Faculté des sciences

Stickiness of supply chain configurations and trade flows of beef from Brazil

Auteur·es : Castin Emilie
Promoteur·rices : P. Meyfroidt
Lecteur·rices : V. Vanacker and B van Wesemael

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Abstract

International trades of agricultural commodities (especially beef, soy and palm oil) are responsible for the majority of deforestation in tropical countries. In order to improve sustainability in the supply chain and help guide supply chain governance take actions to mitigate the social/environmental impacts of agricultural commodities, a new initiatives, Trase, developed new methodological tools to map and spatially analyse the supply chain from the places of production to the country of consumption. This research, apply a methodology developed on the supply chain of soy from Brazil by Reis et al., 2020 to assess the role of the supply chain's stickiness in the efficiency of initiatives towards sustainability. The objective of this research is to understand the relationships between the actors of the Brazilian beef supply chain and the places of production. Brazilian beef production is concentrated by a few states and the export is handled mostly by three major companies (JBS, Minerva, Marfrig). The results of this research are similar to the results on the soy network. Traders with the largest market shares are stickier than the others, slaughterhouses are a key elements in supply chain governance because of their direct contact with places of production. Stickiness is necessary to implement efficient initiatives. Current no-deforestation agreement, do not prevent for leakage and laundering.

Abstract (different language)

Les échanges internationaux de produits agricoles (en particulier le bœuf, le soja et l'huile de palme) sont responsables de la majorité de la déforestation dans les pays tropicaux. Afin d'améliorer la durabilité dans la chaîne d'approvisionnement et d'aider à guider la gouvernance de la chaîne d'approvisionnement à prendre des mesures pour atténuer les impacts sociaux/environnementaux des produits agricoles, une nouvelle initiative, Trase, a développé de nouveaux outils méthodologiques pour cartographier et analyser spatialement la chaîne d'approvisionnement à partir des lieux de production au pays de consommation. Cette recherche applique une

méthodologie développée sur la chaîne d'approvisionnement du soja du Brésil par Reis et al., 2020 pour évaluer le rôle de la rigidité de la chaîne d'approvisionnement dans l'efficacité des initiatives en faveur de la durabilité. L'objectif de cette recherche est de comprendre les relations entre les acteurs de la filière bovine brésilienne et les lieux de production. La production de viande bovine brésilienne est concentrée par quelques États et l'exportation en gérée majoritairement par trois grandes entreprises (JBS, Minerva, Marfrig). Les companies détenant les plus grandes parts de marché sont plus rigide que les autres, les abattoirs sont un élément clé dans la gouvernance de la chaîne d'approvisionnement en raison de leur contact direct avec les lieux de production. La rigidité du réseaux est nécessaire pour mettre en œuvre des initiatives efficaces. Les Accords actuels de non-déforestation, n'empêche pas les fuites et le blanchiment.

Acknowledgement

I would like to sincerely thank my supervisor Professor Meyfroid, for his guidance and availability through this long process. His constructive comments and his insights have been essential in the development of my thesis.

I also would like I would like to express my deepest appreciation to Tiago Reis and Erasmus Zu Ermgassen, whose research guided mine and I thank them for their enthusiasm in helping me navigate the subject.

I'm very grateful for my classmate's occasional help, unconditional support and for listening to me complain.

I cannot leave out my parent's who have always believed in me and supported me through my entire education. Their solicited (and unsolicited) advice has been an invaluable contribution to this thesis. A special thanks to my brother for always making me laugh when I need it the most.

Contents

1 Introduction

As the world population increases and consumption pattern evolve (meat consumption increase), demand for agricultural products is increasing (H. K. Gibbs et al., 2010). To meet demand, producers improve crop yield of their crops and expand agricultural lands. The expansion of agricultural lands is achieved at the expense of forests because the remaining arable lands are located in tropical developing countries where tropical forests currently stands (H. K. Gibbs et al., 2010). Between 2001 and 2015, commodity trade and shifting agriculture caused 27% and 24% of world deforestation (Curtis, Slay, Harris, Tyukavina, & Hansen, 2018). Figure 1.1 illustrate how tropical forests are vulnerable to deforestation as it is the main source commodity driven deforestation. According to some estimates, deforestation amounted to about 5.2 million hectares between 2005 and 2010. Latin America is particularly vulnerable to deforestation with the four countries with the highest deforestation rate located on this continent (Armenteras, Espelta, Rodríguez, & Retana, 2017). In Brazil, Amazon has lost 72,4 million hectares of forests between 1985 and 2018 („Mapbiomas Amazonia Site | Lanzamiento de la Coleción 2.0“, n.d.). Deforestation is a threat to the environment as it is responsible for the net emission of 2.6 gigatonnes of carbon dioxide per year (the second largest source of anthropogenic greenhouse gas emissions) (Pendrill, Persson, et al., 2019b) and biodiversity loss due to loss of the species habitats (Green et al., 2019). and the ecosystem services provided by tropical forest (Godar, Gardner, Tizado, & Pacheco, 2014).

Globalisation, most particularly international trade, influences agricultural production and its localisation. Consequently, international trade affects land use changes and deforestation dynamics (Henders, Persson, & Kastner, 2015). International trade of agricultural commodities like soybean, beef and palm oil are one of the major driver of deforestation (Green et al., 2019). Consumption of soy bean and beef is almost entirely covered by production from Latin America. (Henders et al., 2015). Global market causes the distance between producers and consumer to increase and the multiplication of actors involved (producers, consumers and intermediary actors like companies and investors) (Gardner et al., 2019). The gap between producers and consumers hinders either of these actors to control the way they produce/consume. Moreover, the driver factors and social/environmental impacts are disconnected (Gardner et al., 2019)e. The increasing complexity of international

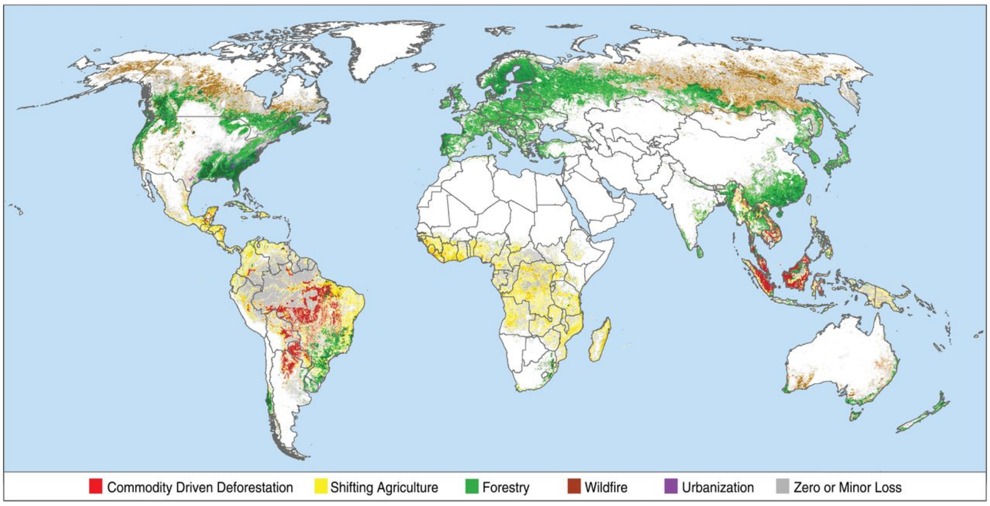


Fig. 1.1.: Drivers of forest cover loss for the period 2001 to 2015 (Curtis, Slay, Harris, Tyukavina, & Hansen, 2018)

trade patterns makes the precise assessment of the impact of international trade a challenging task and makes it difficults to assign responsibility. (Ermgassen et al., 2020; Gardner et al., 2019; Henders et al., 2015). Actors uses the opacity of global trade to mask their actions, while government and companies dedicated to improve sustainability struggle to make sens of their sourcing patterns (Green et al., 2019).

It is, therefore, important to study and understand the relationships between international trade and agricultural commodities production in order to implement efficient measures conductive to a more sustainable supply chain (Godar, Persson, Tizado, & Meyfroidt, 2015; Henders et al., 2015). Understanding the relationships between global consumption and local production will allow for better transparency and traceability of commodities, hence improving the sustainability of food consumption (Godar et al., 2015).Transparency can help provide pragmatic information for decision-makers willing to make change, it is also necessary for hybrid governace (Gardner et al., 2019; Godar & Gardner, 2019) In order to improve sustainability in supply chain and implement initiatives to accomplish that goal, it is necessary to understand how supply chain dynamics work.

The research is based a literature review of the context of the research, a review of important concepts used and an overview of the current situation. The research apply a methodology to analyse stickiness developed by Reis et al., 2020 (on the Brazilian soy supply chain) on the Brazilian beef supply chain. The data collected for this study is part of the Transparency for Sustainable Economies initiative[1] (www.trase.earth) with the goal to improve sustainability in commodities supply chains (Dawkins, Godar, Trimmer, & Gardner, 2015). To achieve this goal, they map the supply chain of Brazilian beef from the region of production (municipality were

[1]The description of the initiative is detailed is 2.4.

cattle are raised) to the logistic hub (slaughterhouses) to exporting companies to finally importing countries.

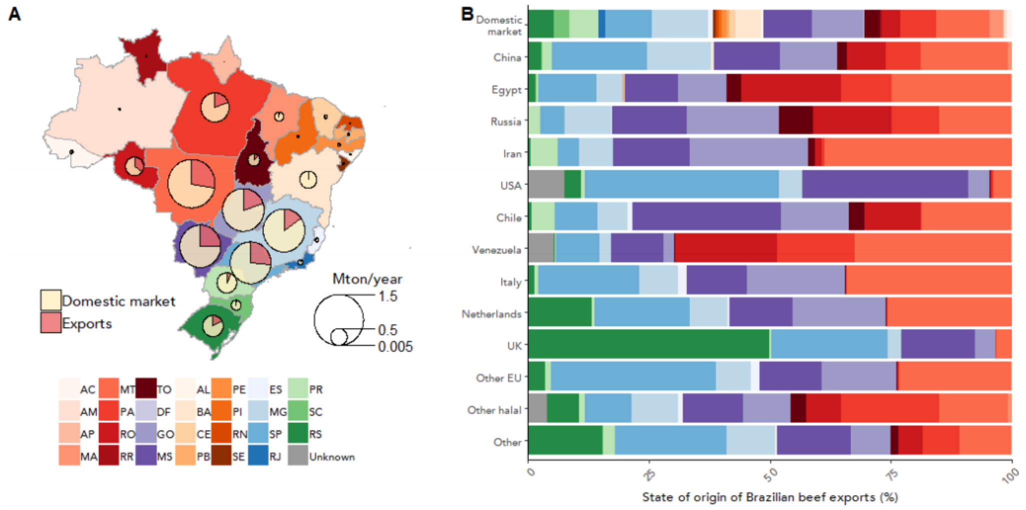


Fig. 1.2.: The origin and destination of Brazilian beef. (A) Cattle production (Mtons/year) and the proportion exported per state in Brazil, shown for 2017. (B) Breakdown of the origin of sourcing per major market. States are colored by region: states in the Legal Amazon in shades of red , the Central-West in purple, the North-East in orange, the South-East in blue, and the South in green (Ermgassen et al., 2020).

