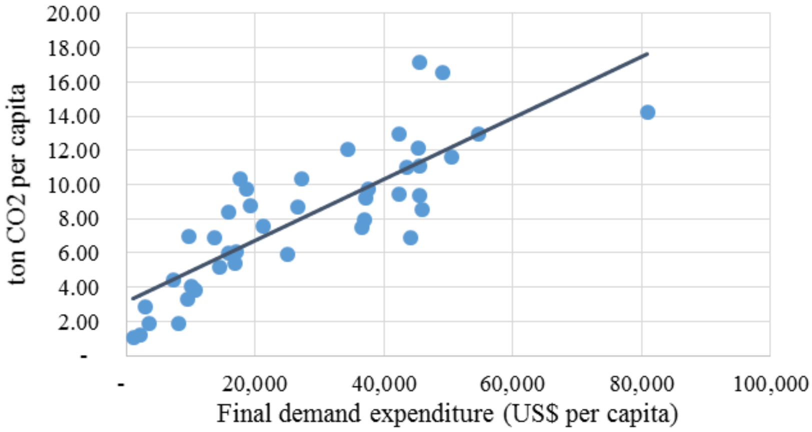

Figure 4.9 – Consumption-based CO_2 emissions (ton per capita) as a function of final demand expenditures (US$ per capita), countries

Applying this exercise to Brazilian states (Figure 4.10), we obtain an unexpected unitary cross-state elasticity $\varepsilon = 1.0038$ (standard error 0.09 and $R^2 = 0.84$).[50] The elasticity is larger than it is when we consider the countries, and the increase in consumption-based CO_2 emissions is stronger as states become wealthier. Thus, the carbon intensity of consumption in per capita terms is constant with rising expenditures across Brazilian states.

[49] Hertwich and Peters (2009) observed a stronger increase of consumption-based CO_2 emissions with expenditures across countries ($\varepsilon = 0.81$, $R^2 = 0.88$). We find it difficult to compare our results because they are sensitive to the countries included in the regression. Hertwich and Peters' database discriminates poor countries in Africa, Southeast Asia, and Latin America.

[50] In this regression, we omit Distrito Federal (per capita consumption-based CO_2 emissions: 4.51 ton / py; per capita final demand expenditure: US$30,341). If this state is included, we observe cross-state elasticity $\varepsilon = 0.87$ (standard error 0.07 and $R^2 = 0.86$).

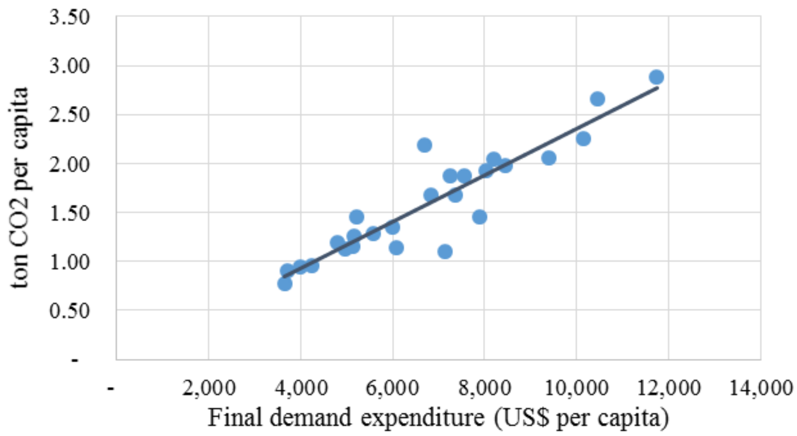

Figure 4.10 – Consumption-based CO_2 emissions (ton per capita) as a function of final demand expenditures (US$ per capita), Brazilian states

Policy-wise, our findings cannot support the claim that the combination of better technologies and structural change concerning consumption will lead to lower carbon intensities as Brazilian states become wealthier, as verified across countries (HERTWICH; PETERS, 2009). This is an indication of the urgency for proactive climate policies, such as that analyzed in the following subsection.

4.3.5 Assessing the potential environmental benefit of technology transfers

The Clean Development Mechanism (CDM) is a cooperative tool established under the Kyoto Protocol that allows industrialized countries with mitigation targets to develop or finance projects that reduce GHG emissions in non-Annex I countries in exchange for emission reduction credits. Thus, CDM intends to help Annex I countries achieve their target at a lower cost while contributing to the sustainable development of host countries. According to Dechezleprêtre *et al* (2008), the CDM is considered a key way to boost the North-South transfers of climate-friendly technologies.

Peters (2008) indicated that the CDM concept is a natural part of consumption-based accounting of emissions because it identifies which industries' and countries' final demand contribute most to emissions. Therefore, consumption-based indicators, which we have analyzed, can be used to identify priority CDM mitigation activities in areas that are sources of exports/outflows of CO_2 emissions.

The differences in production-based intensities across states highlight technology transfers as possible mitigation strategies. To verify the potential environmental benefit from a mechanism of this type inside Brazil, we assess the extent to which Brazil's CO_2 emissions could be reduced via technology transfer if each sector in every state adopted the best available technology in the country in emission terms. We assume that a Brazilian state can adopt the productive technology from another state more readily or less costly than a technology from a foreign country.[51] With this in mind, we restrain the set of technologies that are available to transfers to those existing in the country in 2008 as described by the IO relations in our model.

In our simple exercise, we have not made a distinction between host parties and "parties in Annex I" as in the global CDM, and every state can be both a host and source of technology transfers (e.g., São Paulo is a source for the transfer of climate-friendly technology to Rio de Janeiro in the "transports" industry because of this industry's particular technology, but São Paulo is a host to technology transfer from Rio de Janeiro for the "mining and quarrying" industry).

Thus, we attribute CO_2 coefficients that represent the cleanest technology available for the productive industries in Brazil, as in 2008. Appendix A.4.2 describes the selection criterion. Our results can be interpreted as the upper-bound for the reduction of CO_2 emissions because of energy use in the productive sectors given the technologies available within the country in 2008.[52]

In Brazil, with the transfer of the cleanest sectoral technologies, production-based CO_2 emissions would decline by 152,819 thousand tons. That is, under a technology transfer mechanism, production-based emissions could be reduced by up to 47%. On the other hand, consumption-based CO_2 emissions could be reduced by up to 32%.[53] Table A.4.16 in Appendix A.4.2. details the results.

[51] Note, however, that we are not assessing the costs of the technology transfers in this exercise.

[52] The simulation relies on perfect transfers of technology between states including the energy intensities in the productive activities but also the composition of the energy matrices (i.e., participation of renewable sources and fossil fuels in energy supply).

[53] The potential reduction of consumption-based CO_2 emissions is lower than that of production-based emissions because we do not modify the CO_2 coefficients in foreign countries in our simulation, and part of the now less carbon-intensive production is exported.

Figure 4.11 breaks down the potential reduction in CO_2 emissions by state.[54] The largest decrease in production-based CO_2 emissions would occur, in absolute terms, in Minas Gerais (25,947 thousand tons) and in relative terms, in Espírito Santo (71%). The reductions would be concentrated in the "basic metals and fabricated metal" sector of these states (also in the "transport" sector in Minas Gerais), which show considerably larger CO_2 coefficients than the coefficients for São Paulo's adopted in the simulation. The differential in the CO_2 coefficient for the "basic metals and fabricated metal" sector also accounts for a substantial share of the potential reduction in Rio de Janeiro's production-based emissions. In Bahia, it is the differential in the "chemicals and chemical products" sector's CO_2 coefficient that mostly accounts for the potential reduction.

Reflecting its privileged ownership of relatively clean technologies in 2008, São Paulo is the only state in our simulation with a potential reduction of consumption-based emissions greater than that of production-based emissions. Under a technology transfer mechanism, São Paulo's consumption-based CO_2 emissions could be reduced by up to 20,332 thousand tons (22%).

[54] In this exercise, the carbon intensities analyzed in subsection 4.3.4 are modified but are still distinct for each state. The intensity of production-based CO_2 emissions vary because of the composition of production baskets and the different gross output/value-added ratios in the states' industries. Concerning the per capita consumption-based CO_2 emissions, given the various composition of consumption baskets and different levels of final demand expenditure per capita, they still vary across states.

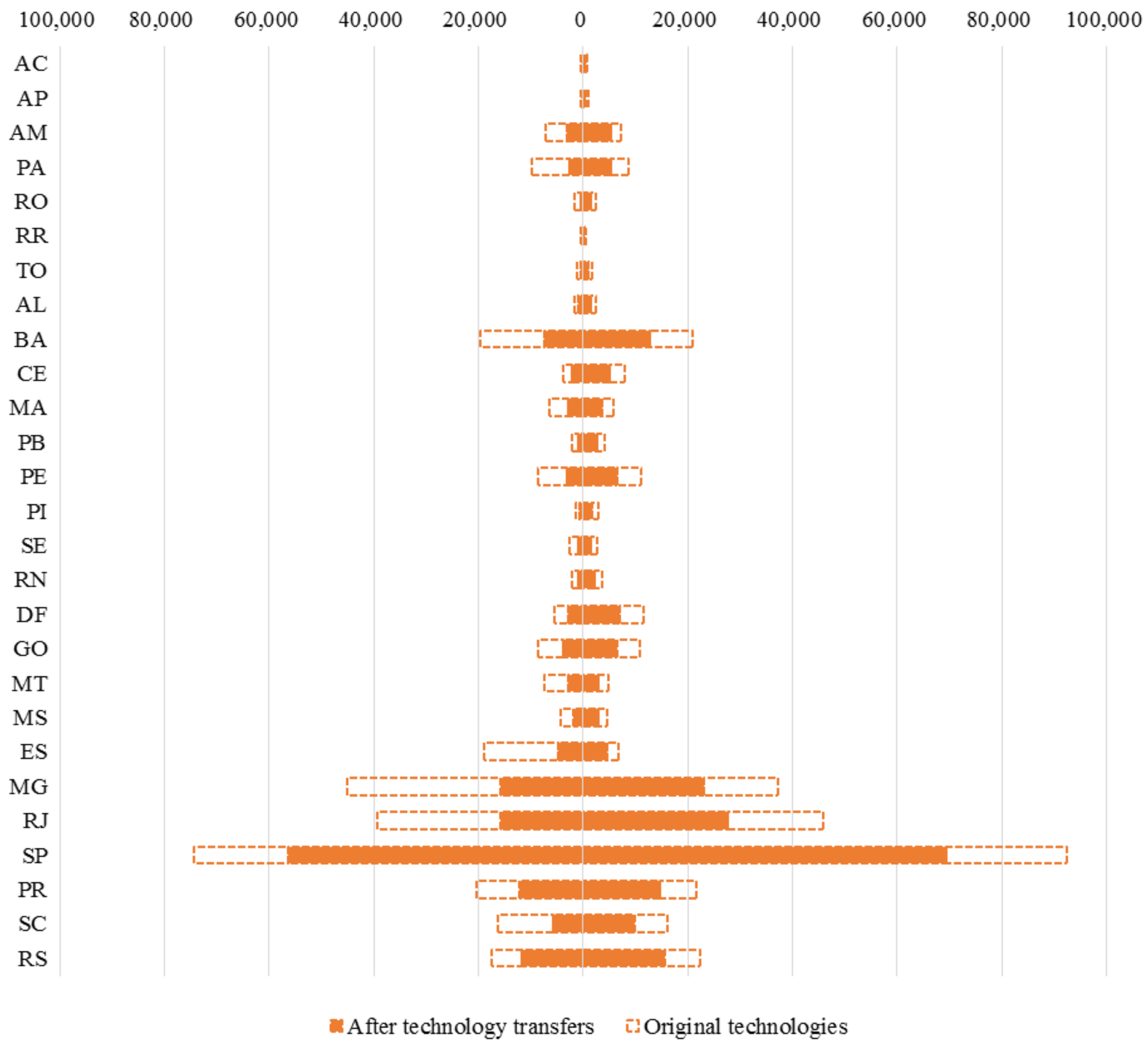

Figure 4.11 – Results of the simulation: potential reduction in production-based and consumption-based CO_2 emissions (in thousand tons)

4.4 Concluding remarks

The fragmentation of production processes has caused profound changes in the spatial organization of economic activity. We observed the dispersal of production at the global level, as more countries can join the fragmented value chains. On the other hand, at the regional level, exploiting economies of scale leads to greater specialization in productive activities, especially intra-establishments, as indicated by Hewings and Oosterhaven (2015). In environmental terms, the consequence is a greater spatial concentration of harmful activities in specialized regions. This is important from the perspective of climate change policies, as binding emission mitigation targets might affect the activity levels within these regions to a larger extent. In this sense, policymakers face the challenge to ensure that regions specializing in pollution-intensive activities adopt clean technologies, as suggested by Peters and Hertwich (2008), rather than further slicing up the value chain and moving the polluting fragments outside the policy's control (i.e. by leaking avoidable carbon) or not participating in climate change regime.

The current framework of climate policies in Brazil suggests that carbon leakage is not regulated within the country – while national policies neglect the regional distributive implications from mitigation efforts, state participation in mitigation commitments via subnational initiatives is limited. On the other hand, since most of the polluting activities, such as mining and metallurgy plants, cannot be easily relocated, given that only certain states are naturally endowed with these resources, it is not expected that the current sub-national policies elaborated at spontaneous and autonomous grounds lead to thorough mitigation efforts.

In this chapter, we consider that it is important to understand the relationship between trade and emissions in order to devise effective climate policies. With this in mind, our objective was to trace the CO_2 emissions embodied in Brazilian states' trade, both within the country and internationally. Recognizing the interconnectedness of domestic and global value chains, we applied a country–state IO table for the year 2008, which explicitly displays the Brazilian states' economic interrelationships and their relationships with foreign countries. To extend the model environmentally, we compiled a novel database reflecting CO_2 emissions from energy use (i.e. fossil fuel combustion) by state and production industry.

A central finding of our analysis is that not only were 28% of global emissions (from fossil fuel combustion) embodied in international trade, but 36% of territorial emissions (from fossil fuel combustion) in Brazil were traded between states. Thus, international and interregional trade play a major role in emissions reduction and should be given due consideration in the climate change policy framework. The current regional mitigation initiatives in Brazil, which are limited to a few states and refer only to the emissions generated within states' territorial boundaries, ignore an important share of national emissions.

Our observation that consumption-based CO_2 emissions intensities do not decrease as states become wealthier points out the necessity of proactive climate policies. In this regard, our study's quantification of consumption-based emissions produces an alternative indicator to the territorial principle that guides the mitigation commitments at both the federal and state levels in Brazil. However, arguably, this solution takes the problem from one extreme to another, that is, shifting the burden of mitigation entirely from producers (who benefit from economic activity in their respective territories) to final consumers. For an intermediate solution, as Peters (2008) indicated for the global level, consumption-based indicators within countries may help establish different commitments that are trade-adjusted, adhering to the principle of "common but differentiated responsibilities" at the regional level. In addition, consumption-based indicators can be used to identify priority mitigation activities under some CDM. In fact, we recognised that transfers of climate-friendly technologies within Brazil offer great potential as a mitigation policy tool. Considering the technologies available within the country in 2008, production-based emissions from energy use could be reduced by up to 47%. The analysis of states' international TiCE can also help prioritize developed foreign countries' CDM initiatives hosted by Brazilian states.

Such potential is possible because of considerable heterogeneities in CO_2 emissions across Brazilian states. In this essay, we not only observed very different carbon quantities in the interregional and international trade flows but also identified huge variations in production-based emission intensities. Similar to our verification for the TiVA flows, we also found that production- and consumption-based emissions are largely concentrated in the more developed Southeast and South regions of Brazil. However, there are important differences in the participation of the states within these regions. Particularly, São Paulo's is less dominant with regard to TiCE, while Espírito Santo and Minas Gerais emerge as main sources of TiCE on account of their mining and metallurgical activities. Unlike the case of China (FENG *et al*, 2013; PEI *et al*, 2015), we do not observe a clear pattern of coastal and rich regions being recipients of net emissions transfers from inland states for the case of Brazil. Given our verification of dissimilarities across neighbouring states, it is vital that subnational climate policies contemplate each case.

Our results refer to CO_2 emissions from fossil fuels combustion in the year 2008. Since then, the share corresponding to energy use in Brazil's GHG emissions has soared (LUCON *et al*, 2015). Thus, we consider that our findings might be amplified with data for more recent years. In this context, it is worrisome that the current mitigation strategy of the federal government for this sector is largely limited to keeping the national energy matrix relatively clean via use of hydroelectricity and biofuels. It therefore appears that an important trade-off has not been adequately weighed: as indicated by Hoekstra and Wiedmann (2014), even though these two energy sources reduce carbon emissions, they inevitably increase land and water footprints. For instance, it is remarkable that ethanol production for use within the state of São Paulo alone accounted for 17.5% of total blue water consumed in the state in 2009 (VISENTIN *et al*, 2015). The severe water crisis that started in 2010 makes it even more pressing to look for energy alternatives. Otherwise, as Abramovay (2010) states, the advantage of having a clean energy matrix may instead become a curse.

We have reiterated throughout this chapter the need for coordination of top-down policies in addressing climate change. Interregional carbon leakage has to be taken into consideration for achieving a nation-wide goal of mitigation, and thus, coordination among the interlinked economies is fundamental. As a matter of fact, devising a central arrangement is easier within countries than at the global level, as the federal government can design policies covering the subnational regions. However, this does not preclude subnational climate initiatives, especially when it is fundamental to encourage new alternatives in the energy sector, as regional policies can recognize spatial particularities and are especially prone to innovations. In this regard, our identification of the most important flows in interregional trade in emissions can provide a solid ground for environmental alliances between states. In doing so, the vertical and horizontal coordination of Brazilian subnational climate policies is likely to increase the chances of more effective implementation.

5 CONCLUDING REMARKS

In this dissertation, we have proposed a new methodological framework for estimating combined country-state IO tables, based on WIOTs and IRIOTs. Our approach is novel as we we do not take one of the datasets as given and adapt the other accordingly (MENG *et al*, 2013; FENG *et al*, 2013; CHERUBINI; LOS, 2012). Instead, we employ the input coefficients from both datasets (rather than the intermediate flows themselves). From the resulting estimated IO tables, quantitative indications of the participation of subnational regions in global production processes can be obtained. In this study, we analyse the economic and environmental aspects of the integration of Brazilian states in GVCs.

Our empirical applications use the WIOT that was constructed in the WIOD project (DIETZENBACHER *et al*, 2013), which is a full inter-country IO table that includes 40 countries and the rest of the world as the 41st country. The IRIOT covers the 27 Brazilian states (GUILHOTO *et al*, 2010). Both the WIOT and the IRIOT aggregate 28 compatible industries for the year 2008.

The dissertation is composed of three essays. In the first essay, in Chapter 2, alongside presenting the methodological framework for estimating the country-state IO table, the objective is to analyze the integration of Brazilian states in the GVCs by means of TiVA analysis. In the second essay, in Chapter 3, the objective is to elucidate the geographical structure of global supply chain flows by means of hierarchical feedback loop methodology, with special attention to the spatial interdependencies of Brazilian states. In the third essay, in Chapter 4, we turn to environmental issues raised by the participation in GVCs. The objective is to trace CO_2 emissions embodied in Brazilian state level trade, both within the country and internationally. The main results of each essay are presented as follows.

In the empirical application of the first essay, we observed that the value-added exports to gross exports ratio (VAX ratio) differs across Brazilian states, indicating that the importance of production sharing for GVC engagement varies widely. While some states export value added mostly directly or indirectly via their own industries (e.g. São Paulo and Pará), others tend to engage international trade more indirectly by providing inputs to other states (e.g. Amazonas and Rio de Janeiro). It is not possible to affirm that industry composition of exports drives aggregate VAX ratios, given that differences within industries across states also account for this finding. The quantification of the states' international TiVA indicated a high concentration in the more developed Southeast and South regions. The state of São Paulo alone accounted for one-third of Brazil's international TiVA in 2008. These regions are also primarily responsible for linking the production of other states to final consumption abroad, that is, they act as major links connecting and extending Brazilian value chains to the GVCs.

In the second essay, the results showed that Brazil's value chains are mostly self-sufficient in intermediate inputs. On the other hand, there is a great degree of production sharing among Brazilian states, even to a greater degree than is observed for EU27. The dominance of the Southeast region's states, especially São Paulo, in the spatial structure of the Brazilian supply chain networks, is reaffirmed by the results of the second essay. Not only are these states major suppliers of intermediates to the value chains of other regions in Brazil, but also in absolute terms (as indicated by the feedback loop analysis) they have central roles for the Brazilian value chains. Fragmentation within great regions is a major phenomenon for the Southeast and (secondary to the links with São Paulo) the South regions. For states elsewhere in the country, supply chain connections with the more developed states in Brazil overshadow production sharing with neighbouring states. Further, the geography of Brazilian production remains relatively unchanged over time (see Perobelli *et al* (2006)). The application of the feedback loop approach at the sectoral level illuminated the nature of the interregional dependencies. For São Paulo's value chains, we observed that the state's end-use production principally affects agricultural activities in the South region. With the other main state partners, supply chain trade seems primarily based on comparative advantages related to natural mineral endowments, along with deliberate policies directed at manufacturing centres elsewhere in the country. At the global level, the second essay discusses the spatial structure of global supply chain networks, where the flows linking major economies across trading blocks are dominant; more than 75% of international supply chain value-added flows link countries in different trading blocks. The fact that supply chains are well defined within blocks is only secondary to this structure. Therefore, our results support the observation that production fragmentation is a truly global phenomenon, not being merely circumscribed to trading blocks.

In the environmental analysis of the third essay, regarding emissions from fossil fuel combustion, a central finding is that 36% of territorial emissions within Brazil were traded between states, versus 28% between countries globally. Thus, the current regional environmental mitigation initiatives in Brazil, which are limited to a few states and refer only to the emissions generated within their territorial boundaries, ignore an important share of national emissions. We have also observed very different carbon contents in the interregional and international trade flows of Brazilian states, as well as great variation in production-based and consumption-based emission intensities. As verified for TiVA flows in the first essay, CO_2 emissions are also concentrated in the Southeast and South regions of Brazil. However, there are important differences in the participation of the states within these regions. Particularly, São Paulo's dominance is less intense in TiCE, while Espírito Santo and Minas Gerais emerge as main sources of TiCE due to mining and metallurgical activities. Finally, the third essay indicates a great potential for transfers of climate-friendly technologies within Brazil as a mitigation policy tool. Considering the technologies available within the country in 2008, we found that production-based emissions from energy use could be reduced by up to 47%.

Finally, the study points out avenues for future research. One of them one derives from the main limitation of our study, which is that our empirical results refer to a single year, 2008. While the WIOD project has published a series of WIOTs for the period 1995-2011, the IRIOTs for Brazilian states are available for only a few years and they are not entirely consistent, due to changes in national accounts methodology executed by the Brazilian Institute of Geography and Statistics over recent years. Should this data limitation be overcome, the understanding of Brazilian state participation in GVCs would benefit from the application of the proposed framework for estimating a time-series of country-state IO tables.

Concerning the methodological framework proposed in Chapter 2 regarding the estimation of the combined country-state IO table, a future study comparing it to alternative methodological approaches (e.g. Meng *et al* (2013)) could be of theoretical interest. It would as well contribute to evaluating the robustness of our empirical findings for the Brazilian states, and the findings of other studies on the regions of China.

Our environmental analysis was restricted to CO_2 emissions from the use of fossil fuels. With the database that we have built as described in Chapter 4 and the adoption of the corresponding coefficients by type of fuel, future studies may quantify other GHGs from energy use related to Brazilian state trade, e.g. CH_4 and N_2O, which are also present in WIOD emission accounts. Concerning other environmental aspects, for which new databases need to be built, at least within Brazil, we note that applying our country-state IO table to quantifying the virtual water content of interstate trade would be of interest, given that the water issue is increasingly important, not only in Brazil, but in other world regions as well. This might contribute to a more comprehensive assessment of the relationship between trade and climate change.

Finally, the contributions of this dissertation can be summarized as follows: proposition of a new theoretical framework for estimating combined country-state IO tables; comprehensive analysis of TiVA for subnational regions (in this case, for the 27 Brazilian states, interconnected to 39 foreign countries); study of the spatial structure of the global economy, by means of the hierarchical feedback loop methodology applied to value-added flows involved in supply chains; development of a new database on fossil fuels use (and corresponding CO_2 emissions) by industry, for each Brazilian state; and, quantification of CO_2 emissions from energy use embodied in Brazilian state trade, both within the country and internationally.

The regional dimension of the emergence of GVCs is a promising research topic. This dissertation is one of the first studies to analyze the subnational regions' interdependencies in an integrated global framework. Next to the empirical findings for Brazilian states' interdependencies – considering both trade and environmental aspects – the dissertation contributes with the proposition of a methodological approach that can be applied to other geographical areas to elucidate the impacts of GVCs around the world. In this way, the dissertation stresses the importance of interlinkages among economies – a topic with long tradition in regional science, and as relevant as ever in the global economy.

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APPENDICES

APPENDIX A.1: LIST OF INDUSTRIES AND REGIONS

Table A.1.1 – List of the 28 industries in the model

Industry	Number
Agriculture, Hunting, Forestry and Fishing	1
Mining and Quarrying	2
Food, Beverages and Tobacco	3
Textiles and Textile Products	4
Leather, Leather and Footwear	5
Wood and Products of Wood and Cork	6
Pulp, Paper, Paper , Printing and Publishing	7
Coke, Refined Petroleum and Nuclear Fuel	8
Chemicals and Chemical Products	9
Rubber and Plastics	10
Other Non-Metallic Mineral	11
Basic Metals and Fabricated Metal	12
Machinery, Nec	13
Electrical and Optical Equipment	14
Transport Equipment	15
Manufacturing, Nec; Recycling	16
Electricity, Gas and Water Supply	17
Construction	18
Wholesale and retail trade	19
Hotels and Restaurants	20
Transport	21
Post and Telecommunications; Other Business Activities	22
Financial Intermediation	23
Real Estate Activities	24
Public Admin and Defence; Compulsory Social Security	25
Education	26
Health and Social Work	27
Other Community, Social and Personal Services; Private Households with Employed Persons	28

Table A.1.2 – List of the 67 regions in the model

	State / Country	Number	Brazilian region
AC:	Acre	1	North
AP:	Amapá	2	North
AM:	Amazonas	3	North
PA:	Pará	4	North
RO:	Rondonia	5	North
RR:	Roraima	6	North
TO:	Tocantins	7	North
AL:	Alagoas	8	Northeast
BA:	Bahia	9	Northeast
CE:	Ceará	10	Northeast
MA:	Maranhão	11	Northeast
PB:	Paraiba	12	Northeast
PE:	Pernambuco	13	Northeast
PI:	Piauí	14	Northeast
SE:	Sergipe	15	Northeast
RN:	Rio Grande do Norte	16	Northeast
DF:	Distrito Federal	17	Central-West
GO:	Goiás	18	Central-West
MT:	Mato Grosso	19	Central-West
MS:	Mato Grosso do Sul	20	Central-West
ES:	Espírito Santo	21	Southeast
MG:	Minas Gerais	22	Southeast
RJ:	Rio de Janeiro	23	Southeast
SP:	São Paulo	24	Southeast
PR:	Paraná	25	South
SC:	Santa Catarina	26	South
RS:	Rio Grande do Sul	27	South
AUS:	Australia	28	
AUT:	Austria	29	
BEL:	Belgium	30	
BGR:	Bulgaria	31	
CAN:	Canada	32	
CHN:	China	33	
CYP:	Cyprus	34	
CZE:	Czech Republic	35	
DEU:	Germany	36	
DNK:	Denmark	37	
ESP:	Spain	38	
EST:	Estonia	39	
FIN:	Finland	40	
FRA:	France	41	
GBR:	United Kingdom	42	
GRC:	Greece	43	
HUN:	Hungary	44	
IDN:	Indonesia	45	
IND:	India	46	
IRL:	Ireland	47	
ITA:	Italy	48	
JPN:	Japan	49	
KOR:	Korea	50	

LTU:	Lithuania	51
LUX:	Luxembourg	52
LVA:	Latvia	53
MEX:	Mexico	54
MLT:	Malta	55
NLD:	Netherlands	56
POL:	Poland	57
PRT:	Portugal	58
ROM:	Romania	59
RUS:	Russia	60
SVK:	Slovak Republic	61
SVN:	Slovenia	62
SWE:	Sweden	63
TUR:	Turkey	64
TWN:	Taiwan	65
USA:	United States	66
RoW:	RoW	67