Brazil the second largest beef producer and the world's largest beef exporter ($1/5$ of its production). The beef production and its export is not homogeneously distributed on Brazil's territory. The states of Rondônia, Mato Grosso, Soa Paulo and Mato Grosso do Sul are the principal states of beef production export more than 25% of that production (figure 1.2[2]). when looking at the biomes, 48,1% of beef exports comes from the Cerrado biome, 25,5% comes from the Amazonia biome, 18,2% comes from the Atlantic forrest, 5% comes from the Pampa biome and only 1.9% comes from the Caatinga and Pantal biome combined. Exports are handled by 200 companies in total but 94,4% of the total volume is handled by 55 companies and 71,7 % of the total volume of beef is handled by 3 companies: JBS, Minerva and Marfig and their subsidiaries. JBS is strongly present in the Amazon biome, exporting 40,3% of the volume from that biome. As for Marfrig, they are mostly present in the Pampa biome, handeling 68,3% of the volume of beef from that biome. The companies operate their own slaughterhouses that source from municipalities directly (cattle have only lived on one farm) or indirectly (cattle have lived on multiple farms before being sold). The largest importing countries are China/Honk Kong, Egypt, Russia, Iran and the European Union (30,2%, 12,4%, 10,4%, 7,1% and 7,1% respectively of the total volume of exported beef) (Ermgassen et al., 2020). Figure 1.2B illustrates from which states each country sources its beef.

[2]AC = Acre, AM = Amazonas, MA = Maranhão, MT = Mato Grosso, PA = Pará, RO = Rondônia, RR = Roraima, TO = Tocantins, DF = Distrito Federal, GO = Goiás, MS = Mato Grosso do Sul, AL = Alagoas, BA = Bahia, PB = Paraíba, PE = Pernambuco, PI = Piauí, RN = Rio Grande do Norte, SE = Sergipe, ES = Espirito Santo, MG = Minas Gerais, SP = São Paulo, RJ = Rio de Janeiro, PR = Parana, SC = Santa Catarina, RS = Rio Grande do Sul

This research project focuses on understanding the dynamics of Brazilian beef exports. The objectives are first to understand the spatial and temporal relationships between trade flows, agents of these exchanges and beef production localisation and secondly to empirically measure the geographical and temporal stability of the supply chain. The hypothesis is that if the supply chain network configuration has no time nor space stickiness, initiatives taken to improve sustainability will be more efficient. Actors can also be held accountable for their actions and their impacts. Moreover, in a more stable configuration actors have a higher capacity to influence their suppliers towards more sustainable practices (Reis et al., 2020).

2 Literature review

2.1 Context

Global changes driven by human activities are cause for concerns. It is not only a threat to Earth's environment but also to human's ability to survive. Indeed, Earth's environment provides services essential to humans well-being (Steffen, Crutzen, & McNeill, 2007). Steffen et al., 2007 define global change as "biophysical and socio-economic changes that are altering the structure and functioning of the Earth system." These changes include land use changes, urbanisation, globalisation, climate changes, nutrients like nitrogen and carbon cycle changes, biodiversity changes, and interactions between them (Steffen et al., 2007).

The development of technologies has allowed for the increase of the inter-connectivity of people and places around the world (Lambin & Meyfroidt, 2011). Also, due to population growth and change in consumption patterns, the demand for agricultural products is constantly increasing. The volume of global trade for agricultural commodities therefore increases (Henders et al., 2015; Tilman et al., 2001). By 2050, one billion hectares of natural land is at risk of conversion into agricultural land (Tilman et al., 2001). Tropical countries in South America and Southeast Asia are especially exposed because the remaining cultivable lands not used yet are the tropical forests (Smith et al., 2010). They also are the principal exporters of agricultural commodities like soy, beef and palm oil. Pendrill, Persson, et al., 2019b estimates that 29-39% of greenhouse gas emission are driven by the international trade due to deforestation (figure 2.1).

Increasing the production of agricultural commodities such as soy, beef and palm oil leads to sociological and environmental impacts (Würtenberger, Koellner, & Binder, 2006). The impact of agriculture on the environment could be as challenging as climate change (Tilman et al., 2001). Researches link agriculture to deforestation. A study from H. K. Gibbs et al., 2010 shows that, between 1980 and 2000, 55% of newly exploited agricultural lands were gained on primeval forests. Another study by Pendrill, Persson, Godar, and Kastner, 2019a associate 80% of deforestation in Tropical and subtropical countries to the expansion of pasture for cattle and the production of forestry products, palm oil, other cereals and soybeans. Furthermore, deforestation contribute the greenhouse gas emission (Pendrill, Persson, et al.,

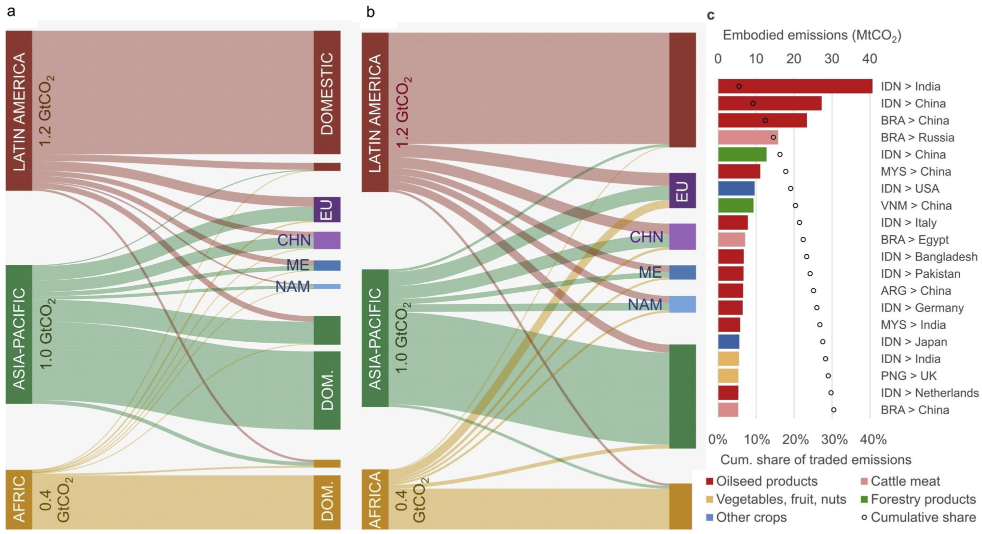


Fig. 2.1.: Trade flows of embodied emissions from deforestation (Pendrill, Persson, et al., 2019b).

2019b). Agriculture also entails biodiversity loss and damage to ecosystems because of habitats destruction and eutrophication (Giam, 2017; Tilman et al., 2001). From a socio-economic perspective, economic growth due to agricultural activities does not close the gap between rich and poor (Würtenberger et al., 2006). Moreover, agricultural activities use 70% of global freshwater, impacting water availability for populations (Flach, Ran, Godar, Karlberg, & Suavet, 2016). Lastly, agriculture is linked to carbon dioxide emissions due to energy consumption and deforestation (Henders et al., 2015). There is a need for a change toward a sustainable agriculture.

Cattle exploitation is the first driver for deforestation in Tropical countries, 40% of deforestation is caused by beef production (Pendrill, Persson, et al., 2019a). Brazil is particularly affected (the structure and dynamics of the Brazilian beef supply chain is detailed in the introduction). The study by Ermgassen et al., 2020 allocate deforesation risks to the actors of the beef supply chain. Risks is not spatially homogeneous on Brazil's territory. Particular traders (like Irmaos Gonclaves) and countries (like Egypt, Iran or United Arab Emirates = halal market) arise as major actors in deforestation risks. The Amazon and the Cerrado biome are the most at risk for deforestation. The study highlight that domestic market is the most at risk for deforestation. However, beef exports are increasing and the expansion seems to occur in area with high deforestation risks.

2.2 Sustainability governance

Globalisation alsoresults in an increase of the distance between the place of production the place of production and the place of consumption Lambin and Meyfroidt, 2011. Socio-environmental impacts caused by international demand are not directly linked to local production places (Gardner et al., 2019). Hence, local production places are left to deal with the consequences of a global problem. To manage a transition towards a more sustainable supply chain of agricultural commodities like soy, beef and palm oil, it is necessary to understand the impact of international trade and to understand supply chain dynamics (Henders et al., 2015; Lambin & Meyfroidt, 2011).

A meaningful way to reduce the impact of agriculture on the environment is the implementation of different initiatives from governmental and private sector (Godar et al., 2014). In Brazil, the slowdown of deforestation has been accomplished by combining policy intervention, private sector initiatives and market conditions (Godar et al., 2014). Policies include trade tariffs, subsidies to producers, regulation of deforestation, certification and market exclusion mechanisms (le Polain de Waroux et al., 2019), land tenure regularisation, creation of new reserves, promotion of more sustainable agricultural practices, land monitoring and enforcement (Godar et al., 2014). Policies are a necessary part of the development of sustainable agriculture at global scale (Würtenberger et al., 2006). Unfortunately, policies need to be properly implemented in order to be efficient. A study by le Polain de Waroux et al., 2019 finds that leakage occurs after the implementation of regulations, cancelling the benefits of the policies and compromising its effectiveness. This study highlights the need for adequate policies. To implement effective policies, it is necessary to understand properly the relationships between trade flows, production places, and actors involved.

Sustainability in supply chain is often associated with transparency. Transparency in this context embodies democracy, participation and accountability (Gardner et al., 2019). Social structures and process influence the structure and dynamics of supply chains. In this day and age, facilitated by the development of technology, exchange of information has increased. Information access has lead to change in governance of supply chains (Gardner et al., 2019). For example, it is possible to monitor deforestation in Brazil. Supply chain governance does not only concern state actor anymore, but interventions (policies, incentives, access to information) by the private sector and hybrid governance has emerged. They change sustainability in the supply chain by changing the behaviour of the different actors (Gardner et al., 2019).

It is essential to understand the dynamics of the supply chains because it is complicated and involve a lot of actors. Therfore, it is not always possible to find a direct link between socio-environmental impacts like land use change or deforestation to specific consumption choice. Identifying key actors and tracing trade patterns to particular places of production is an important step toward a more sustainable supply chain. For example, A study by Godar et al., 2014 shows that small properties holders contribute less to deforestation slowdown than big properties holders. By establishing responsibilities, it is possible to implement initiatives adapted to the capabilities and situation of each actor (Godar et al., 2014). It is not enough just to identify the actors involved, but it also necessary to understand the supply chain dynamics spatially because socio-environmental impacts are spatially heterogeneous even at the country scale. Tracing the entire supply chain from place of production to place of consumption will help understand trade-off and leakage mechanisms (Godar et al., 2015). Therefore, identifying key actors and links between producers and consumers through the supply chain and links between them and the production places will improve the effectiveness of the implementation of policies in the future (Godar et al., 2014; Godar et al., 2015).

2.3 Assessing environmental and socio-economic impacts of trade policies

In 2005, Würtenberger et al., 2006 addressed the lack of concept and method to assess environmental and socio-economic impacts of trade policies. They developed a method to incorporate the environmental and socio-economic impacts of agricultural trade. They combined material flow analysis and multi-criteria approach. The result is a set of indicators assessing the sustainability of a country agricultural practices. This method aggregates the socio-environmental impacts at country scale.