APPENDIX A.2.1: WAPES OF THE ESTIMATION

The combination of the WIOT and the Brazilian IRIOT yields a final demand vector and the input coefficients matrix in (7). We may thus calculate an output vector

$$\begin{pmatrix} \tilde{\mathbf{x}}^R \\ \tilde{\mathbf{x}}^S \\ \tilde{\mathbf{x}}^E \\ \tilde{\mathbf{x}}^W \end{pmatrix} = \left(\mathbf{I} - \begin{bmatrix} \mathbf{A}^{RR} & \mathbf{A}^{RS} & \tilde{\mathbf{A}}^{RE} & \tilde{\mathbf{A}}^{RW} \\ \mathbf{A}^{SR} & \mathbf{A}^{SS} & \tilde{\mathbf{A}}^{SE} & \tilde{\mathbf{A}}^{SW} \\ \tilde{\mathbf{A}}^{ER} & \tilde{\mathbf{A}}^{ES} & \mathbf{A}^{EE} & \mathbf{A}^{EW} \\ \tilde{\mathbf{A}}^{WR} & \tilde{\mathbf{A}}^{WS} & \mathbf{A}^{WE} & \mathbf{A}^{WW} \end{bmatrix} \right)^{-1} \left\{ \begin{pmatrix} \mathbf{c}^{RR} \\ \mathbf{c}^{SR} \\ \hat{\boldsymbol{\sigma}}^{ER}\mathbf{c}^{TR} \\ \hat{\boldsymbol{\sigma}}^{WR}\mathbf{c}^{TR} \end{pmatrix} + \begin{pmatrix} \mathbf{c}^{SR} \\ \mathbf{c}^{SS} \\ \hat{\boldsymbol{\sigma}}^{ES}\mathbf{c}^{TS} \\ \hat{\boldsymbol{\sigma}}^{WS}\mathbf{c}^{TS} \end{pmatrix} + \right.$$
$$\left. \begin{pmatrix} \hat{\boldsymbol{\lambda}}^{RE}\mathbf{c}^{RT} \\ \hat{\boldsymbol{\lambda}}^{SE}\mathbf{c}^{ST} \\ \mathbf{c}^{EE} \\ \mathbf{c}^{WE} \end{pmatrix} + \begin{pmatrix} \hat{\boldsymbol{\lambda}}^{RW}\mathbf{c}^{RT} \\ \hat{\boldsymbol{\lambda}}^{SW}\mathbf{c}^{ST} \\ \mathbf{c}^{EW} \\ \mathbf{c}^{WW} \end{pmatrix} \right\}$$

The first comparison is based on an estimate $\tilde{\mathbf{A}}^{TT}$ of the Brazilian domestic input coefficients. The aggregated Brazilian intra-country deliveries are obtained as

$$\tilde{\mathbf{Z}}^{TT} = \mathbf{A}^{EE}\hat{\tilde{\mathbf{x}}}^E + \mathbf{A}^{WE}\hat{\tilde{\mathbf{x}}}^E + \mathbf{A}^{EW}\hat{\tilde{\mathbf{x}}}^W + \mathbf{A}^{WW}\hat{\tilde{\mathbf{x}}}^W$$

Defining $\tilde{\mathbf{x}}^T = \tilde{\mathbf{x}}^E + \tilde{\mathbf{x}}^W$, we have $\tilde{\mathbf{A}}^{TT} = \tilde{\mathbf{Z}}^{TT}\left(\hat{\tilde{\mathbf{x}}}^T\right)^{-1}$. The estimates $\tilde{\mathbf{A}}^{RT}$ and $\tilde{\mathbf{A}}^{ST}$ are obtained in a similar way. For example, $\tilde{\mathbf{Z}}^{RT} = \mathbf{A}^{RE}\hat{\tilde{\mathbf{x}}}^E + \mathbf{A}^{RW}\hat{\tilde{\mathbf{x}}}^W$ and $\tilde{\mathbf{A}}^{RT} = \tilde{\mathbf{Z}}^{RT}\left(\hat{\tilde{\mathbf{x}}}^T\right)^{-1}$.

The second comparison is based on estimates for the vectors of state exports (i.e. $\tilde{\mathbf{e}}^{ER}$, $\tilde{\mathbf{e}}^{ES}$, $\tilde{\mathbf{e}}^{WR}$, and $\tilde{\mathbf{e}}^{WS}$) and for the vectors of state import coefficients (i.e. estimates of $(\mathbf{m}^E)'(\hat{\mathbf{x}}^E)^{-1}$ and $(\mathbf{m}^W)'(\hat{\mathbf{x}}^W)^{-1}$). For example, for the state exports we have

$$\tilde{\mathbf{e}}^{ER} = \hat{\boldsymbol{\sigma}}^{ER}\mathbf{A}^{TR}\tilde{\mathbf{x}}^R + \hat{\boldsymbol{\sigma}}^{ER}\mathbf{c}^{TR}$$

The row vector with estimates for the state import coefficients (for example for region E) is obtained as

$$(\boldsymbol{\lambda}^{RE})'\mathbf{A}^{RE}(\hat{\boldsymbol{\mu}}^E)^{-1} + (\boldsymbol{\lambda}^{SE})'\mathbf{A}^{SE}(\hat{\boldsymbol{\mu}}^E)^{-1}$$

APPENDIX A.2.2: DETAILED RESULTS OF CHAPTER 2

Table A.2.1 –Brazilian states' multilateral value-added exports (US$ millions) and share of states' total value added (%); multilateral value-added imports (US$ millions) and share of value added embodied in consumption (%)

	Value-added exports	% Value added in production	Value-added imports	% Value added in consumption
Acre	138	4%	282	7%
Amapá	218	6%	383	8%
Amazonas	2,100	8%	4,949	22%
Pará	8,185	27%	3,542	10%
Rondônia	735	8%	937	9%
Roraima	63	2%	166	6%
Tocantins	465	7%	679	9%
Alagoas	894	9%	837	7%
Bahia	7,298	12%	8,420	11%
Ceará	1,729	6%	3,332	10%
Maranhão	2,833	13%	2,654	11%
Paraíba	413	3%	1,660	9%
Pernambuco	1,708	5%	4,578	10%
Piauí	314	4%	1,021	8%
Sergipe	656	7%	941	8%
Rio Grande do Norte	809	6%	1,341	8%
Distrito Federal	965	2%	5,098	7%
Goiás	3,984	10%	4,610	11%
Mato Grosso	6,138	23%	1,631	8%
Mato Grosso do Sul	2,113	12%	2,298	12%
Espírito Santo	8,933	26%	3,372	11%
Minas Gerais	22,227	16%	15,870	11%
Rio de Janeiro	22,929	13%	20,159	11%
São Paulo	65,211	13%	58,117	14%
Paraná	12,483	14%	12,149	14%
Santa Catarina	7,321	12%	7,754	12%
Rio Grande do Sul	14,749	14%	11,407	11%
Brazil	195,610	13%	178,187	12%

Table A.2.2 – VAX ratios by composite industries

	Manufacturing	Non-Manufacturing
Acre	0.90	5.58
Amapá	0.34	2.17
Amazonas	0.92	4.21
Pará	0.45	0.98
Rondônia	0.32	3.07
Roraima	0.65	2.91
Tocantins	0.56	1.55
Alagoas	0.42	4.69
Bahia	0.38	2.34
Ceará	0.58	2.18
Maranhão	0.56	1.61
Paraíba	0.70	2.66
Pernambuco	0.77	2.22
Piauí	2.00	1.70
Sergipe	0.90	7.55
Rio Grande do Norte	0.49	2.70
Distrito Federal	0.74	1.65
Goiás	0.46	1.39
Mato Grosso	0.25	1.15
Mato Grosso do Sul	0.37	1.70
Espírito Santo	0.52	1.12
Minas Gerais	0.51	1.19
Rio de Janeiro	0.56	1.33
São Paulo	0.52	1.90
Paraná	0.35	2.13
Santa Catarina	0.48	3.04
Rio Grande do Sul	0.39	2.30
Brazil	0.48	1.57
China	0.43	1.66
India	0.39	1.62
Russia	0.74	0.98
US	0.46	1.25
Mexico	0.38	1.47
Canada	0.41	1.27
Germany	0.42	2.31
Spain	0.40	1.52
France	0.36	2.28
United Kingdom	0.44	1.20
Italy	0.42	2.29
Other EU27	0.36	1.10
Japan	0.52	2.32
Korea	0.42	1.55
Taiwan	0.30	2.97
Other countries + RoW	0.34	0.99
Foreign countries	0.41	1.29

Table A.2.3 – Bilateral VAX ratios, Brazil

	Value-added exports to gross exports ratio	Value-added imports to gross imports ratio
China	0.69	0.78
India	3.09	1.00
Russia	1.38	2.59
US	1.05	0.99
Mexico	0.81	0.86
Canada	0.98	0.88
Germany	0.73	0.92
Spain	1.13	0.87
France	1.01	0.93
United Kingdom	1.30	1.14
Italy	0.99	0.89
Other EU27	0.82	0.94
Japan	1.24	1.33
Korea	0.86	0.92
Taiwan	0.63	0.83
Other countries + RoW	0.80	0.70

Table A.2.4 – Bilateral VAX ratios, Rio de Janeiro

	Value-added exports to gross exports ratio	Value-added imports to gross imports ratio
China	0.47	1.29
India	13.47	1.46
Russia	215.95	5.04
US	5.45	0.96
Mexico	2.29	2.19
Canada	6.19	1.11
Germany	1.36	1.08
Spain	1.60	0.90
France	1.29	0.86
United Kingdom	1.43	1.04
Italy	1.84	0.98
Other EU27	1.02	1.02
Japan	32.66	2.06
Korea	63.74	2.02
Taiwan	17.69	2.31
Other countries + RoW	1.27	0.69

Table A.2.5 – Multilateral trade and value-added balances with foreign countries, for Brazilian states (US$ millions)

	Gross Trade			Trade in Value Added		
	Exports	Imports	Balance	Exports	Imports	Balance
Acre	39	123	-83	138	282	-144
Amapá	216	199	17	218	383	-166
Amazonas	1,507	7,759	-6,252	2,100	4,949	-2,849
Pará	10,891	2,527	8,364	8,185	3,542	4,643
Rondonia	657	542	115	735	937	-202
Roraima	30	77	-47	63	166	-102
Tocantins	336	421	-85	465	679	-215
Alagoas	994	489	505	894	837	57
Bahia	9,760	9,342	418	7,298	8,420	-1,122
Ceará	1,548	2,610	-1,062	1,729	3,332	-1,603
Maranhão	2,720	2,367	352	2,833	2,654	179
Paraiba	317	981	-664	413	1,660	-1,248
Pernambuco	1,294	3,627	-2,333	1,708	4,578	-2,869
Piauí	180	382	-202	314	1,021	-708
Sergipe	178	572	-394	656	941	-285
Rio Grande do Norte	475	744	-269	809	1,341	-532
Distrito Federal	660	2,914	-2,254	965	5,098	-4,133
Goiás	4,455	4,443	12	3,984	4,610	-626
Mato Grosso	8,191	1,579	6,612	6,138	1,631	4,508
Mato Grosso do Sul	2,233	2,346	-113	2,113	2,298	-185
Espírito Santo	10,349	3,591	6,758	8,933	3,372	5,561
Minas Gerais	26,649	17,218	9,431	22,227	15,870	6,358
Rio de Janeiro	21,029	21,585	-556	22,929	20,159	2,771
São Paulo	76,443	83,607	-7,164	65,211	58,117	7,094
Paraná	16,373	15,844	529	12,483	12,149	333
Santa Catarina	8,347	8,500	-153	7,321	7,754	-434
Rio Grande do Sul	20,035	14,093	5,942	14,749	11,407	3,342
Brazil	225,905	208,481	17,423	195,610	178,187	17,423

Table A.2.6 – Decomposition of multilateral value-added exports: direct, intermediate and indirect exports (US$ millions)

	Direct exports of final products	Intermediate products directly imported	Indirect exports	
			Brazilian GVCs	Foreign GVCs
Acre	4	73	45	16
Amapá	9	160	16	32
Amazonas	281	1,076	480	263
Pará	186	6,274	309	1,416
Rondônia	154	358	137	85
Roraima	4	37	15	7
Tocantins	35	260	104	65
Alagoas	262	432	117	84
Bahia	943	4,520	673	1,163
Ceará	367	872	239	251
Maranhão	81	1,961	317	474
Paraíba	86	206	69	51
Pernambuco	244	950	290	223
Piauí	21	172	81	39
Sergipe	37	379	154	86
Rio Grande do Norte	99	453	151	107
Distrito Federal	137	569	132	127
Goiás	742	2,123	566	552
Mato Grosso	1,132	3,505	499	1,003
Mato Grosso do Sul	388	1,107	358	260
Espírito Santo	287	6,646	622	1,377
Minas Gerais	2,310	14,600	1,935	3,382
Rio de Janeiro	1,429	15,124	2,380	3,996
São Paulo	16,925	35,042	4,318	8,926
Paraná	3,097	6,462	1,373	1,550
Santa Catarina	1,970	3,545	998	808
Rio Grande do Sul	4,761	6,999	1,297	1,693
Brazil	35,989	113,908	17,676	28,038

Table A.2.7 – Decomposition of multilateral value-added imports: direct, intermediate and indirect exports (US$ millions)

	Direct imports of final products	Intermediate products directly imported	Indirect imports	
			Brazilian GVCs	Foreign GVCs
Acre	45	96	135	7
Amapá	66	132	164	21
Amazonas	2,051	1,159	553	1,185
Pará	665	972	1,681	224
Rondônia	164	325	397	51
Roraima	21	73	69	3
Tocantins	122	246	272	39
Alagoas	109	289	406	34
Bahia	1,679	3,617	2,096	1,028
Ceará	671	1,349	1,101	211
Maranhão	566	901	914	273
Paraíba	333	516	699	113
Pernambuco	928	1,874	1,483	293
Piauí	126	335	526	35
Sergipe	150	303	440	48
Rio Grande do Norte	226	446	599	70
Distrito Federal	708	2,780	1,408	203
Goiás	922	2,284	969	435
Mato Grosso	139	714	715	63
Mato Grosso do Sul	541	1,026	582	150
Espírito Santo	849	785	1,363	375
Minas Gerais	3,047	7,265	3,886	1,671
Rio de Janeiro	3,989	8,827	5,572	1,771
São Paulo	17,280	29,611	3,918	7,308
Paraná	3,050	5,696	1,742	1,660
Santa Catarina	1,852	3,155	1,983	763
Rio Grande do Sul	2,204	5,691	2,176	1,337
Brazil	42,500	80,466	35,850	19,372

Table A.2.8 – Decomposition of Brazilian states' inflows, aggregation over sources (US$ millions)