Studies by Kastner, Kastner, and Nonhebel, 2011 and Henders et al., 2015 assess environmental impacts of a product consumed in a country by tracing the origin (which country) of a particular product in a particular country. It's the country-to-country analysis using origin-destination matrices. Results are the quantification of consumption of a product originating from a country, which is later linked to environmental impacts. The problem with this approach is the scale of aggregation. The impacts are estimated at country scale and not attributed to a specific region. This approach does not take the heterogeneity within the country itself into account, where impacts can significantly differ. Moreover, different policies might need to be implemented to different regions in order to foster efficiency, since environment and actors may differ by region.

Godar et al., 2015 develop a new approach to trace socio-environmental impacts of production and consumption of agricultural commodities. They address the gap of the inadequacy of the scale of previous studies. This model allows a spatial disaggregation of the trade links and hence of the impacts they cause. The model uses optimisation and a matrix derived from the data to produce a final matrix which contains the amount of goods produced in each production location going to any country. The model allows linking specific trade patterns to a specific production location. Downscaling the analysis of trade patterns allows for a better understanding of socio-environmental impacts of globalisation. Flach et al., 2016 uses this method to assess the water impacts of agricultural commodities. Their analysis shows different results with this new approach than with the country-to-country analysis, emphasising the importance of a more spatially explicit analysis.

2.4 Current development in improving sustainability

Trase, an independent initiative dedicated to improving sustainability in supply chains, developed a new approach to provide supply chain mapping. The approach uses a methodology developed by Godar et al., 2015 that analyses spatially commodities trade flows. The methodology called SEI-PCS (Spatially Explicit Information on Production to Consumption Systems) maps the supply chain from the region of production to the country of consumption through exporter and importer companies using material flow analysis (Godar, 2018). For each commodity, Trase identify subnational origin of trade flows then, using a logistic-based decision tree, links the flows to a logistic hub (intermediary facilities before exportation). The decision tree uses customs information and independent datasets to link flows together. The process tracks data to determine dates, volumes, ownership, exporting facility, port of export, and the country of import for specific shipments (Godar, 2018; zu Ermgassen et al., 2020).

The general objective is to improve the transparency of the supply chain and its dynamics to enhance sustainability in the international trade system (Dawkins et al., 2015) The method refines the spatial resolution of supply chain mapping, allowing to identify specific places of production accounting for the spatial heterogeneity of socio-environmental impacts. It also allows to assign responsibility and accounts for indirect impacts of globalisation (Dawkins et al., 2015). In general, this new approach will help inform and coordinate active initiatives among those who can initiate and hold change toward the sustainability of international trade (Dawkins et al., 2015).

Because the actors of the supply chain can be tracked in space and time, it allows linking specific actors to specific places of production. Therefore, the responsible parties are held accountable for that region socio-environmental risks. This method ensures consistency within the supply chain by linking raw products like soybeans and cattle to transformed products like soy cake and beef. Therefore, transformed products are also entirely traceable through the supply chain. Commodities flows are quantified via commodity equivalent which converts modified products to commodity equivalent (usually the raw form of the commodity) using official conversion coefficients. Data availability constrains supply chain accuracy. The data come from official sources and do not pose a confidentiality problem because they are aggregated per year, commodity equivalent and destination country. An advantage of this supply chain mapping method, it is that it makes possible to develop quantitative and qualitative indicators to characterise the chain (Godar, 2018).

2.5 The contribution of stickiness

Studies about supply chain and trade network have shown that a certain rigidity is observed in trade patterns (Reis et al., 2020). In 1969, Paul Armington made the assumption that identical products from different countries are not substitutes for each other. Goods are distinguished by their country of origin (Lloyd & Zhang, 2006). Villoria and Hertel, 2011 test the hypotheses that global trade is influenced by geography, the place of origin of a product affects the international trade patterns. Other studies used simplified models that did not take into account this theory to assess indirect environmental impacts of international trade. The results of their research reject the integrated world model in favour of Armington's model. This research is crucial as having an adequate model to represent trades is key to the path towards a more sustainable supply chain. Moreover, it shows that the geography of trade patterns is essential in supply chain analysis and the study of their impacts. A study by Garrett, Rueda, and Lambin, 2013 illustrate Armington's model and the influence of consumer preferences on trade patterns. And shows that because the impact of globalisation depends on trade relationships stemming from integration. Countries could take advantage of customer preferences (towards sustainability) on the international market.

Studies link stickiness to different factors: ethnic networks (Coughlin & Wall, 2011), colonial linkages (Head, Mayer, & Ries, 2010), geographic proximity, common language, piracy, governance regimes, institutional quality, the capacity to enforce contracts, technological capacity, social dependence and investments (Reis et al., 2020). These studies explain the economic aspect of the supply chain but fail to include the geographic stickiness between places and actors. They also do not introduce the usefulness of stickiness in improving sustainability in supply chains (Reis et al., 2020). This reserach's definition of stickiness is the definition elaborated by (Reis et al., 2020): "the overall capacity of supply chains, and actors therein, to maintain their geographic network configurations over time, i.e., the network of trade linkages and flows between specific places of production and consumption, and specific actors including producers, traders, retailers, and consumers".

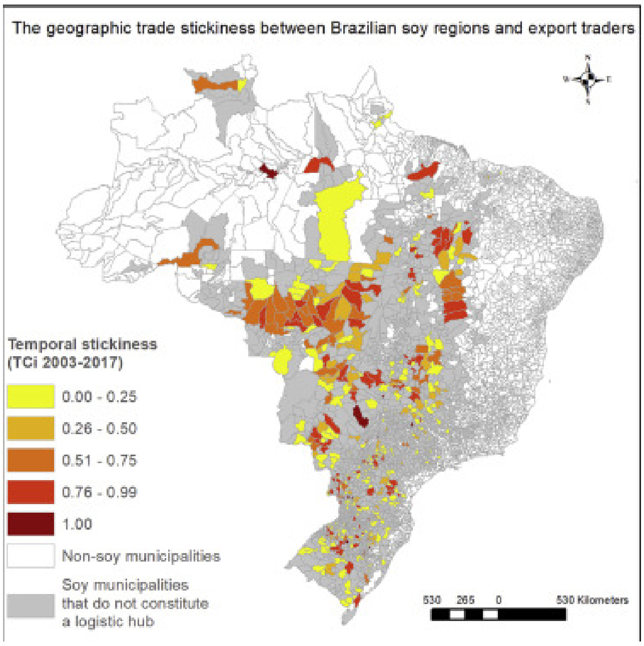


Fig. 2.2.: Spatial distribution of stickiness (persistence) of traders to sourcing areas (Reis et al., 2020).

The study by Reis et al., 2020 developed a conceptual framework to analyse the geographic stickiness of the global network of soy trade from Brazil, to measure the stability and rigidity of the relationships between regions of production and actors in the network empirically (figure 2.2) and try to understand the influence of stickiness in the supply chain governance such as its affect initiatives towards sustainability. The study determines that soy traders with the largest market share are geographically stickier and are the ones to sign zero-deforestation commitments. This analysis of stickiness uncovers information about the behaviour of the different decision-maker of the supply chain and their relationship with the production places, therefore enlightening the efficiency of policies and initiatives put in place by the supply chain governance.

3 Methodology

3.1 Methodological approach

When analysing a network through space and time, the probability that nodes connected at a given time will still be connected the following timestep can not be ignored (Nicosia et al., 2013). This assumption comes from Armington's theory. Armington's assumption states that contrary to the integrated world market (IWM) theory, where the world market is guided by one world price for each commodity, commodities prices are actually differentiated by their origin. Identical products from different countries are not perfect substitutes for each other (Garrett et al., 2013). It is due, for example, to the perceived quality of an exporter or trade agreements between states. It results in persistence in trade patterns (Villoria & Hertel, 2011). The objective of the research is to characterise the evolution of the Brazilian beef network through space and time.

To pursue that goal, we apply the methodology developed by Reis et al., 2020 on the Brazilian soy supply chain (mentioned in 2.5). The methodology allows for a characterisation of the network of the supply chain. The nodes represent the actors in the supply chain and the edges of the network represent the flows of beef linking two nodes (which represent the trade exchange of the beef). Figure 3.1 illustrate an example of the evolution of a simplified network. The metric used characterises the stickiness of both the presence of the link/node and its intensity (Reis et al., 2020). There is four levels of actors in the supply chain: municipalities, logistic hubs, trading companies and consuming countries. Municipalities are the aggregation of all farmers raising cattle in each municipalities of Brazil. Logistic hubs are facilities were the meat is processed and exported (usually a slaughterhouse). Trading companies are companies trading beef between logistic hubs and consuming countries.

Temporal and spatial analysis of networks with this metric estimates how susceptible the network is to change (Tang et al., 2013). The network stickiness is estimated by the temporal correlation coefficient (C). This metric has been developed by Nicosia et al., 2013. C is the probability of an edge to persist year on year (Büttner, Salau, & Krieter, 2016a).

3.2 Data

3.2.1 Data collection

In order to analyse the Brazilian beef supply chain network, it requires to trace export flows at sub-national level. The data for this study was collected by Ermgassen et al., 2020. First, cattle exports flows are linked back to the slaughterhouse by crossing custom data, export licences and tax registration of slaughterhouses. Secondly, the municipalities were the cattle were raised in are extracted from state and federal data, MAPA [1]. These data retrace all cattle movements in Brazil. It usually goes from farms to slaughterhouses. However, there are intermediary movements between farms. For example, a farm sells to another farm where the cattle will be fattened. These intermediary movements are not explicitly identified in the final data, but when modelling the origin of cattle per slaughterhouse, these movements are aggregated to the municipal level. Finally, all the different pieces of information are matched together. Overall, 92% of cattle flows could be traced back to their export facilities, usually a slaughterhouse. Only 1% could not be traced back and remained completely unidentified. The rest could be traced back to at least the state of slaughter level (Ermgassen et al., 2020). The quantity of beef production is converted into a Carcass/offval Weight Equivalent (CWE) to be comparable between flows.

As mentioned in section 1, the Brazilian beef supply chain is a concentrated market. Beef production is concentrated in the states of Rondônia, Mato Grosso, Sao Paulo and Mato Grosso do Sul in the Amazon and Cerado biomes. Three companies dominates the export market (JBS, Minerva and Marfrig). The major countries importing beef are China/Hong Kong, Egypt, Russia, Iran and the European Union.

3.2.2 Data preparation

First, flows are aggregated by year, municipalities, logistic hubs, exporters and countries of consumption. These flows are aggregated together since these cattle products constitute the same edge of the network. Next, binary and weighted graphs of the networks (= a picture of the network) are constructed for every year (2015, 2016, 2017). Binary graphs represent the network edges where one one means there is an exchange and zero there is no exchange. Weighted graphs are weighted by the amount of cattle product exchanged.

[1]Ministério da Agricultura, Pecuária e Abastecimento = Ministry of Agriculture, Livestock, and Supply

3.3 Temporal correlation coefficient

The first formula of the temporal correlation coefficient is introduced by Nicosia et al., 2013 to improve the understanding of network system. Previously researcher analysed static networks. Adding the temporal dimension brings information on temporal correlation and causality. The formula was later modified by Pigott and Herrera, 2014 in order to correct a problem occurring with unconnected nodes. Indeed, the formula proposed by Nicosia et al., 2013 does not consider that the number of nodes (N) active in the network can change over time, causing an underestimation of C_m (Pigott & Herrera, 2014). However, the formula proposed by Pigott and Herrera, 2014 entails a new shortcoming when the number of active nodes is superior to the number of maximum connected nodes (Büttner et al., 2016a). Büttner et al., 2016a propose a new formula for C_m to remedy the problem. It is their variation of the temporal correlation coefficient that is used in this research.

The temporal correlation coefficient is a multi-steps calculation. First, for each node, the consistency of the linkage around the node (C_i)is calculated.

$$C_i(t_m, t_{m+1}) = \frac{\sum a_{ij}(t_m) a_{ij}(t_{m+1})}{\sqrt{[\sum a_{ij}(t_m)][\sum a_{ij}(t_{m+1})]}} \tag{3.1}$$

Where $a_{ij}(t_m)$ is an entry of an unweighted or weighted adjacency matrix giving the interaction of the node i with all the other nodes for a time step. The unweighted coefficient is noted C_i and the weighted coefficient is noted WP_i.

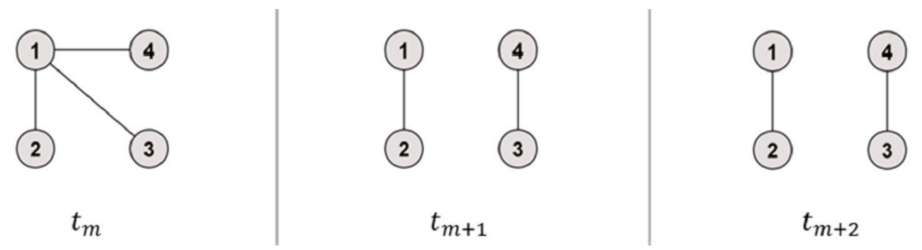


Fig. 3.1.: Illustration of evolution of the network overtime (Büttner, Salau, & Krieter, 2016a)

Second, the consistency of linkage configuration for the all graph between two years (C_m) is calculated.

$$C_m = \frac{1}{max[A(t_m), A(t_{m+1})]} \sum C_i(t_m, t_{m+1}) \tag{3.2}$$

Where $max[A(t_m), A(t_{m+1})]$ is the maximal number of active nodes at one time step.

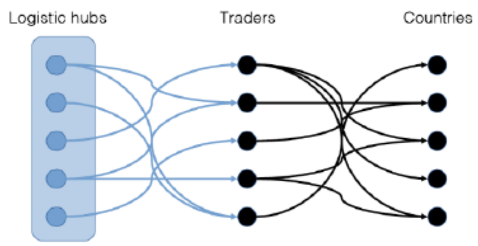
Finally it allows to calculate the temporal correlation coefficient (C).

$$C = \frac{1}{M-1} \sum C_m \tag{3.3}$$

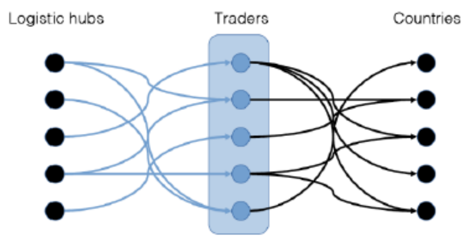
Where M is the total number of years.

The temporal correlation coefficient ranges from 0 to 1, where 0 corresponds to a complete change of the network configuration which mean a lack of stickiness and 1 complete stickiness of the network. For example, on figure 3.1, the stickiness coefficient between t_m and $t_m + 1$ would be < 1 while the stickiness coefficient between t_{m+1} and t_{m+2} would be 1.

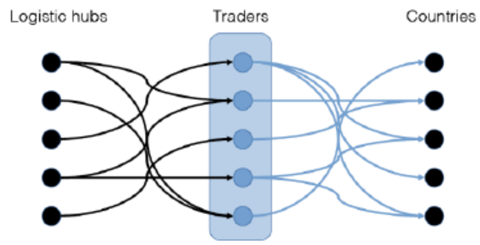
The coefficient C_i and WP_i characterise the changes of the flows of around a particular nodes. The flows existence (C_i) and its intensity (WP_i). In the Brazilian beef network, different type of nodes can be identified: municipalities of production, logistic hubs, trading companies and countries of consumption. The network will be analysed according the different kind of relationships between these nodes: flows between producing municipalities and importing logistic hubs, flows between exporting logistic hubs and importing companies (figure 3.2a and 3.2b), flows between exporting companies and importing countries (figure 3.2c and 3.2d).



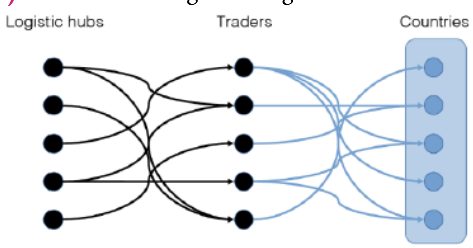
(a) Logistic hubs supplying traders



(b) Traders sourcing from logistic hubs



(c) Traders supplying countries



(d) Countries sourcing from traders

Fig. 3.2.: Illustration of the different type of relationships in the network (Reis et al., 2020)

3.4 Evaluation and justification

To this day, there are but a few methods to properly (accounting for time variation) characterise the structure of networks. The method used in this research is relatively new and still in development (Büttner, Salau, & Krieter, 2016b). Studies have shown that temporal variability is essential for studying network structure. It definitively helps understand the dynamics of the network (Büttner et al., 2016a). It allows the revelation of information about the network structure not obtainable with static metrics. The latter can overestimate available links and underestimate their length (Tang et al., 2013). The advantage of temporal analysis is that it does not depend on the number of interacting agents. The choice of length window in the analysis is important because it influences the statistical properties of the network (Büttner et al., 2016a). For cattle, biological cycles might result in patterns in the network. However, the length of the time window in this research is defined by data availability. For each year, the amount of cattle traded between each agent is quantified.

4 Results

We analysed the stickiness of the Brazilian beef supply chain over a network composed of a total of 3639 nodes comprising more than 3137 municipalities where the cattle are raised, 156 logistic hubs where the cattle transit before being exported by 196 companies to 150 importing countries where beef is being consumed. The data covers trades flows between these agents over 2015 and 2017. A sample of the network illustrated in figure 4.1, represents, the volume of beef exchanged from the logistic hub to the country of consumption via the four exporting companies with the largest market shares (JBS S/A, Minerva S.A., Marfrig global foods S.A., Mtaboi Alimentos LDTA) in 2017. We analyse stickiness between 2015 and 2017 from an exporting (outgoing flow) or importing (incoming flow) perspective. The network is created both in a non-weighted and a weighted matrix. The first measures the consistency of the linkages, whether a linkage between two nodes exists or not. The second measures the stickiness in volume exchanged. The stickiness coefficient for the unweighted network is C_i (3.1) and for the weighted network WP_i (3.1 with weighted matrix).

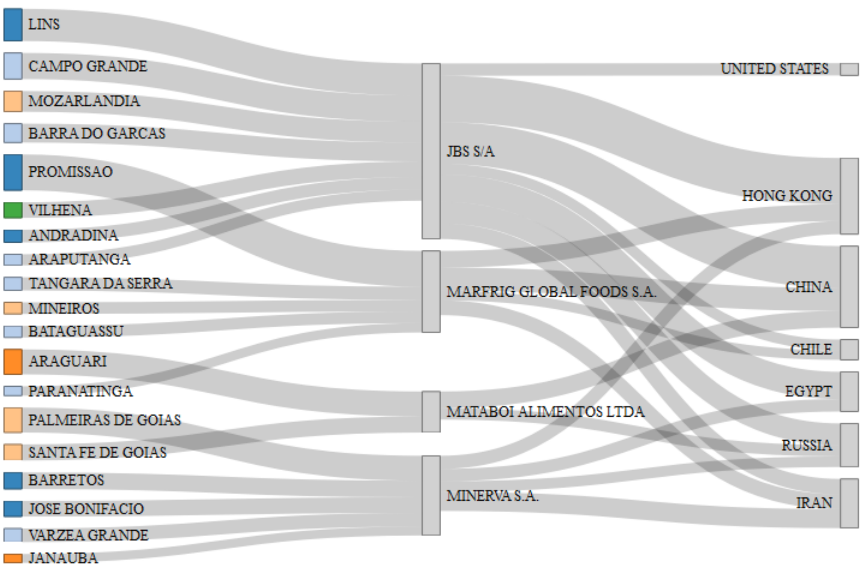
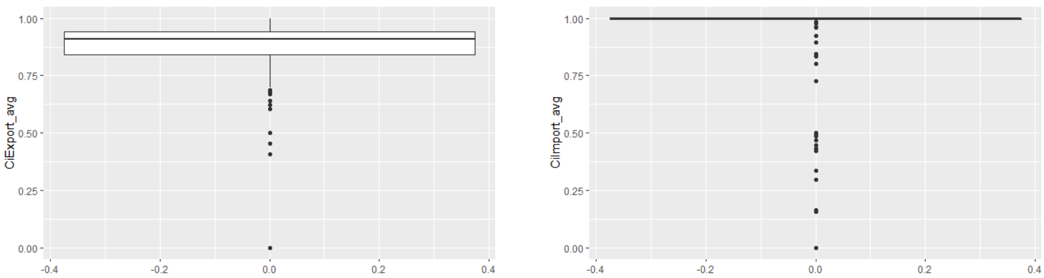


Fig. 4.1.: Trade flow of Brazilian beef of the biggest exchanges of the top four exporting companies in 2017, from the municipality the where slaughterhouses are located to the country of consumption. Dark blue = Sao Paulo state, light blue = Mato Grosso State, yellow = Goias state, green = Rondonia state, orange = Minasgerais state.

The results of the overall network show that the stickiness coefficients C of the entire network from the exporting and importing perspective are similar (0.56 and 0.55, respectively). The weighted stickiness coefficient WP is smaller than C but also similar from the exporting and importing perspective (0.21 and 0.22). The coefficients are independent of the size of the network, allowing to compare the stickiness of the different types of nodes and the differences within groups (Reis et al., 2020). The analysis is further subdivided between the different kind of relationships of the network: trade flows between municipalities and slaughterhouses, trades between the logistic hubs and the trading companies and trades between companies and countries.

4.1 Municipalities-logistic hubs relationship



(a) Exporting municipalities **(b)** Importing logistic hubs

Fig. 4.2.: Distribution of the average C_i for exporting municipalities and importing logistic hubs.

The relationship between municipalities and slaughterhouses appears very stable. Most municipalities have an average C_i close to 1 as only 25% of the municipalities have an average C_i inferior to 0,84 (Figure 4.2a). In the same way, 95% of logistic hubs importing beef from municipalities have an average C_i of over 0.99 (Figure 4.2b). The exchanges between municipalities and slaughterhouses vary very little. The stickiness between municipalities and logistic hubs is the results of the way data were collected. Indeed, as the animal movement data are aggregated across years, the municipalities supplying each slaughterhouse in 2015, 2016 and 2017 remain the same.