	Absorption	Reflection	Redirection	
			Other states	Foreign countries
Acre	1,486	18	149	30
Amapá	1,826	10	65	67
Amazonas	8,213	1,514	7,445	1,331
Pará	16,588	241	1,734	3,267
Rondônia	4,634	105	845	361
Roraima	770	13	98	19
Tocantins	3,115	72	692	187
Alagoas	4,306	101	901	554
Bahia	29,482	960	6,612	4,841
Ceará	11,516	235	2,201	658
Maranhão	9,306	118	997	857
Paraíba	7,464	94	888	190
Pernambuco	16,373	278	2,555	743
Piauí	6,112	55	505	135
Sergipe	4,544	121	914	236
Rio Grande do Norte	6,216	125	907	325
Distrito Federal	22,239	139	1,267	270
Goiás	15,699	879	5,712	2,407
Mato Grosso	8,011	647	4,842	3,516
Mato Grosso do Sul	7,119	400	2,297	1,140
Espírito Santo	12,941	541	3,018	3,348
Minas Gerais	56,116	2,445	13,542	9,983
Rio de Janeiro	64,657	1,741	8,944	6,408
São Paulo	90,242	3,671	40,197	24,501
Paraná	29,211	1,846	13,224	8,360
Santa Catarina	23,011	1,164	8,455	4,055
Rio Grande do Sul	33,511	1,963	12,196	8,693
Brazil	494,709	19,494	141,201	86,480

Table A.2.9 – Decomposition of Brazilian states imports, aggregation over sources (US$ millions)

	Absorption	Reflection	Redirection	
			Other states	Foreign countries
Acre	98	1	21	3
Amapá	169	2	16	13
Amazonas	4,128	77	3,151	402
Pará	1,472	104	338	614
Rondônia	380	8	119	35
Roraima	62	0	13	2
Tocantins	295	4	100	22
Alagoas	280	11	147	50
Bahia	5,287	333	2,505	1,218
Ceará	1,785	26	665	134
Maranhão	1,563	67	474	302
Paraíba	760	5	184	32
Pernambuco	2,523	45	874	185
Piauí	311	2	57	11
Sergipe	346	9	181	36
Rio Grande do Norte	517	9	176	44
Distrito Federal	2,527	9	333	44
Goiás	2,805	72	1,211	355
Mato Grosso	568	72	618	334
Mato Grosso do Sul	1,422	55	652	216
Espírito Santo	1,764	144	976	767
Minas Gerais	9,916	426	4,478	2,398
Rio de Janeiro	12,973	806	5,353	2,453
São Paulo	50,582	2,284	21,452	9,309
Paraná	9,006	484	4,661	1,693
Santa Catarina	4,927	226	2,484	863
Rio Grande do Sul	7,781	664	3,911	1,737
Brazil	124,247	5,946	55,152	23,272

Table A.2.10 – Decomposition of Brazilian exports, by destination country (US$ millions)

	Absorption	Reflection	Redirection	
			Other states	Foreign countries
China	16,456	12	135	10,403
India	451	0	1	83
Russia	2,731	0	1	113
USA	25,522	10	67	3,834
Mexico	3,751	4	14	1,341
Canada	2,507	2	12	1,263
Germany	10,978	19	74	7,114
Spain	2,584	1	8	966
France	3,948	4	18	2,001
United Kingdom	3,833	1	9	865
Italy	4,415	3	19	1,808
Other EU27	13,207	18	77	9,612
Japan	4,046	1	11	1,020
Korea	1,540	1	13	1,279
Taiwan	654	1	11	974
Other countries + RoW	67,103	80	446	18,431
Foreign countries	163,726	158	919	61,104

APPENDIX A.3: COMPOSITE INDUSTRIES FOR THE SECTORAL FEEDBACK LOOP ANALYSIS

Table A.3.1 – Composite industries for obtaining the sectoral feedback loop hierarchy

Composite industry		Original industry	
1	Agriculture	1	Agriculture, Hunting, Forestry and Fishing
2	Mining and Quarrying	2	Mining and Quarrying
3	Agribusiness	3	Food, Beverages and Tobacco
		4	Textiles and Textile Products
		5	Leather, Leather and Footwear
		6	Wood and Products of Wood and Cork
		7	Pulp, Paper, Paper , Printing and Publishing
4	Basic Metals and Fabricated Metal	12	Basic Metals and Fabricated Metal
5	Other manufacturing	8	Coke, Refined Petroleum and Nuclear Fuel
		9	Chemicals and Chemical Products
		10	Rubber and Plastics
		11	Other Non-Metallic Mineral
		13	Machinery, Nec
		14	Electrical and Optical Equipment
		15	Transport Equipment
		16	Manufacturing, Nec; Recycling
		17	Electricity, Gas and Water Supply
		18	Construction
6	Transport	21	Transport
7	Services	19	Wholesale and retail trade
		20	Hotels and Restaurants
		22	Post and Telecommunications; Other Business Act.
		23	Financial Intermediation
		24	Real Estate Activities
		25	Public Admin and Defence; Compulsory Social Sec.
		26	Education
		27	Health and Social Work
		28	Other Community, Social and Personal Services

APPENDIX A.4.1: DETAILED RESULTS OF CHAPTER 4

Table A.4.1 – CO_2 emissions (thousand tons) by industry in 2008, Brazilian states

Industry	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI
Agriculture	138	31	255	567	465	48	388	0	844	57	967	192	506	245
Mining and Quarrying	2	48	252	1,339	23	2	10	0	410	0	177	34	11	10
Food, Beverages and Tobacco	5	1	93	86	48	2	21	5	223	61	29	24	150	40
Textiles and Textile Products	0	0	2	3	0	0	0	0	16	40	2	22	21	3
Leather, Leather and Footwear	1	0	0	7	4	0	1	0	4	14	1	40	5	1
Wood and Products of Wood	3	4	3	77	14	1	0	0	48	8	3	0	1	0
Pulp, Paper,	2	6	395	76	5	1	4	0	405	4	10	55	147	16
Refined Petroleum	0	0	376	10	1	0	3	60	1,399	56	43	64	61	11
Chemicals and Chemical Products	2	0	219	162	6	1	23	220	3,652	21	209	23	1,188	37
Rubber and Plastics	2	0	172	11	2	0	4	47	777	4	4	24	92	5
Other Non-Metallic Mineral	18	8	119	594	26	2	53	0	171	116	105	318	525	94
Basic Metals and Fabricated Metal	3	8	1,009	3,072	61	1	7	0	2,452	36	1,386	45	779	67
Machinery, Nec	0	0	18	1	4	0	0	1	47	9	1	0	7	1
Electrical and Optical Equipment	0	0	172	0	0	0	0	1	49	12	0	1	9	0
Transport Equipment	0	0	325	2	4	0	0	2	108	22	1	0	16	3
Manufacturing, Nec; Recycling	0	0	16	3	0	0	0	0	18	3	1	2	7	2
Electricity, Gas and Water Supply	64	69	636	857	425	48	216	29	1,029	16	234	388	1,345	177
Construction	2	1	8	14	2	1	5	2	33	16	9	4	12	3
Wholesale and retail trade	4	5	24	34	13	2	9	1	68	11	27	18	47	13
Hotels and Restaurants	3	3	28	25	5	2	4	0	64	5	18	14	46	8
Transport	121	175	2,797	2,574	500	102	360	1,194	7,381	3,343	3,105	826	3,194	578
Other Business Activities	4	4	25	41	11	4	7	1	38	5	22	16	67	10
Financial Intermediation	1	0	3	5	1	1	1	1	16	2	3	3	12	2
Real Estate Activities	0	0	1	2	0	0	0	0	2	0	1	1	2	0
Public Admin and Defence	17	23	56	80	36	19	26	1	324	33	53	48	129	35
Education	6	7	22	25	10	5	8	0	54	6	23	23	43	10
Health and Social Work	3	4	16	17	7	3	6	0	44	6	15	14	37	11
Other Services	2	3	15	25	8	2	6	0	56	6	18	14	45	10
Households	75	83	316	763	222	36	148	325	2,174	803	508	396	973	292
Total	**476**	**482**	**7,373**	**10,474**	**1,902**	**281**	**1,312**	**1,891**	**21,904**	**4,716**	**6,974**	**2,608**	**9,476**	**1,688**

Table A.4.1 (continued)

Industry	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Brazil
Agriculture	127	165	109	687	2,662	1,061	117	1,866	415	3,463	1,174	2,032	620	19,203
Mining and Quarrying	398	528	4	359	25	101	2,519	1,635	227	219	9	141	52	8,534
Food, Beverages and Tobacco	27	25	31	199	323	146	46	607	393	1,436	209	383	531	5,143
Textiles and Textile Products	16	35	1	0	9	12	7	244	40	368	9	264	34	1,150
Leather, Leather and Footwear	6	1	0	0	8	10	2	43	11	118	2	20	6	305
Wood and Products of Wood	0	0	0	17	37	3	16	115	56	270	39	68	105	891
Pulp, Paper,	11	12	41	0	16	24	383	186	119	1,240	378	454	429	4,418
Refined Petroleum	7	19	0	199	133	150	192	779	1,747	4,780	1,192	12	986	12,279
Chemicals and Chemical Products	121	38	97	61	538	106	170	425	893	2,762	424	684	774	12,855
Rubber and Plastics	10	11	5	13	43	7	36	90	190	587	90	343	164	2,734
Other Non-Metallic Mineral	287	82	419	246	216	120	107	2,952	1,158	4,706	2,701	1,150	179	16,471
Basic Metals and Fabricated Metal	15	29	139	614	195	282	9,858	17,903	11,332	7,987	102	2,336	524	60,241
Machinery, Nec	3	1	1	4	1	9	19	74	114	704	40	159	124	1,342
Electrical and Optical Equipment	0	0	1	6	1	1	23	61	139	1,049	43	58	136	1,764
Transport Equipment	1	0	0	10	1	2	44	176	254	1,208	92	91	1,057	3,419
Manufacturing, Nec; Recycling	1	2	2	1	2	1	6	31	42	210	14	39	50	456
Electricity, Gas and Water Supply	461	231	326	17	519	275	1,081	6	5,314	183	677	1,820	255	16,698
Construction	4	5	13	12	8	7	29	33	83	814	48	20	41	1,229
Wholesale and retail trade	10	17	41	12	45	24	52	41	493	182	20	93	169	1,479
Hotels and Restaurants	10	19	55	12	19	14	17	264	152	698	96	58	107	1,747
Transport	1,027	885	3,001	6,151	2,471	1,909	3,198	17,283	13,492	40,055	12,927	5,664	10,277	144,588
Other Business Activities	12	17	116	17	29	27	26	55	304	149	20	103	103	1,232
Financial Intermediation	2	3	38	1	6	5	10	10	125	52	4	17	37	361
Real Estate Activities	0	1	2	0	1	1	2	1	19	9	1	3	6	56
Public Admin and Defence	34	45	867	41	55	46	79	113	1,133	532	60	85	385	4,352
Education	12	20	24	5	20	17	30	69	329	191	26	48	122	1,155
Health and Social Work	8	13	42	6	17	13	25	75	246	218	29	35	97	1,005
Other Services	9	14	72	2	22	19	33	34	396	104	13	63	132	1,121
Households	212	310	641	1,093	384	381	792	3,855	5,071	7,358	2,157	1,437	2,819	33,623
Total	**2,833**	**2,529**	**6,090**	**9,786**	**7,805**	**4,770**	**18,918**	**49,028**	**44,288**	**81,653**	**22,596**	**17,681**	**20,320**	**359,853**

Table A.4.2 – Production-based and consumption-based CO_2 emissions, net emission transfers (in thousand tons)

	Production-based emissions	Consumption-based emissions	Net emission transfer
Acre	401	780	-378
Amapá	435	895	-460
Amazonas	7,058	7,336	-278
Pará	9,711	8,735	976
Rondônia	1,680	2,500	-819
Roraima	245	453	-208
Tocantins	1,163	1,730	-567
Alagoas	1,567	2,408	-840
Bahia	19,730	21,031	-1,301
Ceará	3,913	7,950	-4,037
Maranhão	6,546	5,749	797
Paraíba	2,212	4,213	-2,001
Pernambuco	8,502	10,992	-2,490
Piauí	1,396	2,975	-1,578
Sergipe	2,621	2,581	39
Rio Grande do Norte	2,222	3,573	-1,351
Distrito Federal	5,450	11,523	-6,074
Goiás	8,693	10,933	-2,240
Mato Grosso	7,435	4,948	2,486
Mato Grosso do Sul	4,389	4,504	-115
Espírito Santo	18,987	6,849	12,137
Minas Gerais	45,173	37,279	7,893
Rio de Janeiro	39,217	45,816	-6,600
São Paulo	74,312	92,412	-18,100
Paraná	20,439	21,638	-1,199
Santa Catarina	16,244	16,133	111
Rio Grande do Sul	17,502	22,406	-4,905
Brazil	327,240	358,343	-31,102
China	5,490,880	3,868,982	1,621,898
India	1,265,525	1,208,975	56,550
Russia	1,332,766	997,572	335,194
USA	4,357,361	5,070,614	-713,254
Mexico	324,155	382,938	-58,783
Canada	396,510	431,510	-35,000
Germany	630,422	810,821	-180,399
Spain	234,982	340,629	-105,647
France	246,121	431,507	-185,386
United Kingdom	430,240	580,163	-149,923
Italy	350,154	475,771	-125,617
Other EU27	1,256,015	1,485,389	-229,374
Japan	960,528	1,173,257	-212,729
Korea	482,798	464,898	17,900
Taiwan	267,873	192,867	75,006
Other countries + RoW	5,422,650	5,501,985	-79,335
Foreign countries	23,448,979	23,417,877	31,102

Table A.4.3 – Participation of domestic, Brazilian states, and foreign countries' components in production-based and consumption-based CO_2 emissions (%)

	Production-based			Consumption-based		
	Domestic	BRA states	Foreign countries	Domestic	BRA states	Foreign countries
Acre	58.83	33.57	7.60	30.29	49.25	20.46
Amapá	55.22	16.60	28.18	26.82	47.97	25.21
Amazonas	27.71	60.05	12.24	26.66	24.53	48.81
Pará	25.02	20.15	54.83	27.81	48.02	24.17
Rondônia	44.28	42.40	13.32	29.77	45.80	24.44
Roraima	59.48	33.93	6.60	32.16	46.89	20.95
Tocantins	46.59	41.20	12.22	31.32	44.45	24.23
Alagoas	49.31	36.72	13.97	32.10	46.28	21.63
Bahia	43.02	31.91	25.07	40.36	33.52	26.12
Ceará	64.57	27.33	8.10	31.78	41.89	26.33
Maranhão	29.06	39.92	31.02	33.09	35.26	31.65
Paraíba	56.72	37.09	6.19	29.78	44.72	25.50
Pernambuco	51.42	38.50	10.08	39.77	34.51	25.71
Piauí	65.07	27.42	7.51	30.54	47.40	22.06
Sergipe	36.95	51.28	11.77	37.51	40.04	22.45
Rio Grande do Norte	48.18	39.31	12.51	29.96	48.30	21.74
Distrito Federal	70.50	25.72	3.77	33.34	43.49	23.16
Goiás	50.26	33.12	16.62	39.96	34.56	25.48
Mato Grosso	25.56	44.89	29.55	38.40	40.51	21.09
Mato Grosso do Sul	37.61	42.97	19.42	36.65	34.43	28.92
Espírito Santo	10.11	41.22	48.67	28.03	40.81	31.15
Minas Gerais	36.48	32.29	31.24	44.20	30.85	24.95
Rio de Janeiro	48.22	32.43	19.35	41.27	35.08	23.64
São Paulo	46.46	35.77	17.77	37.36	26.66	35.99
Paraná	38.49	43.96	17.55	36.36	29.87	33.77
Santa Catarina	37.08	44.72	18.20	37.33	30.96	31.71
Rio Grande do Sul	44.12	35.50	20.38	34.46	33.43	32.11
Brazil	40.87	36.24	22.88	37.33	33.10	29.58
China	62.35	0.54	37.10	88.49	0.17	11.34
India	80.71	0.26	19.03	84.48	0.06	15.45
Russia	64.46	0.40	35.14	86.11	0.13	13.76
US	88.90	0.21	10.89	76.40	0.27	23.33
Mexico	81.05	0.19	18.76	68.61	0.47	30.92
Canada	61.30	0.72	37.98	56.33	0.36	43.31
Germany	60.86	0.59	38.54	47.32	0.55	52.13
Spain	71.22	0.31	28.47	49.13	0.46	50.41
France	67.94	0.33	31.73	38.75	0.52	60.73
United Kingdom	71.52	0.28	28.20	53.04	0.32	46.64
Italy	70.83	0.34	28.83	52.13	0.45	47.42
Other EU27	66.93	0.36	32.71	56.59	0.44	42.96
Japan	78.19	0.23	21.57	64.02	0.24	35.74
Korea	61.00	0.44	38.56	63.35	0.29	36.36
Taiwan	47.50	0.66	51.85	65.97	0.31	33.72
Other countries + RoW	71.84	0.67	27.49	70.80	0.47	28.73
Foreign countries	71.93	0.45	27.62	72.02	0.32	27.66

Table A.4.4– Interregional trade in CO_2 emissions (in thousand tons)

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
AC	-	0	2	4	2	0	1	1	7	3	2	4	5	1	1	2	7	3	2	2	3	12	14	30	7	6	12	135
AP	0	-	1	2	0	0	0	0	4	2	1	1	2	0	1	1	4	2	1	1	2	8	8	17	4	3	7	72
AM	12	13	-	136	46	9	20	28	172	84	60	47	116	38	33	44	161	97	72	42	91	352	532	1,509	171	134	221	4,238
PA	5	6	34	-	14	3	11	16	86	51	60	26	58	23	13	30	119	45	26	25	44	165	242	486	105	86	176	1,956
RO	6	2	36	17	-	1	2	5	31	13	15	8	17	6	5	7	53	14	10	11	22	63	76	161	42	22	69	713
RR	0	0	1	3	1	-	0	0	5	2	1	1	2	1	0	1	3	2	1	1	1	7	23	15	3	4	5	83
TO	1	2	7	23	3	1	-	3	24	16	21	7	14	7	4	5	31	18	5	6	11	57	51	95	18	14	36	479
AL	1	2	6	16	6	1	3	-	52	19	6	16	62	8	11	7	16	10	6	5	7	38	112	95	22	21	28	576
BA	18	20	85	177	54	10	37	80	-	189	107	102	285	77	103	98	272	166	100	86	165	588	692	1,778	323	293	389	6,296
CE	3	5	16	45	8	2	5	10	78	-	32	38	70	49	9	70	33	30	11	10	17	79	95	213	38	48	54	1,069
MA	12	9	35	176	29	6	39	26	200	85	-	39	85	83	16	43	108	88	60	23	40	365	244	480	103	80	138	2,613
PB	5	2	9	20	5	1	3	15	57	61	15	-	71	10	9	61	41	12	7	9	16	58	68	162	24	30	48	820
PE	7	9	40	82	21	5	14	82	372	206	76	213	-	50	45	98	158	56	34	37	71	221	289	662	117	93	216	3,274
PI	1	2	5	16	3	1	3	3	22	33	45	5	12	-	2	4	12	8	4	4	6	26	36	75	17	14	25	383
SE	3	4	16	27	10	2	6	23	142	36	24	15	42	14	-	16	87	37	14	17	31	108	145	309	55	45	118	1,344
RN	2	3	14	24	7	1	4	6	67	50	12	22	34	10	8	-	31	20	12	9	17	79	64	234	48	36	59	873
DF	4	7	15	44	18	2	13	7	80	25	12	21	25	17	6	14	-	127	11	12	18	209	387	205	34	39	51	1,402
GO	9	11	38	110	22	5	39	23	145	75	49	45	85	33	22	48	169	-	50	35	49	384	303	729	166	97	139	2,879
MT	10	15	60	134	50	5	16	26	204	86	62	60	95	46	27	41	98	74	-	64	55	280	598	672	258	131	171	3,337
MS	6	7	43	68	17	3	9	14	102	41	30	26	45	21	14	20	53	45	43	-	28	147	256	530	142	87	88	1,886
ES	18	18	117	185	52	10	36	55	440	155	101	83	222	59	57	82	248	219	115	82	-	817	1,013	2,543	429	272	395	7,826
MG	40	44	227	401	112	24	82	116	843	460	230	176	438	127	122	164	555	587	226	175	552	-	2,237	4,565	778	538	764	14,585
RJ	42	42	210	464	124	25	84	116	717	338	226	177	449	136	121	181	572	448	244	171	504	1,444	-	3,665	692	691	837	12,718
SP	95	117	499	1,082	310	54	183	262	1,932	769	440	435	971	334	232	403	1,320	1,032	548	432	630	3,702	5,535	-	1,807	1,317	2,141	26,581
PR	37	37	105	402	96	19	68	76	527	178	125	123	212	97	60	113	338	268	191	122	140	1,006	1,225	2,309	-	529	582	8,986
SC	24	26	98	271	63	13	45	63	387	172	136	90	196	74	58	86	295	183	106	99	150	683	835	1,675	716	-	721	7,265
RS	24	25	79	266	72	11	48	56	354	183	138	102	183	88	53	87	229	187	103	71	125	604	992	1,421	345	366	-	6,212
Total	384	430	1,800	4,194	1,145	212	769	1,114	7,050	3,330	2,027	1,884	3,794	1,410	1,034	1,726	5,012	3,778	2,005	1,550	2,796	11,500	16,075	24,635	6,463	4,995	7,490	118,602

Table A.4.5 – Share of bilateral trade in CO_2 emissions in total interregional trade (%)

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
AC	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.01	0.01	0.01	0.11
AP	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.06
AM	0.01	0.01	-	0.11	0.04	0.01	0.02	0.02	0.15	0.07	0.05	0.04	0.10	0.03	0.03	0.04	0.14	0.08	0.06	0.04	0.08	0.30	0.45	1.27	0.14	0.11	0.19	3.57
PA	0.00	0.01	0.03	-	0.01	0.00	0.01	0.01	0.07	0.04	0.05	0.02	0.05	0.02	0.01	0.03	0.10	0.04	0.02	0.02	0.04	0.14	0.20	0.41	0.09	0.07	0.15	1.65
RO	0.00	0.00	0.03	0.01	-	0.00	0.00	0.00	0.03	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.04	0.01	0.01	0.01	0.02	0.05	0.06	0.14	0.04	0.02	0.06	0.60
RR	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.07
TO	0.00	0.00	0.01	0.02	0.00	0.00	-	0.00	0.02	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.03	0.02	0.00	0.00	0.01	0.05	0.04	0.08	0.01	0.01	0.03	0.40
AL	0.00	0.00	0.00	0.01	0.00	0.00	0.00	-	0.04	0.02	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.09	0.08	0.02	0.02	0.02	0.49
BA	0.01	0.02	0.07	0.15	0.05	0.01	0.03	0.07	-	0.16	0.09	0.09	0.24	0.06	0.09	0.08	0.23	0.14	0.08	0.07	0.14	0.50	0.58	1.50	0.27	0.25	0.33	5.31
CE	0.00	0.00	0.01	0.04	0.01	0.00	0.00	0.01	0.07	-	0.03	0.03	0.06	0.04	0.01	0.06	0.03	0.03	0.01	0.01	0.01	0.07	0.08	0.18	0.03	0.04	0.05	0.90
MA	0.01	0.01	0.03	0.15	0.02	0.01	0.03	0.02	0.17	0.07	-	0.03	0.07	0.07	0.01	0.04	0.09	0.07	0.05	0.02	0.03	0.31	0.21	0.40	0.09	0.07	0.12	2.20
PB	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.01	0.05	0.05	0.01	-	0.06	0.01	0.01	0.05	0.03	0.01	0.01	0.01	0.01	0.05	0.06	0.14	0.02	0.02	0.04	0.69
PE	0.01	0.01	0.03	0.07	0.02	0.00	0.01	0.07	0.31	0.17	0.06	0.18	-	0.04	0.04	0.08	0.13	0.05	0.03	0.03	0.06	0.19	0.24	0.56	0.10	0.08	0.18	2.76
PI	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.00	0.01	-	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02	0.03	0.06	0.01	0.01	0.02	0.32
SE	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.02	0.12	0.03	0.02	0.01	0.04	0.01	-	0.01	0.07	0.03	0.01	0.01	0.03	0.09	0.12	0.26	0.05	0.04	0.10	1.13
RN	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.06	0.04	0.01	0.02	0.03	0.01	0.01	-	0.03	0.02	0.01	0.01	0.01	0.07	0.05	0.20	0.04	0.03	0.05	0.74
DF	0.00	0.01	0.01	0.04	0.02	0.00	0.01	0.01	0.07	0.02	0.01	0.02	0.02	0.01	0.00	0.01	-	0.11	0.01	0.01	0.02	0.18	0.33	0.17	0.03	0.03	0.04	1.18
GO	0.01	0.01	0.03	0.09	0.02	0.00	0.03	0.02	0.12	0.06	0.04	0.04	0.07	0.03	0.02	0.04	0.14	-	0.04	0.03	0.04	0.32	0.26	0.61	0.14	0.08	0.12	2.43
MT	0.01	0.01	0.05	0.11	0.04	0.00	0.01	0.02	0.17	0.07	0.05	0.05	0.08	0.04	0.02	0.03	0.08	0.06	-	0.05	0.05	0.24	0.50	0.57	0.22	0.11	0.14	2.81
MS	0.01	0.01	0.04	0.06	0.01	0.00	0.01	0.01	0.09	0.03	0.03	0.02	0.04	0.02	0.01	0.02	0.04	0.04	0.04	-	0.02	0.12	0.22	0.45	0.12	0.07	0.07	1.59
ES	0.02	0.02	0.10	0.16	0.04	0.01	0.03	0.05	0.37	0.13	0.08	0.07	0.19	0.05	0.05	0.07	0.21	0.18	0.10	0.07	-	0.69	0.85	2.14	0.36	0.23	0.33	6.60
MG	0.03	0.04	0.19	0.34	0.09	0.02	0.07	0.10	0.71	0.39	0.19	0.15	0.37	0.11	0.10	0.14	0.47	0.50	0.19	0.15	0.47	-	1.89	3.85	0.66	0.45	0.64	12.30
RJ	0.04	0.04	0.18	0.39	0.10	0.02	0.07	0.10	0.60	0.28	0.19	0.15	0.38	0.11	0.10	0.15	0.48	0.38	0.21	0.14	0.42	1.22	-	3.09	0.58	0.58	0.71	10.72
SP	0.08	0.10	0.42	0.91	0.26	0.05	0.15	0.22	1.63	0.65	0.37	0.37	0.82	0.28	0.20	0.34	1.11	0.87	0.46	0.36	0.53	3.12	4.67	-	1.52	1.11	1.81	22.41
PR	0.03	0.03	0.09	0.34	0.08	0.02	0.06	0.06	0.44	0.15	0.11	0.10	0.18	0.08	0.05	0.10	0.28	0.23	0.16	0.10	0.12	0.85	1.03	1.95	-	0.45	0.49	7.58
SC	0.02	0.02	0.08	0.23	0.05	0.01	0.04	0.05	0.33	0.15	0.11	0.08	0.16	0.06	0.05	0.07	0.25	0.15	0.09	0.08	0.13	0.58	0.70	1.41	0.60	-	0.61	6.13
RS	0.02	0.02	0.07	0.22	0.06	0.01	0.04	0.05	0.30	0.15	0.12	0.09	0.15	0.07	0.04	0.07	0.19	0.16	0.09	0.06	0.10	0.51	0.84	1.20	0.29	0.31	-	5.24
Total	0.32	0.36	1.52	3.54	0.97	0.18	0.65	0.94	5.94	2.81	1.71	1.59	3.20	1.19	0.87	1.45	4.23	3.19	1.69	1.31	2.36	9.70	13.55	20.77	5.45	4.21	6.32	100.00

Table A.4.6 – Interregional trade in CO_2 emissions / interregional trade in value added (thousand tons / 2008 US$ million)