To consider the impact of beef production on the environment, the graph figure 4.3 shows that there is no notable differences in the average C_i between the municipalities in the different biomes except for the Caatinga biome. The value of the temporal coefficient of the municipalities in this biome is more variable than in other biomes. The relationships between farmers and slaughterhouses change more than in other biomes. Also, the map figure 4.3 shows that the municipalities in the Amazon biome have different behaviour depending on their location. The stickiness of municipalities East of the biome is mostly high (between 0.81 and

1.00). However, some municipalities with a very low C_i (light blue) are clustered in deep Amazonia. These municipalities are in the states of Acre and Roraima. The latter mostly produces beef consumed on the domestic market and exports very little (Ermgassen et al., 2020). The map also shows that in the state of Amazonas, the municipalities do not export beef. Indeed, production of beef in the Amazonas states is only consumed in the domestic market (figure1.2) (Ermgassen et al., 2020). In the center of the Cerrado biome, there is also a cluster of municipalities with a lower C_i value than the rest of the surrounding municipalities.

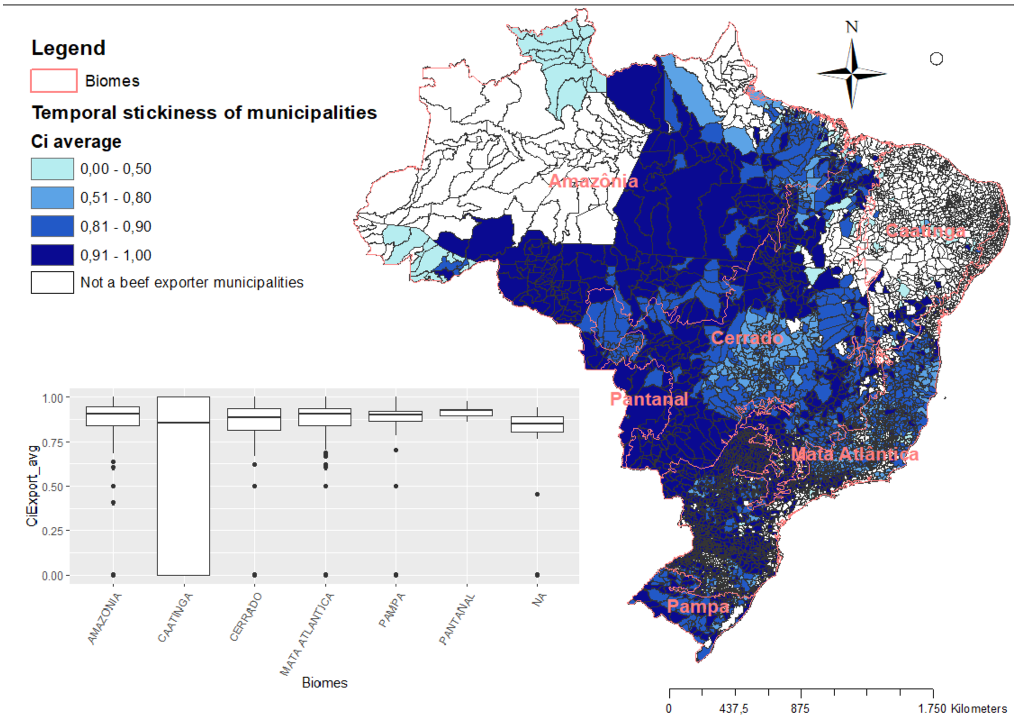
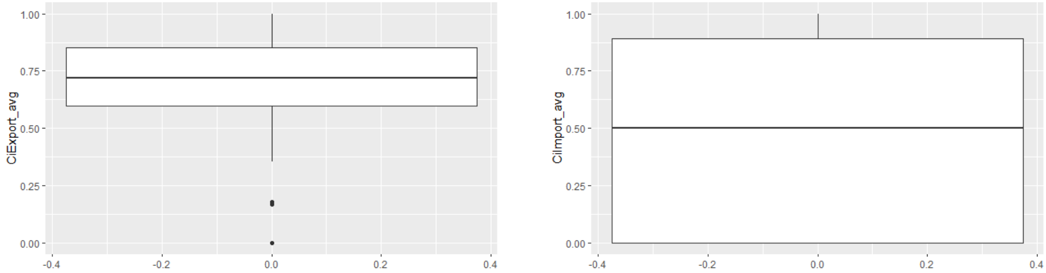


Fig. 4.3.: Distribution of the average C_i of municipalities by biomes and map of the municipalities average Ci.

4.2 Logistic hubs-trading companies relationship

Overall, logistic hubs have a significantly higher stickiness than companies (figure 4.4) and the distribution of the average C_i of importing companies is wider than the distribution of the average C_i of logistic hubs (standard deviation is equal to 0.4 and 0.25, respectively) and centre around a mean of 0.44 against 0.69 for the logistic hubs (t.test p-value is equal to 2.5×10^{-13}). Trading companies often own their logistic hub/slaughterhouse. Logistic hubs without a trading company ownership are generally less sticky and logistic hubs owned by one of the top four companies with the largest market shares are generally stickier than the rest of the logistic hubs (see the graph figure A showing the distribution of the average C_i of exporting logistic hubs by company ownership).



(a) Exporting logistic hubs **(b)** Importing trading companies

Fig. 4.4.: Distribution of the average C_i for exporting logistic hubs and importing trading companies.

The boxplots on figure 4.5 shows the distribution of the average C_i of the logistic hubs and the map illustrates the value of the stickiness coefficient of each logistic hub and the mean average by state. The state of Roraima does not show a logistic hub on the map but a value of stickiness when aggregated by state because the beef traded was traced to an unknown logistic hub in the Roraima state. The exact location of the logistic hub is unknown. There is no logistic hubs in the state of Amazonas and Amapá in the Amazonia biome and in the states of Piauí, Caerá, Paraíba, Pernambuco, Algoas and Sergipe in the Caatinga biome. The states of Acre and Roraima in the Amazonia biome have a particularly low stickiness. The state of Maranhão in the Cerrado and Amazon biomes also has a low mean average C_i (<0.5). However, the variability in that state is higher than the states of Acre and Roraima.

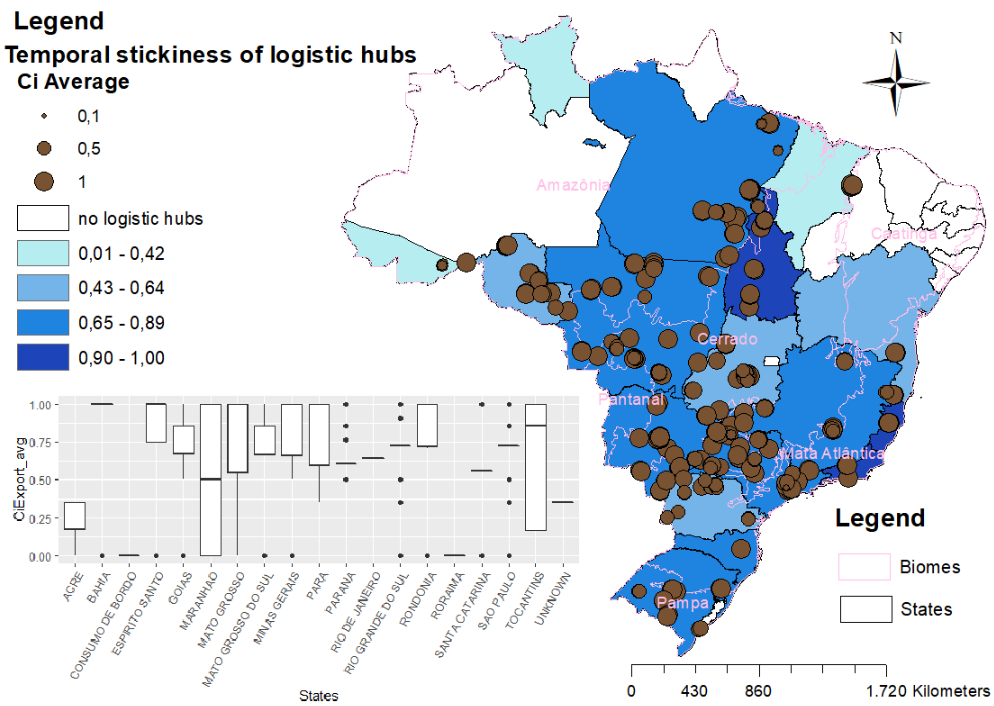


Fig. 4.5.: Distribution of the C_i of exporting logistic hubs by states

We classified the logistic hubs by the volume of beef traded. High volumes are the upper 10% quantile, low volumes are the lower 70% quantile, and the medium class is the rest. We observe that logistic hubs exporting small amounts of beef are less sticky than logistic hubs trading larger volumes (figure 4.6, confirmed by a p-value of t.test comparing the means of each volume group is inferior to 0.05. The different groups have significantly different behaviour. Most of the slaughterhouses handling high volumes are owned by one of the top four exporters.

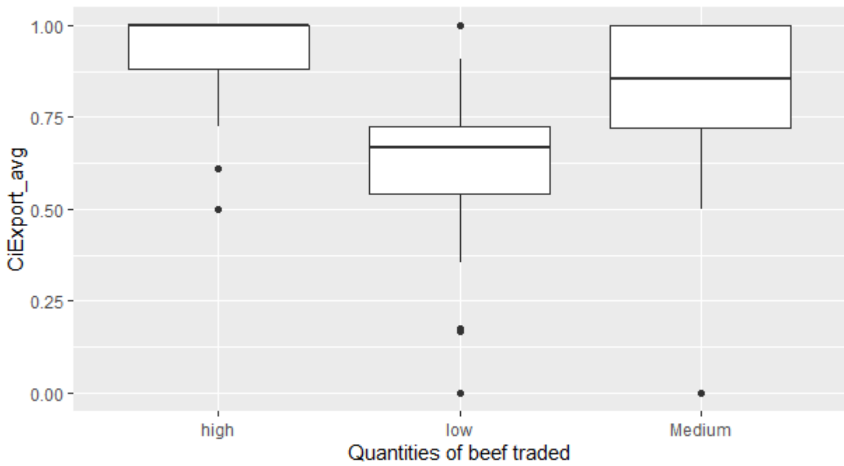


Fig. 4.6.: Distribution of the average C_i by quantity of beef traded of exporting logistic hubs.

Most of the beef production exported comes from slaughterhouses in the Amazonia and the Cerrado biomes. In the Amazonia biome, the majority of the production comes from states at the Eastern border of the biome, including Rondônia, Mato Grosso and Pará. These latter states are stickier than states more remote like Acre and Roraima. The difficulty to access remote places could account for the instability around the nodes in these regions. Also, the quantity of beef produced by the states of Acre and Roraima is negligible compared to the states of Mato Grosso and Para. As seen in figure 4.6, the quantity traded by the logistic hubs is also linked to the stickiness of the node. Figure 4.5 allows to identify that the logistic hubs in the states that produces the most beef (Mato Grosso, Mato Grosso Do Sul, Sao Poalo, Minas Gerais, Goias and Para) are also generally more sticky. As seen on the graph figure 4.7, Pearson's correlation test indicates that there is a true correlation ($p\text{-value} < 0.05$, correlation value = 0.27) between the amount of beef exported by a logistic hub and the value of the stickiness coefficient.