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
AC	-	0.17	0.13	0.16	0.22	0.22	0.18	0.21	0.14	0.19	0.22	0.19	0.17	0.17	0.19	0.23	0.14	0.20	0.24	0.23	0.20	0.15	0.17	0.20	0.18	0.14	0.21	0.18
AP	0.29	-	0.08	0.12	0.29	0.20	0.17	0.26	0.11	0.30	0.22	0.16	0.17	0.27	0.15	0.24	0.19	0.21	0.30	0.22	0.17	0.12	0.17	0.21	0.15	0.10	0.23	0.16
AM	0.28	0.32	-	0.28	0.34	0.34	0.31	0.31	0.31	0.31	0.28	0.31	0.29	0.28	0.27	0.29	0.33	0.27	0.34	0.27	0.27	0.30	0.29	0.32	0.32	0.30	0.30	0.31
PA	0.56	0.35	0.35	-	0.40	0.50	0.41	0.43	0.46	0.39	0.42	0.30	0.31	0.34	0.44	0.46	0.28	0.45	0.54	0.48	0.39	0.33	0.35	0.42	0.41	0.29	0.45	0.38
RO	0.33	0.28	0.24	0.26	-	0.30	0.27	0.28	0.24	0.29	0.37	0.27	0.28	0.28	0.26	0.33	0.51	0.28	0.32	0.41	0.42	0.30	0.35	0.31	0.26	0.27	0.46	0.32
RR	0.27	0.23	0.14	0.23	0.30	-	0.21	0.18	0.20	0.24	0.21	0.24	0.15	0.20	0.15	0.35	0.12	0.20	0.26	0.25	0.26	0.19	0.46	0.20	0.19	0.20	0.22	0.23
TO	0.33	0.14	0.26	0.30	0.15	0.35	-	0.22	0.28	0.22	0.35	0.17	0.17	0.18	0.27	0.34	0.14	0.33	0.34	0.36	0.38	0.23	0.22	0.27	0.26	0.21	0.30	0.24
AL	0.19	0.29	0.22	0.27	0.31	0.23	0.21	-	0.24	0.33	0.19	0.33	0.25	0.22	0.15	0.31	0.16	0.23	0.20	0.17	0.20	0.25	0.60	0.20	0.22	0.24	0.20	0.26
BA	0.53	0.49	0.53	0.55	0.53	0.57	0.56	0.51	-	0.56	0.52	0.53	0.49	0.50	0.40	0.57	0.44	0.60	0.57	0.52	0.52	0.56	0.53	0.43	0.55	0.54	0.51	0.49
CE	0.12	0.14	0.11	0.13	0.13	0.16	0.13	0.15	0.14	-	0.12	0.18	0.15	0.17	0.11	0.23	0.10	0.14	0.14	0.10	0.10	0.11	0.12	0.13	0.13	0.14	0.11	0.13
MA	0.91	0.47	0.36	0.58	0.60	0.78	0.62	0.55	0.55	0.49	-	0.52	0.37	0.48	0.42	0.55	0.42	0.69	0.67	0.40	0.47	0.63	0.46	0.40	0.41	0.42	0.40	0.48
PB	0.43	0.38	0.38	0.33	0.38	0.45	0.36	0.46	0.43	0.42	0.37	-	0.31	0.36	0.31	0.43	0.43	0.37	0.38	0.38	0.43	0.31	0.41	0.33	0.34	0.38	0.43	0.37
PE	0.47	0.45	0.46	0.46	0.45	0.49	0.45	0.41	0.47	0.50	0.45	0.38	-	0.45	0.33	0.42	0.51	0.48	0.47	0.49	0.52	0.50	0.51	0.42	0.46	0.48	0.48	0.46
PI	0.36	0.32	0.23	0.28	0.36	0.37	0.32	0.36	0.31	0.41	0.36	0.30	0.32	-	0.30	0.34	0.27	0.33	0.38	0.31	0.27	0.25	0.29	0.30	0.27	0.22	0.28	0.30
SE	0.49	0.43	0.41	0.43	0.45	0.47	0.42	0.46	0.47	0.45	0.43	0.41	0.38	0.40	-	0.49	0.41	0.46	0.47	0.46	0.44	0.40	0.49	0.45	0.41	0.37	0.45	0.44
RN	0.24	0.27	0.29	0.25	0.29	0.33	0.29	0.31	0.31	0.37	0.29	0.30	0.26	0.24	0.24	-	0.33	0.34	0.33	0.31	0.34	0.33	0.33	0.30	0.33	0.34	0.33	0.31
DF	0.19	0.31	0.14	0.19	0.25	0.28	0.18	0.20	0.18	0.44	0.12	0.27	0.16	0.21	0.12	0.34	-	0.20	0.25	0.14	0.16	0.16	0.39	0.32	0.21	0.13	0.20	0.23
GO	0.30	0.28	0.26	0.29	0.30	0.29	0.29	0.26	0.28	0.29	0.24	0.27	0.27	0.27	0.28	0.30	0.23	-	0.29	0.26	0.26	0.27	0.31	0.26	0.27	0.30	0.26	0.27
MT	0.37	0.42	0.31	0.37	0.44	0.36	0.37	0.34	0.38	0.39	0.30	0.37	0.31	0.35	0.31	0.41	0.28	0.33	-	0.37	0.33	0.33	0.54	0.34	0.32	0.30	0.33	0.36
MS	0.44	0.38	0.32	0.41	0.48	0.40	0.36	0.35	0.37	0.38	0.30	0.37	0.35	0.35	0.34	0.40	0.36	0.37	0.42	-	0.37	0.40	0.46	0.33	0.32	0.38	0.34	0.36
ES	0.86	0.59	1.05	0.92	0.76	0.93	0.94	0.85	0.89	0.79	0.93	0.72	0.74	0.60	0.90	0.94	0.53	1.00	1.12	1.01	-	0.56	0.63	0.87	1.00	0.90	0.86	0.78
MG	0.42	0.38	0.45	0.40	0.41	0.48	0.40	0.43	0.44	0.45	0.41	0.40	0.42	0.37	0.43	0.45	0.43	0.47	0.45	0.42	0.36	-	0.43	0.41	0.51	0.48	0.47	0.43
RJ	0.31	0.27	0.31	0.33	0.28	0.35	0.29	0.35	0.31	0.37	0.31	0.31	0.33	0.26	0.31	0.34	0.29	0.33	0.31	0.28	0.36	0.29	-	0.33	0.29	0.32	0.25	0.31
SP	0.19	0.18	0.15	0.19	0.18	0.20	0.17	0.19	0.17	0.22	0.15	0.18	0.18	0.17	0.16	0.21	0.15	0.16	0.18	0.15	0.14	0.15	0.20	-	0.15	0.15	0.16	0.17
PR	0.35	0.30	0.26	0.35	0.36	0.41	0.37	0.31	0.33	0.33	0.23	0.32	0.27	0.28	0.24	0.36	0.37	0.33	0.36	0.26	0.23	0.32	0.30	0.28	-	0.29	0.26	0.30
SC	0.40	0.35	0.37	0.39	0.39	0.41	0.40	0.36	0.39	0.40	0.34	0.38	0.34	0.36	0.36	0.43	0.44	0.41	0.41	0.39	0.37	0.41	0.37	0.35	0.31	-	0.35	0.36
RS	0.25	0.27	0.21	0.25	0.27	0.26	0.26	0.23	0.26	0.25	0.19	0.26	0.21	0.23	0.21	0.26	0.27	0.23	0.26	0.20	0.23	0.24	0.30	0.19	0.20	0.24	-	0.23
Total	0.30	0.27	0.25	0.29	0.28	0.32	0.28	0.30	0.27	0.34	0.25	0.29	0.27	0.26	0.26	0.32	0.26	0.27	0.29	0.25	0.25	0.24	0.29	0.35	0.26	0.25	0.26	0.28

Table A.4.7 – Balance of interregional trade in CO_2 emissions (thousand tons)

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
AC	-	0	-9	-1	-4	0	-0	-0	-11	-0	-10	-1	-3	0	-2	-1	3	-5	-8	-4	-15	-28	-28	-64	-29	-18	-12	-249
AP	-0	-	-12	-4	-1	-0	-1	-2	-16	-3	-8	-2	-8	-1	-3	-2	-2	-9	-14	-6	-16	-36	-34	-100	-33	-24	-19	-357
AM	9	12	-	102	10	8	13	22	87	68	25	38	76	32	18	30	145	58	12	-0	-25	125	322	1,010	66	35	141	2,439
PA	1	4	-102	-	-3	0	-12	-1	-91	5	-116	6	-24	7	-14	6	76	-65	-108	-43	-141	-236	-222	-596	-297	-185	-90	-2,238
RO	4	1	-10	3	-	0	-0	-1	-23	5	-14	3	-4	3	-5	0	34	-8	-40	-7	-31	-49	-47	-149	-54	-40	-3	-432
RR	-0	0	-8	-0	-0	-	-0	-0	-6	0	-5	0	-3	1	-1	-0	2	-3	-4	-2	-9	-17	-2	-38	-16	-10	-7	-129
TO	0	1	-13	12	0	0	-	1	-12	11	-17	4	0	4	-2	1	18	-21	-11	-4	-25	-25	-32	-88	-50	-30	-12	-290
AL	0	2	-22	1	1	0	-1	-	-28	8	-20	1	-20	5	-12	0	9	-13	-20	-9	-48	-78	-5	-168	-54	-41	-28	-539
BA	11	16	-87	91	23	6	12	28	-	111	-93	45	-86	54	-39	32	191	21	-104	-17	-275	-254	-25	-153	-204	-94	35	-754
CE	0	3	-68	-5	-5	-0	-11	-8	-111	-	-53	-23	-135	16	-27	20	8	-45	-75	-31	-138	-381	-242	-556	-140	-124	-129	-2,261
MA	10	8	-25	116	14	5	17	20	93	53	-	24	9	38	-8	31	96	39	-2	-8	-61	134	19	40	-23	-55	1	586
PB	1	2	-38	-6	-3	-0	-4	-1	-45	23	-24	-	-142	5	-6	39	19	-33	-52	-17	-67	-118	-109	-273	-99	-61	-54	-1,064
PE	3	8	-76	24	4	3	-0	20	86	135	-9	142	-	38	4	65	133	-29	-61	-8	-152	-217	-159	-309	-95	-103	34	-520
PI	-0	1	-32	-7	-3	-1	-4	-5	-54	-16	-38	-5	-38	-	-11	-6	-5	-25	-42	-17	-53	-101	-99	-259	-81	-61	-63	-1,027
SE	2	3	-18	14	5	1	2	12	39	27	8	6	-4	11	-	8	81	14	-13	3	-25	-14	24	77	-6	-13	65	310
RN	1	2	-30	-6	-0	0	-1	-0	-32	-20	-31	-39	-65	6	-8	-	17	-27	-29	-11	-65	-85	-116	-169	-64	-50	-28	-852
DF	-3	2	-145	-76	-34	-2	-18	-9	-191	-8	-96	-19	-133	5	-81	-17	-	-41	-87	-41	-231	-347	-185	-1,115	-304	-256	-178	-3,610
GO	5	9	-58	65	8	3	21	13	-21	45	-39	33	29	25	-14	27	41	-	-24	-10	-169	-204	-145	-304	-102	-86	-48	-899
MT	8	14	-12	108	40	4	11	20	104	75	2	52	61	42	13	29	87	24	-	21	-60	54	353	124	67	26	67	1,333
MS	4	6	0	43	7	2	4	9	17	31	8	17	8	17	-3	11	41	10	-21	-	-54	-28	85	97	20	-12	17	335
ES	15	16	25	141	31	9	25	48	275	138	61	67	152	53	25	65	231	169	60	54	-	265	509	1,914	289	122	270	5,030
MG	28	36	-125	236	49	17	25	78	254	381	-134	118	217	101	14	85	347	204	-54	28	-265	-	794	863	-228	-146	161	3,084
RJ	28	34	-322	222	47	2	32	5	25	242	-19	109	159	99	-24	116	185	145	-353	-85	-509	-794	-	-1,870	-533	-144	-155	-3,356
SP	64	100	-1,010	596	149	38	88	168	153	556	-40	273	309	259	-77	169	1,115	304	-124	-97	-1,914	-863	1,870	-	-502	-358	720	1,946
PR	29	33	-66	297	54	16	50	54	204	140	23	99	95	81	6	64	304	102	-67	-20	-289	228	533	502	-	-187	237	2,522
SC	18	24	-35	185	40	10	30	41	94	124	55	61	103	61	13	50	256	86	-26	12	-122	146	144	358	187	-	355	2,270
RS	12	19	-141	90	3	7	12	28	-35	129	-1	54	-34	63	-65	28	178	48	-67	-17	-270	-161	155	-720	-237	-355	-	-1,278
Total	249	357	-2,439	2,238	432	129	290	539	754	2,261	-586	1,064	520	1,027	-310	852	3,610	899	-1,333	-335	-5,030	-3,084	3,356	-1,946	-2,522	-2,270	1,278	0.00

Table A.4.8 – Exports in CO_2 emissions (in thousand tons), Brazilian states

	CHN	IND	RUS	USA	MEX	CAN	DEU	ESP	FRA	GBR	ITA	Other EU27	JPN	KOR	TWN	Other + RoW	Total
AC	3	0	1	3	0	0	2	1	1	2	1	3	1	0	0	12	31
AP	12	1	1	44	2	3	4	1	2	3	2	8	3	1	1	32	123
AM	56	8	14	137	28	16	52	15	24	24	23	74	20	8	4	362	864
PA	543	60	57	1,249	110	289	270	93	188	102	126	410	442	86	27	1,272	5,325
RO	14	1	23	21	2	3	11	6	6	11	8	21	6	2	1	86	224
RR	1	0	0	2	0	0	1	0	1	1	1	2	1	0	0	6	16
TO	25	1	6	12	1	2	7	12	5	4	3	15	4	1	0	44	142
AL	12	4	10	33	3	7	13	4	7	6	5	26	4	3	1	83	219
BA	406	50	66	911	168	89	422	101	166	137	220	537	134	48	25	1,465	4,946
CE	17	3	7	56	7	7	27	8	13	15	15	43	7	2	1	88	317
MA	208	26	27	460	58	48	90	57	56	44	48	165	75	24	10	633	2,030
PB	9	1	3	30	3	3	8	3	4	4	5	13	4	2	1	44	137
PE	54	9	16	150	19	20	50	17	25	30	24	83	21	8	4	328	857
PI	12	1	2	13	2	2	7	3	5	4	3	10	5	1	1	34	105
SE	21	3	5	51	6	5	16	6	8	8	8	36	8	3	1	125	308
RN	14	2	4	61	4	5	15	9	9	12	8	34	6	2	1	93	278
DF	14	1	5	24	3	3	19	4	7	8	9	29	9	2	1	67	205
GO	159	34	49	134	19	18	105	87	58	48	42	163	53	18	5	454	1,444
MT	375	14	52	168	13	23	107	107	80	79	71	254	59	39	10	745	2,197
MS	94	7	28	139	9	13	43	13	31	22	22	72	28	13	3	314	852
ES	722	93	114	2,484	279	176	393	192	217	164	231	590	436	383	138	2,630	9,241
MG	1,178	159	207	2,799	359	272	936	245	407	333	427	1,196	634	365	214	4,380	14,110
RJ	893	98	101	1,132	181	122	364	156	212	179	200	619	198	86	41	3,009	7,590
SP	847	118	257	2,157	330	244	830	249	404	349	365	1,255	336	137	70	5,261	13,209
PR	332	29	74	428	60	64	280	71	132	98	106	366	115	48	15	1,367	3,586
SC	185	25	60	425	62	58	175	53	85	90	80	263	127	31	12	1,225	2,957
RS	298	30	85	603	69	48	202	58	96	86	89	313	97	38	14	1,441	3,567
Total	6,502	778	1,274	13,725	1,798	1,542	4,448	1,569	2,249	1,862	2,143	6,601	2,834	1,353	601	25,600	74,880

Table A.4.9 – Share of bilateral trade in CO_2 emissions in total exports (%), Brazilian states