The top four trading companies are stickier than the other companies are (figure 4.8). The respective average Ci's of the top companies are 0.93, 0.81, 0.91 and 0.78 for the companies JBS S/A, Marfrig global foods S.A., Mataboi Alimentos LDTA, Minerva S.A. respectively. In contrast, the mean average C_i of the other companies

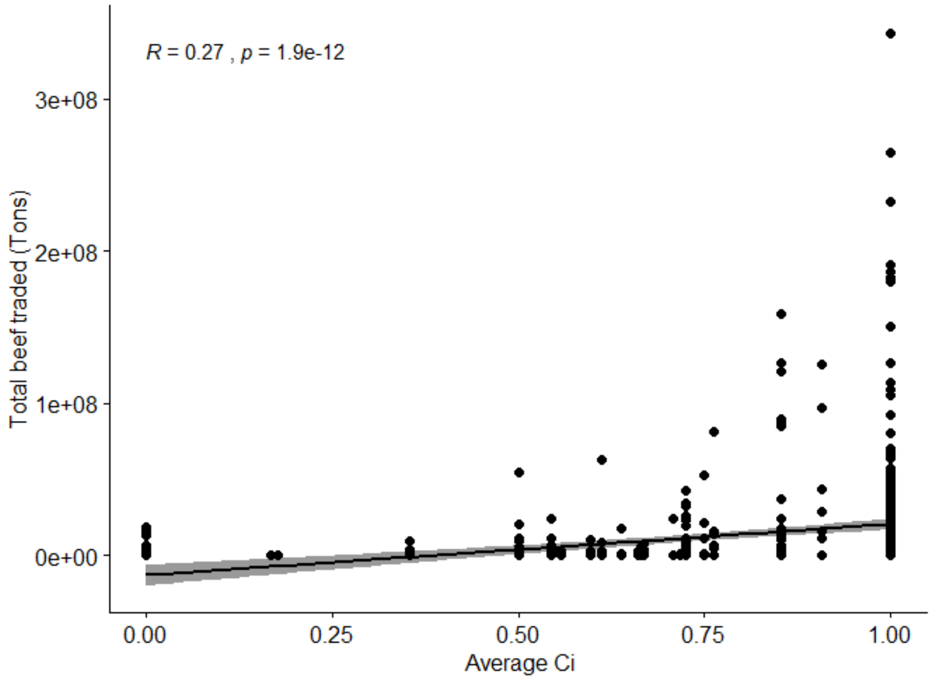


Fig. 4.7.: Correlation plot between the amount of beef traded and the stickiness of exporting logistic hubs.

is 0.5. However, some companies with lower market shares have higher average Ci, some of them have an average C_i of 1. The localisation of the top trader companies slaughterhouses is illustrated on the map figure A. The company JBS S/A is the company which possesses the largest market shares. They also possess the most slaughterhouses located in the Amazonia, Cerrado and Mata Atlântica biome. The second company with the highest shares is Minerva S.A. Their slaughterhouses are mostly located in the Cerrado biome. The company Marfrig global foods S.A. owns slaughterhouses in almost all biomes (Amazonia, Cerrado, Pampa and Mata Atlântica). The company Mataboi Alimentos LDTA has a significantly lower market share than the three other companies and owns slaughterhouses in the Cerrado biome.

Multiple slaughterhouses have signed the Terms of Adjustment of Conduct (TAC). With this agreement, slaughterhouses oblige themselves not to commit new deforestation for cattle ranching, no invasion of indigenous lands and protected areas, no slavery work, no land grabbing and land conflicts and commit to enforce a tracking system when buying stock. As shown on the graph figure 8, slaughterhouses which have signed the agreement are generally more stable than the ones who have not (t.test p-value is equal to 0.006). As seen on the map figure 4.9, all slaughterhouses with a TAC agreement are located in the Amazonia biome or the Cerrado biome.

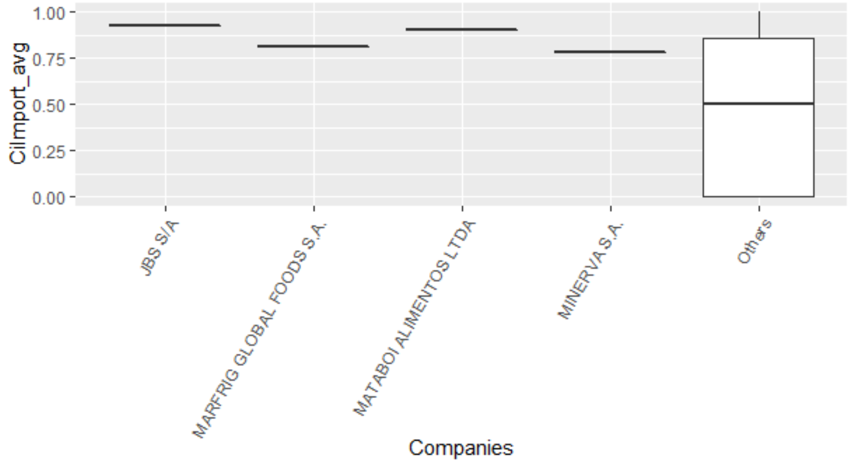


Fig. 4.8.: Distribution of the average C_i of importing trading companies.

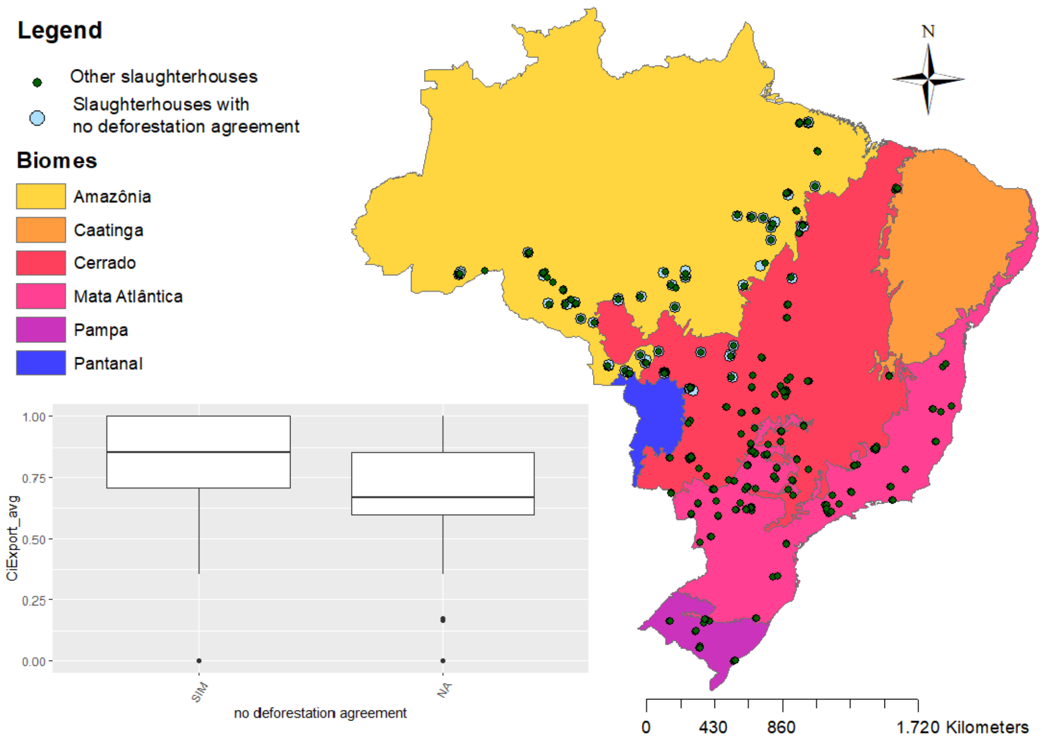
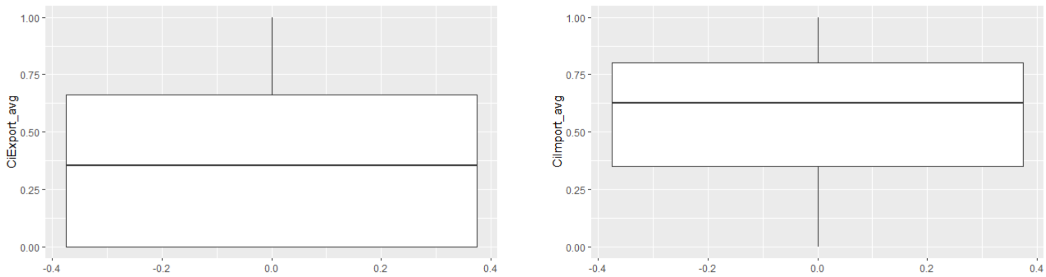


Fig. 4.9.: Distribution of the average C_i of logistic hub with a no deforestation agreement or not and localistaion of the slaughterhouses.

4.3 Trading companies-consumption countries relationship

Comparing figure 4.10a and 4.4b shows that the distribution of the average C_i of the trading companies from the exporting perspective is different from the distribution of the average C_i of the trading companies from the importing perspective. In general, trading companies importing from logistic hubs are stickier than trading companies exporting to countries (means of 0.44 and 0.35, respectively, with a p-value of the t.test = 0.017). With a mean average C_i equal to 0.55, importing countries are stickier than trading companies (figure 4.10b).



(a) Exporting trading companies

(b) Importing contries

Fig. 4.10.: Distribution of the average C_i for exporting logistic hubs and importing countries.

Similarly, from the importing perspective of the trading companies, the top four trading companies exporting to countries are generally stickier than the other companies (figure 4.11). The companies holding the largest market shares seems to be very stable when trading beef. Other companies with fewer market shares change more easily suppliers and buyers in order to remain competitive on the market.

We analysed the geographical distribution of the average C_i of the importing countries. Figure 4.12a illustrates the distribution of the average C_i by continents and figure 4.12b illustrates the distribution of he average C_i by different regions of the world. The regions are defined according to the Statistics Division of the United Nations Secretariat. The different continents have somewhat consistent behaviours. North America comprises Northern America, Central America and the Caribbean. On the continent of Oceania, the variability seems very high. When looking at the graph of the distribution of the average C_i by regions (figure 4.12b), we see that Australia and New Zealand are very close to an average C_i of 1. However, Polynesia and Melanesia are significantly less sticky. The major importing countries (China, Hong Kong, Egypt, Russia and Iran) all have a similar value of the stickiness coefficient (between 0.65 and 0.80). In Europe, a notable difference is found between the countries of the European Union (EU) and other countries like Montenegro, Albania