	CHN	IND	RUS	MEX	CAN	DEU	ESP	FRA	GBR	ITA	Other EU27	JPN	KOR	USA	TWN	Other + RoW	Total
AC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04
AP	0.02	0.00	0.00	0.06	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.04	0.16
AM	0.08	0.01	0.02	0.18	0.04	0.02	0.07	0.02	0.03	0.03	0.03	0.10	0.03	0.01	0.01	0.48	1.15
PA	0.73	0.08	0.08	1.67	0.15	0.39	0.36	0.12	0.25	0.14	0.17	0.55	0.59	0.11	0.04	1.70	7.11
RO	0.02	0.00	0.03	0.03	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.11	0.30
RR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
TO	0.03	0.00	0.01	0.02	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.02	0.01	0.00	0.00	0.06	0.19
AL	0.02	0.00	0.01	0.04	0.00	0.01	0.02	0.00	0.01	0.01	0.01	0.03	0.01	0.00	0.00	0.11	0.29
BA	0.54	0.07	0.09	1.22	0.22	0.12	0.56	0.13	0.22	0.18	0.29	0.72	0.18	0.06	0.03	1.96	6.60
CE	0.02	0.00	0.01	0.08	0.01	0.01	0.04	0.01	0.02	0.02	0.02	0.06	0.01	0.00	0.00	0.12	0.42
MA	0.28	0.03	0.04	0.61	0.08	0.06	0.12	0.08	0.08	0.06	0.06	0.22	0.10	0.03	0.01	0.85	2.71
PB	0.01	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.00	0.00	0.06	0.18
PE	0.07	0.01	0.02	0.20	0.02	0.03	0.07	0.02	0.03	0.04	0.03	0.11	0.03	0.01	0.01	0.44	1.14
PI	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.05	0.14
SE	0.03	0.00	0.01	0.07	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.05	0.01	0.00	0.00	0.17	0.41
RN	0.02	0.00	0.00	0.08	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.05	0.01	0.00	0.00	0.12	0.37
DF	0.02	0.00	0.01	0.03	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.04	0.01	0.00	0.00	0.09	0.27
GO	0.21	0.05	0.07	0.18	0.03	0.02	0.14	0.12	0.08	0.06	0.06	0.22	0.07	0.02	0.01	0.61	1.93
MT	0.50	0.02	0.07	0.22	0.02	0.03	0.14	0.14	0.11	0.11	0.10	0.34	0.08	0.05	0.01	1.00	2.93
MS	0.13	0.01	0.04	0.19	0.01	0.02	0.06	0.02	0.04	0.03	0.03	0.10	0.04	0.02	0.00	0.42	1.14
ES	0.96	0.12	0.15	3.32	0.37	0.24	0.52	0.26	0.29	0.22	0.31	0.79	0.58	0.51	0.18	3.51	12.34
MG	1.57	0.21	0.28	3.74	0.48	0.36	1.25	0.33	0.54	0.44	0.57	1.60	0.85	0.49	0.29	5.85	18.84
RJ	1.19	0.13	0.13	1.51	0.24	0.16	0.49	0.21	0.28	0.24	0.27	0.83	0.26	0.11	0.06	4.02	10.14
SP	1.13	0.16	0.34	2.88	0.44	0.33	1.11	0.33	0.54	0.47	0.49	1.68	0.45	0.18	0.09	7.03	17.64
PR	0.44	0.04	0.10	0.57	0.08	0.09	0.37	0.10	0.18	0.13	0.14	0.49	0.15	0.06	0.02	1.83	4.79
SC	0.25	0.03	0.08	0.57	0.08	0.08	0.23	0.07	0.11	0.12	0.11	0.35	0.17	0.04	0.02	1.64	3.95
RS	0.40	0.04	0.11	0.81	0.09	0.06	0.27	0.08	0.13	0.12	0.12	0.42	0.13	0.05	0.02	1.92	4.76
Total	8.68	1.04	1.70	18.33	2.40	2.06	5.94	2.10	3.00	2.49	2.86	8.82	3.79	1.81	0.80	34.19	100.00

Table A.4.10 – Exports in CO_2 emissions / exports in value added (thousand tons / 2008 US$ million), Brazilian states

	CHN	IND	RUS	MEX	CAN	DEU	ESP	FRA	GBR	ITA	Other EU27	JPN	KOR	USA	TWN	Other + RoW	Total
AC	0.23	0.22	0.23	0.23	0.22	0.21	0.21	0.22	0.24	0.17	0.18	0.22	0.23	0.24	0.24	0.23	0.22
AP	0.52	0.69	0.47	0.88	0.72	0.75	0.49	0.44	0.54	0.38	0.40	0.34	0.54	0.59	0.64	0.45	0.56
AM	0.47	0.51	0.44	0.43	0.38	0.39	0.44	0.44	0.47	0.35	0.38	0.44	0.47	0.50	0.47	0.38	0.41
PA	0.55	0.76	0.65	0.59	0.82	0.72	0.74	0.61	0.59	0.58	0.62	0.68	0.81	0.64	0.71	0.69	0.65
RO	0.32	0.34	0.26	0.39	0.43	0.36	0.32	0.29	0.31	0.27	0.28	0.30	0.32	0.35	0.36	0.30	0.30
RR	0.27	0.24	0.28	0.27	0.26	0.23	0.22	0.25	0.30	0.19	0.19	0.24	0.34	0.28	0.27	0.26	0.26
TO	0.30	0.35	0.26	0.37	0.39	0.32	0.31	0.29	0.33	0.27	0.26	0.30	0.33	0.35	0.38	0.30	0.31
AL	0.35	0.35	0.16	0.26	0.35	0.18	0.34	0.32	0.41	0.21	0.27	0.28	0.28	0.38	0.32	0.21	0.24
BA	0.71	0.81	0.66	0.72	0.65	0.62	0.62	0.67	0.66	0.51	0.70	0.72	0.68	0.75	0.74	0.67	0.68
CE	0.20	0.20	0.16	0.18	0.16	0.17	0.21	0.18	0.28	0.12	0.16	0.23	0.16	0.19	0.18	0.18	0.18
MA	0.52	0.86	0.60	0.91	0.98	0.82	0.68	0.57	0.64	0.54	0.62	0.64	0.67	0.73	0.82	0.75	0.72
PB	0.48	0.44	0.32	0.28	0.47	0.31	0.30	0.32	0.39	0.22	0.26	0.33	0.38	0.44	0.41	0.38	0.33
PE	0.61	0.67	0.45	0.59	0.66	0.48	0.40	0.48	0.52	0.33	0.37	0.43	0.56	0.61	0.63	0.52	0.50
PI	0.34	0.38	0.31	0.42	0.55	0.32	0.31	0.33	0.32	0.23	0.26	0.31	0.33	0.39	0.37	0.34	0.33
SE	0.53	0.50	0.45	0.49	0.50	0.45	0.39	0.44	0.48	0.36	0.38	0.41	0.49	0.50	0.50	0.50	0.47
RN	0.39	0.39	0.34	0.37	0.37	0.31	0.27	0.31	0.34	0.26	0.27	0.34	0.38	0.39	0.39	0.36	0.34
DF	0.27	0.25	0.24	0.24	0.22	0.19	0.13	0.23	0.30	0.14	0.16	0.23	0.26	0.24	0.24	0.23	0.21
GO	0.30	0.70	0.27	0.47	0.58	0.36	0.44	0.64	0.42	0.30	0.35	0.39	0.34	0.40	0.44	0.32	0.36
MT	0.36	0.35	0.35	0.44	0.44	0.39	0.42	0.35	0.36	0.35	0.36	0.38	0.35	0.36	0.37	0.33	0.36
MS	0.37	0.43	0.32	0.58	0.57	0.42	0.42	0.43	0.41	0.34	0.36	0.42	0.37	0.37	0.45	0.37	0.40
ES	0.86	1.19	1.21	0.91	1.55	1.13	0.97	1.09	0.98	0.89	0.77	0.96	1.15	1.72	1.64	1.15	1.03
MG	0.81	0.89	0.58	0.61	0.69	0.62	0.49	0.61	0.64	0.53	0.50	0.60	0.55	0.87	1.02	0.67	0.63
RJ	0.19	0.37	0.37	0.38	0.51	0.35	0.30	0.34	0.34	0.26	0.35	0.30	0.31	0.30	0.39	0.41	0.33
SP	0.22	0.24	0.20	0.22	0.19	0.21	0.17	0.21	0.18	0.18	0.18	0.18	0.23	0.25	0.21	0.21	0.20
PR	0.26	0.29	0.26	0.36	0.32	0.29	0.28	0.28	0.31	0.26	0.29	0.32	0.28	0.26	0.32	0.27	0.29
SC	0.46	0.48	0.37	0.42	0.39	0.41	0.36	0.36	0.38	0.32	0.36	0.40	0.37	0.45	0.50	0.41	0.40
RS	0.19	0.24	0.19	0.29	0.27	0.22	0.25	0.23	0.29	0.19	0.22	0.27	0.24	0.20	0.22	0.24	0.24
Total	0.35	0.47	0.33	0.44	0.43	0.42	0.33	0.39	0.37	0.30	0.35	0.35	0.45	0.56	0.58	0.37	0.38

Table A.4.11 – Imports in CO_2 emissions (in thousand tons), Brazilian states

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
CHN	33	69	1,976	499	187	19	117	138	1,341	544	263	356	610	197	130	184	544	625	230	341	769	2,579	2,589	10,044	2,226	1,718	1,499	29,829
IND	4	5	55	51	19	2	12	14	145	203	127	31	69	20	21	26	103	87	31	44	58	277	305	955	223	183	209	3,279
RUS	9	11	95	113	29	5	21	28	331	96	182	52	152	34	33	41	144	162	68	66	89	539	531	1,500	385	220	441	5,378
USA	15	20	193	249	48	9	35	51	405	158	163	81	262	53	62	76	264	242	91	102	165	792	1,159	3,043	534	352	519	9,141
MEX	1	1	24	10	3	1	2	2	40	9	7	5	26	3	3	4	15	11	5	5	13	53	55	208	62	25	37	630
CAN	6	7	44	62	17	3	12	19	129	58	41	29	86	20	17	25	89	114	42	39	54	363	304	777	215	105	184	2,861
DEU	9	10	77	88	27	6	18	19	160	77	48	35	107	24	25	33	115	88	34	53	61	348	463	1,209	240	147	215	3,737
ESP	1	1	10	13	4	1	5	3	58	16	8	6	17	4	4	5	19	15	7	8	13	56	94	229	54	32	44	726
FRA	1	2	13	15	4	1	3	4	30	13	9	6	20	4	4	5	28	18	7	9	15	71	119	269	65	30	44	809
GBR	2	2	21	21	6	1	4	5	55	21	25	10	37	7	6	9	42	26	10	15	19	94	177	380	76	45	68	1,184
ITA	2	2	18	22	6	1	5	6	49	20	12	10	25	7	6	9	35	26	10	14	23	156	141	394	81	51	78	1,206
Other EU27	9	11	91	101	28	5	19	24	201	87	71	41	123	28	27	37	141	111	47	65	76	402	551	1,434	325	190	282	4,528
JPN	3	4	118	41	10	2	7	10	94	35	23	18	43	11	11	15	47	85	20	20	49	201	222	791	145	89	128	2,243
KOR	2	3	128	33	9	1	6	9	90	30	29	16	41	9	9	13	41	189	17	19	70	156	192	674	127	90	112	2,116
TWN	2	3	87	30	10	1	6	8	76	30	40	16	33	9	8	11	36	36	15	17	40	148	154	639	123	82	96	1,757
Other + RoW	60	74	630	764	203	36	146	183	2,290	696	770	363	1,174	227	215	283	1,005	951	410	485	617	3,065	3,778	10,709	2,426	1,758	3,239	36,558
Total	160	226	3,580	2,111	611	95	419	521	5,493	2,093	1,819	1,074	2,827	656	579	777	2,669	2,786	1,043	1,302	2,134	9,301	10,833	33,255	7,308	5,116	7,194	105,982

Table A.4.12 – Share of bilateral trade in CO_2 emissions in total imports (%), Brazilian states

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
CHN	0.03	0.07	1.86	0.47	0.18	0.02	0.11	0.13	1.27	0.51	0.25	0.34	0.58	0.19	0.12	0.17	0.51	0.59	0.22	0.32	0.73	2.43	2.44	9.48	2.10	1.62	1.41	28.15
IND	0.00	0.01	0.05	0.05	0.02	0.00	0.01	0.01	0.14	0.19	0.12	0.03	0.06	0.02	0.02	0.02	0.10	0.08	0.03	0.04	0.06	0.26	0.29	0.90	0.21	0.17	0.20	3.09
RUS	0.01	0.01	0.09	0.11	0.03	0.00	0.02	0.03	0.31	0.09	0.17	0.05	0.14	0.03	0.03	0.04	0.14	0.15	0.06	0.06	0.08	0.51	0.50	1.42	0.36	0.21	0.42	5.07
MEX	0.01	0.02	0.18	0.23	0.05	0.01	0.03	0.05	0.38	0.15	0.15	0.08	0.25	0.05	0.06	0.07	0.25	0.23	0.09	0.10	0.16	0.75	1.09	2.87	0.50	0.33	0.49	8.63
CAN	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.04	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.05	0.05	0.20	0.06	0.02	0.03	0.59
DEU	0.01	0.01	0.04	0.06	0.02	0.00	0.01	0.02	0.12	0.05	0.04	0.03	0.08	0.02	0.02	0.02	0.08	0.11	0.04	0.04	0.05	0.34	0.29	0.73	0.20	0.10	0.17	2.70
ESP	0.01	0.01	0.07	0.08	0.03	0.01	0.02	0.02	0.15	0.07	0.05	0.03	0.10	0.02	0.02	0.03	0.11	0.08	0.03	0.05	0.06	0.33	0.44	1.14	0.23	0.14	0.20	3.53
FRA	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.05	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.05	0.09	0.22	0.05	0.03	0.04	0.69
GBR	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.01	0.01	0.01	0.02	0.00	0.00	0.01	0.03	0.02	0.01	0.01	0.01	0.07	0.11	0.25	0.06	0.03	0.04	0.76
ITA	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.01	0.05	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.04	0.02	0.01	0.01	0.02	0.09	0.17	0.36	0.07	0.04	0.06	1.12
Other EU27	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.01	0.05	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.02	0.15	0.13	0.37	0.08	0.05	0.07	1.14
JPN	0.01	0.01	0.09	0.10	0.03	0.01	0.02	0.02	0.19	0.08	0.07	0.04	0.12	0.03	0.03	0.04	0.13	0.11	0.04	0.06	0.07	0.38	0.52	1.35	0.31	0.18	0.27	4.27
KOR	0.00	0.00	0.11	0.04	0.01	0.00	0.01	0.01	0.09	0.03	0.02	0.02	0.04	0.01	0.01	0.01	0.04	0.08	0.02	0.02	0.05	0.19	0.21	0.75	0.14	0.08	0.12	2.12
USA	0.00	0.00	0.12	0.03	0.01	0.00	0.01	0.01	0.08	0.03	0.03	0.02	0.04	0.01	0.01	0.01	0.04	0.18	0.02	0.02	0.07	0.15	0.18	0.64	0.12	0.08	0.11	2.00
TWN	0.00	0.00	0.08	0.03	0.01	0.00	0.01	0.01	0.07	0.03	0.04	0.01	0.03	0.01	0.01	0.01	0.03	0.03	0.01	0.02	0.04	0.14	0.15	0.60	0.12	0.08	0.09	1.66
Other + RoW	0.06	0.07	0.59	0.72	0.19	0.03	0.14	0.17	2.16	0.66	0.73	0.34	1.11	0.21	0.20	0.27	0.95	0.90	0.39	0.46	0.58	2.89	3.56	10.10	2.29	1.66	3.06	34.49
Total	0.15	0.21	3.38	1.99	0.58	0.09	0.40	0.49	5.18	1.97	1.72	1.01	2.67	0.62	0.55	0.73	2.52	2.63	0.98	1.23	2.01	8.78	10.22	31.38	6.90	4.83	6.79	100.00