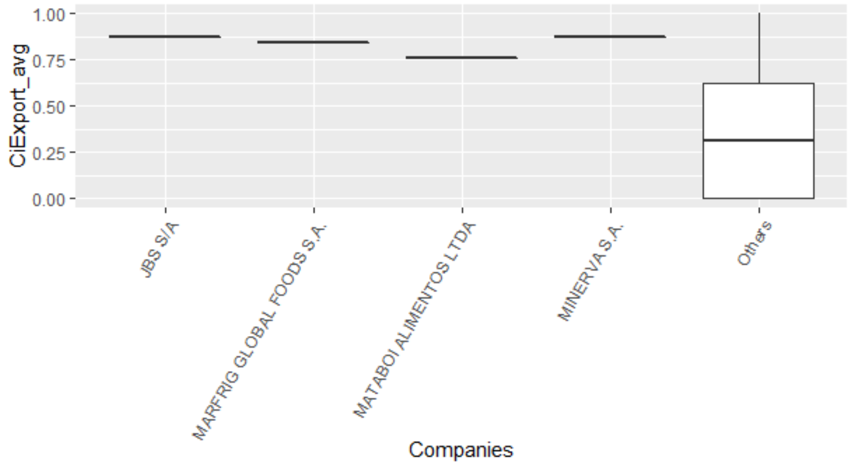
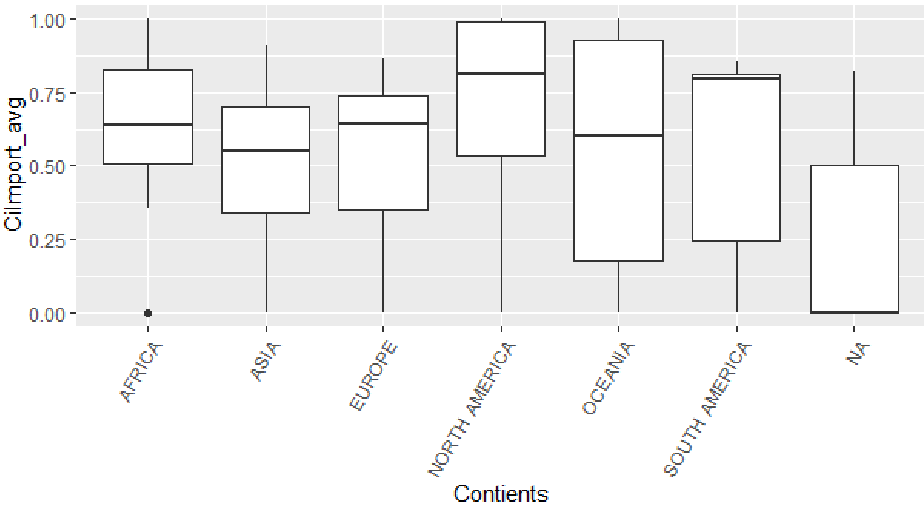


Fig. 4.11.: Distribution of the average C_i for exporting trading companies

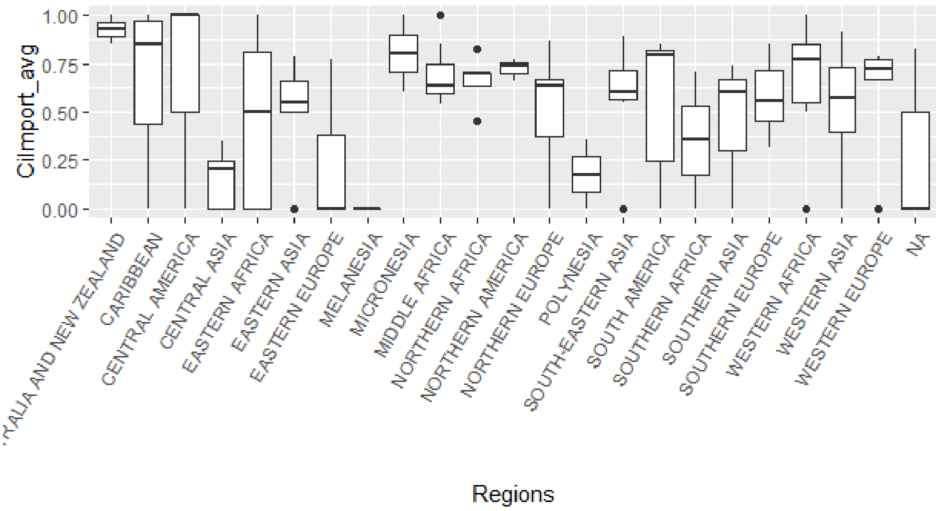
and Serbia. The countries of the EU with the exception of Portugal and including Switzerland, have a stickiness coefficient similar to the major importing countries mentioned above. They other countries including Portugal have a lower stickiness coefficient (<0.60). The stickiness does not appear to have a specific spatial tendency, analysing the stickiness according to regulation (safety, environmental, ...) that countries of group of countries (like the European Union) might have could reveal new information.

4.4 Weighted temporal coefficient

When analysing the weighted coefficient, we observe the same tendencies, with lower coefficient values. This is to be expected, as volume exchanged is more likely to vary in time than the existence of relationship between the different partners. The graphs are illustrated in A.



(a) Distribution of the average C_i of importing countries by continents



(b) Distribution of the average C_i of importing countries by regions

Fig. 4.12.: Distribution of the average C_i of importing countries by region of the world.

5 Discussion

The results of the analysis reveal useful information over the cattle supply chain. Generally, logistic hubs are the stickiest agent of the supply chain. Logistic hubs in the states of Acre and Roraima in the deep Amazonia are less sticky than the rest of the states. The stickiness of traders with higher beef market shares is higher than other traders. Slaughterhouses trading higher volume of beef are stickier than slaughterhouses trading lower volumes. Moreover, the stickiness of slaughterhouses with a TAC agreement is also higher. Importing countries have very different behaviour, and there is no apparent tendency by region.

The stickiness coefficient metric allows for the characterisation of the entire network of the Brazilian beef supply chain, to analyse the presence and the intensity of linkages, and to highlight the behaviour of the different actors in the Brazilian beef supply chain. With this analysis, we identify key actors and their impact spatially. We also identify which relationships are the most stable. The analysis of the stickiness of the Brazilian beef network is a direct application of the methodology applied to the Brazilian soy network by Reis et al., 2020.

5.1 Comparison with the analysis on Brazilian soy network

The results of the stickiness for the beef supply chain is similar to the stickiness results of the soy supply chain studied by Reis et al., 2020. Both supply chains have the same structure: they are highly concentrated. 31 out of 1709 companies handle 82% of soy traded and 3 companies out of 200 accounts for 71,7% of the beef traded. These major traders also own the facilities they operate from in specific regions. Both the case of soy and beef, large market share traders are stickier than low market shares holders. Major traders have a broad geographic reach that stays constant while smaller traders must adapt to market circumstances and opportunities (they do not depend on specific places to trade soy/beef) (Reis et al., 2020). Unlike soy, the analysis of the stickiness is not possible over time as data were only available over 3 years. In the soy supply chain, the relationship between traders and logistic hubs increase over time. It would also be interesting to observe the evolution of the stickiness coefficient over more years to analyse the persistence, resistance and resilience of the supply chain.

The length of the time window of the data allows for the analysis of the persistence of relationships. We identify the largest traders as the stickiest and remote region in the amazon to be less sticky. This information can help to understand why these regions and actors behave the way they do. Therefore, it could result in the implementation of policies toward sustainability that are adapted and efficient for each region and actors. The stickiness analysis allows understanding how strong the relationship is between the actors and the places of production. This knowledge is critical to the implementation of action toward sustainability in the supply chain. We cannot analyse the resistance to shock and the recovery capacity of the network with a timeframe of only three years as we did not identify a shock in that timeframe and the length of the timeframe would not allow to observe the reactions to it.

The stickiness of the relationship between municipalities and logistic hubs is a reflection of the way the data were collected. The animal movement data are aggregated across multiple years, so the municipalities supplying each slaughterhouse in 2015, 2016 and 2017 are the same. Aggregating the data is necessary and caused by the complexity of cattle movement. Cattle live multiple years, and they can be moved to multiple farms during these years before being slaughtered in a slaughterhouse. The details of the matching of animal movement to the slaughterhouse are detailed in (Ermgassen et al., 2020). Analysing the stickiness of the trade between the municipalities of production and the logistic hubs based on this dataset is therefore not relevant. Because of the aggregation of the animal movements, the value of the stickiness coefficient should be 1 for all exchanges. In this analysis, the coefficient values of the municipalities different from 1 is a result of the way the coefficient is calculated. For example, a municipality that does not export beef at all during one of the three years will result in a coefficient of 0. Even if they produce a limited amounts of beef, it might end up in bringing the trade with a given logistic hub to 0 for a given year, but still maintaining enough volumes to some other to be a link in the non-weighted network. If this happens, the stickiness coefficient value will be between 0 and 1.

5.2 Assessing the efficiency of no-deforestation commitments

The hypothesis is that if the supply chain is geographically sticky, policies and commitments implemented by governments and organizations will be more effective. Also, a strong actor-geography connection means a better accountability for environmental damages (Reis et al., 2020). In 2009, meatpacking companies in Parà signed the Terms of Adjustment of Conduct (TAC) agreement. The agreement forbids companies to purchase beef from farm properties which resort to illegal deforestation. The agreement has now been extended to the states of Acre, Rondônia, Amazonas and Mato Grosso (Holly K. Gibbs et al., 2016). In the Amazon biome, 82% of cattle export is covered by the TAC agreement (Ermgassen et al., 2020).

A study by Holly K. Gibbs et al., 2016 demonstrates that the agreement was a driven factor for change in the state of Parà. After the agreement, slaughterhouses avoid purchasing beef from farms resorting to deforestation. Excluding properties means a reduced market for the farmers who allow deforestation. The results of the research suggest that the agreement helped reduce deforestation by farmers. The role of the stickiness of the network in term of the TAC agreement is pertinent. Indeed, the results of Holly K. Gibbs et al., 2016 shows that deforestation rates were 75% lower for stable properties (properties selling cattle to slaughterhouses before and after the agreement) against 50% lower for properties selling cattle to slaughterhouse only after the agreement.

Stability in the relationship between producers and slaughterhouse is a key element in the effectiveness of the agreement. Slaughterhouses are essential in the battle against deforestation, because of their location, their direct interaction with farmers and their ability to restrict the market. The benefits of stickiness observed in the study by Holly K. Gibbs et al., 2016 is different from the stickiness observed in this research. First, the agreement is implemented at the properties level while this study aggregates the cattle production at the municipality level. In Holly K. Gibbs et al., 2016, the stickiness is between farmers and slaughterhouses while in this research, the stickiness is between slaughterhouses and exporting companies. In Holly K. Gibbs et al., 2016 study, the stability might be correlated to more effectiveness of the agreement while this study shows that slaughterhouses which have signed the agreement are stickier than the ones who have not signed the agreement. When combining both information, the stability of the network is necessary for effective policy implementation. The stability might be induced with those policies.

The subject calls for more analysis to determine to which degree the agreement is responsible and what happened in the other states where there is less pressure to comply with the agreement. Additionally, the current agreement only covers part of the cattle supply chain. Due to the complexity of the supply chain (indirect supplying of cattle), leakage and laundering is still a problem not addressed with the agreement. The market could shift toward slaughterhouses that have not signed the agreement or cattle can be raised by a farm resorting to deforestation then moved to a farm complying to the agreement before being sold to a slaughterhouse (figure 5.1). Tracking animal movements could help resolve these issues (Holly K. Gibbs

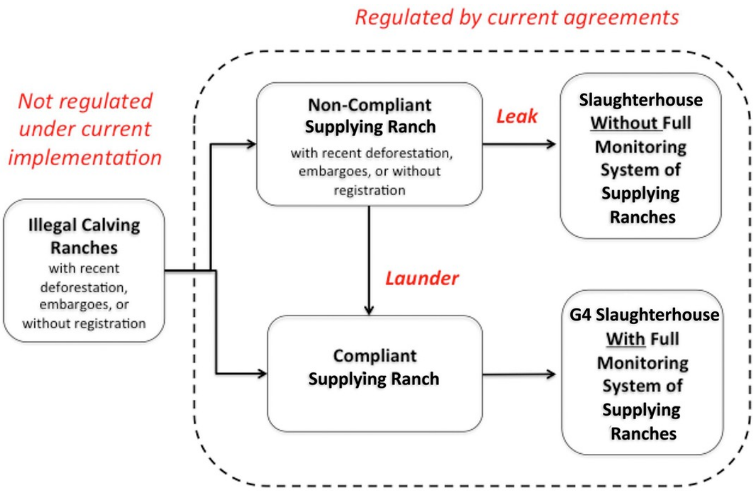


Fig. 5.1.: Illustration of leakage and laundering mechanism (Holly K. Gibbs et al., 2016)

et al., 2016). The study of stickiness could help understand the mechanisms of leakage and other spillovers (Reis et al., 2020). Stickiness could help identify regions where leakage would be more likely to occur. For example, traders could shift their purchases toward regions not covered by restrictions and where they have already high stickiness (a strong report with the producers) (Reis et al., 2020).