Table A.4.13 – Imports in CO_2 emissions / imports in value added (thousand tons / 2008 US$ million), Brazilian states

	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	SE	RN	DF	GO	MT	MS	ES	MG	RJ	SP	PR	SC	RS	Total
CHN	1.54	1.46	1.36	1.55	1.45	1.58	1.48	1.48	1.45	1.54	1.53	1.22	1.52	1.63	1.54	1.54	1.53	1.60	1.64	1.42	1.43	1.53	1.50	1.43	1.48	1.48	1.52	1.46
IND	1.55	1.53	1.45	1.54	1.53	1.55	1.45	1.53	1.56	1.32	1.70	1.58	1.49	1.65	1.50	1.51	1.52	1.55	1.58	1.46	1.58	1.56	1.56	1.52	1.49	1.51	1.50	1.52
RUS	1.37	1.36	1.34	1.34	1.36	1.37	1.37	1.37	1.25	1.36	1.27	1.33	1.25	1.37	1.39	1.36	1.32	1.41	1.40	1.38	1.36	1.41	1.33	1.30	1.39	1.35	1.27	1.32
MEX	0.51	0.46	0.41	0.47	0.49	0.51	0.51	0.50	0.47	0.48	0.52	0.49	0.50	0.49	0.49	0.42	0.45	0.46	0.47	0.47	0.40	0.43	0.43	0.40	0.43	0.44	0.43	0.43
CAN	0.35	0.34	0.31	0.34	0.38	0.39	0.35	0.35	0.26	0.37	0.33	0.37	0.36	0.35	0.34	0.37	0.35	0.34	0.34	0.35	0.33	0.30	0.35	0.32	0.24	0.33	0.29	0.31
DEU	0.43	0.43	0.40	0.42	0.45	0.43	0.44	0.45	0.42	0.42	0.42	0.43	0.43	0.44	0.44	0.43	0.41	0.46	0.46	0.42	0.42	0.45	0.39	0.41	0.44	0.43	0.44	0.42
ESP	0.41	0.33	0.29	0.29	0.41	0.42	0.34	0.29	0.28	0.29	0.30	0.29	0.32	0.31	0.31	0.29	0.24	0.28	0.27	0.31	0.23	0.24	0.27	0.22	0.23	0.25	0.25	0.25
FRA	0.26	0.32	0.29	0.30	0.31	0.33	0.27	0.31	0.47	0.25	0.33	0.30	0.32	0.31	0.32	0.31	0.33	0.30	0.31	0.31	0.29	0.29	0.32	0.28	0.27	0.29	0.29	0.30
GBR	0.15	0.14	0.14	0.15	0.15	0.14	0.15	0.15	0.15	0.15	0.14	0.15	0.15	0.15	0.15	0.14	0.12	0.13	0.15	0.13	0.14	0.13	0.12	0.14	0.13	0.14	0.14	0.14
ITA	0.17	0.18	0.20	0.20	0.20	0.18	0.20	0.20	0.20	0.18	0.25	0.19	0.21	0.18	0.20	0.18	0.16	0.20	0.21	0.16	0.21	0.20	0.21	0.19	0.19	0.20	0.19	0.19
Other EU27	0.17	0.17	0.18	0.19	0.18	0.16	0.19	0.19	0.21	0.18	0.18	0.20	0.19	0.18	0.19	0.18	0.16	0.19	0.19	0.16	0.20	0.18	0.19	0.18	0.19	0.19	0.19	0.19
JPN	0.31	0.27	0.28	0.28	0.32	0.30	0.29	0.30	0.30	0.29	0.31	0.30	0.29	0.30	0.32	0.29	0.23	0.30	0.31	0.26	0.28	0.29	0.27	0.25	0.28	0.28	0.30	0.27
KOR	0.35	0.33	0.27	0.33	0.34	0.34	0.34	0.34	0.32	0.33	0.35	0.33	0.33	0.34	0.34	0.33	0.34	0.30	0.34	0.34	0.31	0.33	0.34	0.31	0.31	0.33	0.32	0.32
USA	0.70	0.68	0.50	0.67	0.69	0.70	0.69	0.68	0.64	0.69	0.85	0.67	0.68	0.69	0.67	0.67	0.66	0.50	0.69	0.71	0.55	0.67	0.64	0.59	0.67	0.68	0.68	0.61
TWN	1.02	0.92	0.66	0.94	1.03	1.03	1.03	1.00	0.87	0.99	1.80	1.00	0.99	1.05	0.94	0.95	1.01	1.00	1.06	1.06	0.81	0.88	0.90	0.86	0.83	0.93	0.98	0.89
Other + RoW	0.57	0.56	0.64	0.65	0.63	0.59	0.62	0.66	0.71	0.61	0.73	0.67	0.68	0.63	0.65	0.62	0.61	0.68	0.71	0.56	0.67	0.63	0.59	0.64	0.65	0.67	0.72	0.65
Total	0.57	0.59	0.72	0.60	0.65	0.57	0.62	0.62	0.65	0.63	0.69	0.65	0.62	0.64	0.62	0.58	0.52	0.60	0.64	0.57	0.63	0.59	0.54	0.57	0.60	0.66	0.63	0.59

Table A.4.14 – Balance of international trade in CO_2 emissions (thousand tons), Brazilian states

	CHN	IND	RUS	MEX	CAN	DEU	ESP	FRA	GBR	ITA	Other EU27	JPN	KOR	USA	TWN	Other + RoW	Total
AC	-31	-4	-8	-12	-0	-5	-8	-1	-0	-0	-1	-6	-2	-2	-2	-47	-129
AP	-58	-4	-10	25	1	-3	-5	0	1	0	-0	-2	-1	-2	-3	-41	-103
AM	-1,920	-47	-81	-57	4	-28	-25	5	11	2	5	-17	-97	-120	-83	-268	-2,717
PA	44	9	-56	1,000	100	227	182	80	173	81	105	310	401	53	-3	508	3,214
RO	-174	-18	-5	-27	-1	-13	-16	3	2	6	3	-7	-5	-7	-9	-118	-387
RR	-18	-2	-5	-7	-0	-3	-5	-0	-0	-1	-0	-4	-0	-1	-1	-30	-79
TO	-92	-12	-15	-23	-1	-10	-11	7	2	-0	-1	-5	-3	-5	-6	-102	-277
AL	-126	-10	-18	-17	0	-13	-7	0	3	1	-0	2	-5	-5	-7	-100	-302
BA	-935	-95	-264	506	129	-40	262	43	136	82	171	336	40	-42	-51	-825	-547
CE	-527	-200	-89	-102	-2	-51	-50	-8	-0	-6	-4	-44	-28	-27	-29	-609	-1,776
MA	-55	-101	-156	298	51	6	42	48	47	19	36	94	52	-5	-30	-136	211
PB	-347	-30	-49	-51	-2	-25	-27	-3	-2	-6	-5	-27	-14	-15	-15	-320	-937
PE	-556	-60	-136	-113	-8	-66	-57	-0	5	-7	-1	-40	-22	-33	-30	-846	-1,970
PI	-184	-19	-32	-40	-1	-19	-17	-1	1	-3	-3	-18	-6	-8	-9	-193	-551
SE	-110	-18	-28	-11	3	-12	-9	2	4	2	3	8	-2	-6	-7	-89	-271
RN	-170	-24	-37	-16	-0	-20	-18	4	3	3	-0	-4	-8	-10	-10	-189	-499
DF	-530	-101	-140	-240	-12	-86	-96	-15	-21	-34	-27	-112	-39	-39	-35	-938	-2,464
GO	-466	-53	-113	-109	8	-96	17	72	40	22	15	52	-32	-171	-30	-498	-1,341
MT	145	-17	-16	77	8	-18	72	100	73	69	62	207	40	22	-5	335	1,154
MS	-247	-37	-38	37	4	-25	-10	5	22	7	8	7	8	-6	-14	-171	-450
ES	-48	35	25	2,319	266	122	332	179	202	145	208	513	387	313	98	2,013	7,107
MG	-1,401	-118	-332	2,007	305	-91	588	189	337	239	271	794	433	209	66	1,315	4,809
RJ	-1,696	-208	-431	-27	127	-182	-99	62	92	2	59	69	-24	-106	-113	-769	-3,243
SP	-9,197	-837	-1,243	-885	121	-533	-380	20	135	-31	-30	-179	-455	-537	-569	-5,448	-20,046
PR	-1,894	-194	-312	-106	-2	-151	40	17	68	23	25	42	-31	-78	-108	-1,059	-3,721
SC	-1,533	-158	-160	74	37	-47	28	21	55	45	29	72	37	-59	-70	-532	-2,159
RS	-1,201	-179	-356	84	32	-136	-13	14	51	19	11	31	-30	-74	-83	-1,798	-3,627
Total	-23,327	-2,501	-4,104	4,583	1,168	-1,318	711	843	1,440	679	937	2,073	591	-763	-1,156	-10,957	-31,102

APPENDIX A.4.2: SIMULATION OF TECHNOLOGY TRANSFERS

For the simulation of technology transfer, we have selected the CO_2 emission coefficients according to the following criterion: for each sector, the lowest coefficient that corresponded to a state with share larger than 5% in the country's total output for that sector. With this criterion, we intend to simulate the adoption of the best sectoral technology in emission terms by all states, considering the technologies that were available in Brazil as in 2008 and that were representative to the national production. In the simulation, we have attributed the selected coefficients to all states.

The sectoral coefficients that were selected for the simulation are presented below, as well as their original states and participation in the national total output.

Table A.4.15 – Sectoral coefficients for the simulation (coefficients in thousand tons of CO_2 per US$ million)

	Industry	Coeff. (kt of CO_2 / US$ million)	State	% national total output
1	Agriculture, Hunting, Forestry and Fishing	0.0335	RS	12%
2	Mining and Quarrying	0.0045	RJ	54%
3	Food, Beverages and Tobacco	0.0101	PR	10%
4	Textiles and Textile Products	0.0040	PR	5%
5	Leather, Leather and Footwear	0.0012	RS	36%
6	Wood and Products of Wood and Cork	0.0101	PR	31%
7	Pulp, Paper, Paper , Printing and Publishing	0.0299	RJ	8%
8	Coke, Refined Petroleum and Nuclear Fuel	0.1062	SP	44%
9	Chemicals and Chemical Products	0.0427	SP	49%
10	Rubber and Plastics	0.0326	SP	52%
11	Other Non-Metallic Mineral	0.0685	ES	6%
12	Basic Metals and Fabricated Metal	0.1924	SP	35%
13	Machinery, Nec	0.0072	PR	9%
14	Electrical and Optical Equipment	0.0096	PR	7%
15	Transport Equipment	0.0080	PR	9%
16	Manufacturing, Nec; Recycling	0.0046	PR	13%
17	Electricity, Gas and Water Supply	0.0006	MG	11%
18	Construction	0.0025	MG	10%
19	Wholesale and retail trade	0.0011	PR	8%
20	Hotels and Restaurants	0.0175	RJ	14%
21	Transport	0.7857	SP	35%
22	Post and Telecommunications; Other Bus. Activities	0.0012	SP	44%
23	Financial Intermediation	0.0005	PR	6%
24	Real Estate Activities	0.0001	PR	6%
25	Public Admin and Defence; Compulsory Soc. Security	0.0073	MG	7%
26	Education	0.0045	PR	6%
27	Health and Social Work	0.0056	PR	5%
28	Other Community, Social and Personal Services	0.0047	PR	6%

Table A.4.16 – Results of the simulation: production-based and consumption-based CO_2 emissions, net emission transfers (in thousand tons)

	Production-based emissions	Consumption-based emissions	Net emission transfer
Acre	137	473	-336
Amapá	174	563	-390
Amazonas	3,198	5,461	-2,263
Pará	3,340	5,598	-2,258
Rondônia	540	1,573	-1,033
Roraima	101	269	-168
Tocantins	389	1,088	-698
Alagoas	832	1,508	-675
Bahia	7,784	13,275	-5,491
Ceará	2,162	5,147	-2,985
Maranhão	3,130	3,812	-682
Paraíba	833	2,686	-1,853
Pernambuco	3,233	6,840	-3,607
Piauí	579	1,836	-1,257
Sergipe	910	1,606	-695
Rio Grande do Norte	818	2,196	-1,377
Distrito Federal	2,863	7,175	-4,311
Goiás	3,878	6,788	-2,911
Mato Grosso	2,790	2,953	-163
Mato Grosso do Sul	1,973	2,904	-931
Espírito Santo	5,598	4,792	807
Minas Gerais	19,226	24,236	-5,010
Rio de Janeiro	17,020	28,674	-11,653
São Paulo	61,398	72,090	-10,692
Paraná	12,694	15,129	-2,435
Santa Catarina	6,213	10,401	-4,188
Rio Grande do Sul	12,605	16,239	-3,635
Brazil	174,421	245,312	-70,891
China	5,490,880	3,865,428	1,625,452
India	1,265,525	1,208,542	56,983
Russia	1,332,766	996,918	335,847
US	4,357,361	5,062,667	-705,306
Mexico	324,155	381,912	-57,757
Canada	396,510	430,635	-34,124
Germany	630,422	808,718	-178,297
Spain	234,982	339,779	-104,796
France	246,121	430,428	-184,307
United Kingdom	430,240	579,218	-148,978
Italy	350,154	474,672	-124,518
Other EU27	1,256,015	1,482,337	-226,323
Japan	960,528	1,171,609	-211,081
Korea	482,798	464,056	18,742
Taiwan	267,873	192,499	75,374
Other countries + RoW	5,422,650	5,488,668	-66,019
Foreign countries	23,448,979	23,378,088	70,891