6 Conclusion

New approaches like Trase, brings new insight to the study of supply chain governance. Spatially explicit studies are critical in improving supply chain transparency and sustainability in the supply chains. Stickiness is a essential elements in understanding supply chain dynamics.

The analysis of the stickiness of the Brazilian beef supply chain is similar to the analysis of the Brazilian soy supply chain. Empirically measuring the stickiness of the Brazilian beef supply chain shows that traders with large market shares are stickier than other traders. The more volume a slaughterhouse (often owned by trading companies) trade the stickier they are and slaughterhouses with a TAC agreement are stickier than slaughterhouses without agreements. Slaughterhouses are important actors in the supply chain because of their direct contact with producers and the leverage they have on the market. Stickiness could help implement efficient policies and initiatives to improve sustainability in supply chains. Indeed current no-deforestation agreements like TAC do not avoid leakage and laundering. Stickiness could help identify the regions where leakage would occur. Further research could improve the understanding of the stickiness patterns (what factors affects it) to further understand the relationships between the actors and the places of production.

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List of Figures

Appendix

A

Appendix A

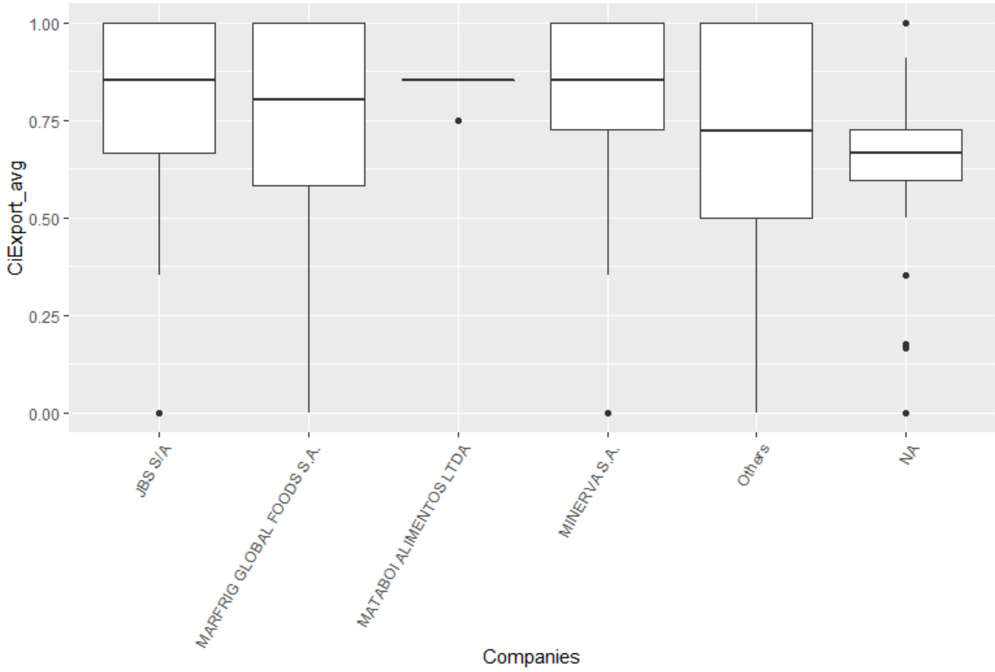


Fig. .A.: Average Ci of exporting Logistic hubs by company ownership

Appendix B

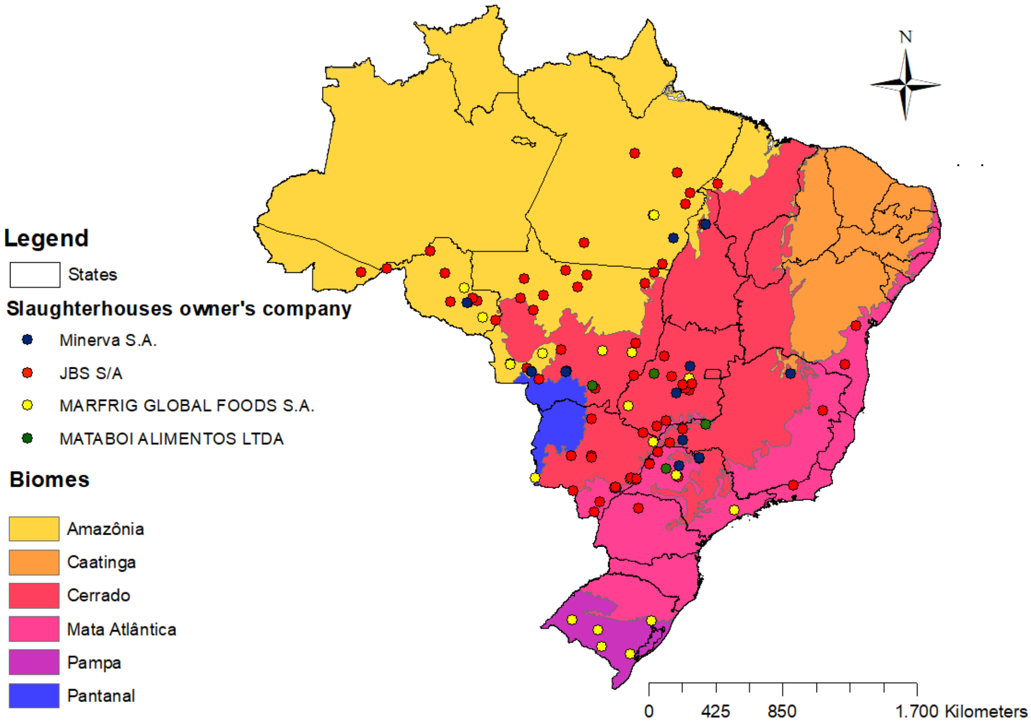


Fig. .B.: Map of the location of the slaughterhouses owned by one of the major exporting companies

Appendix C

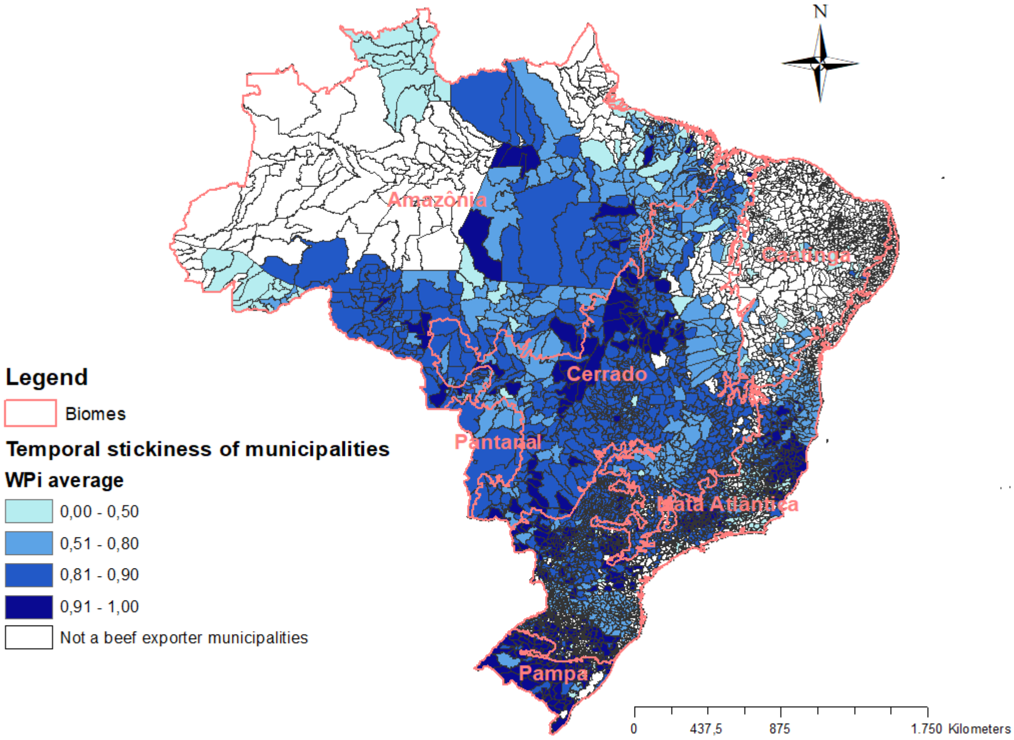
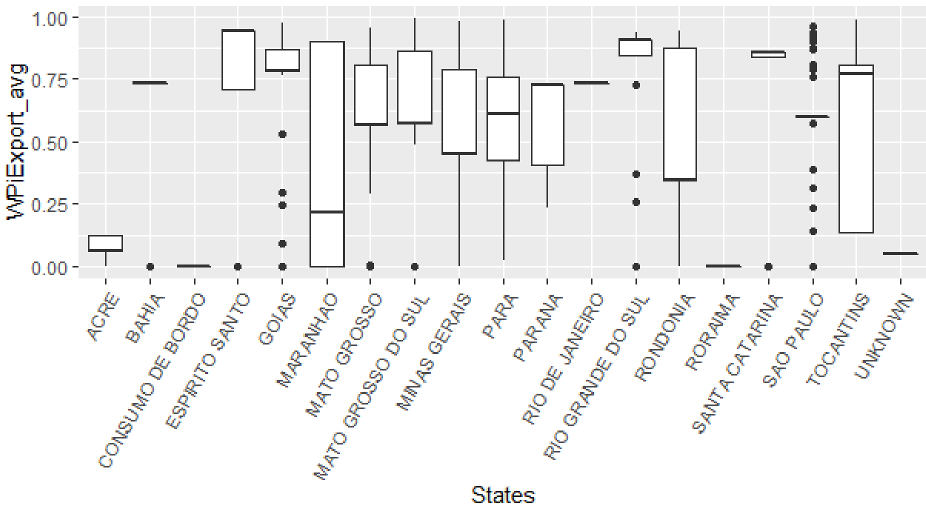
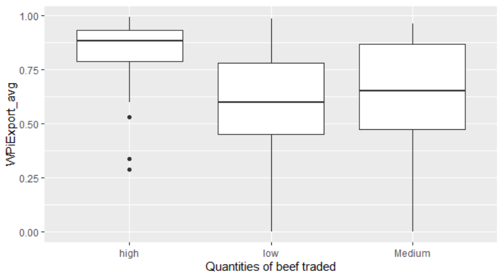


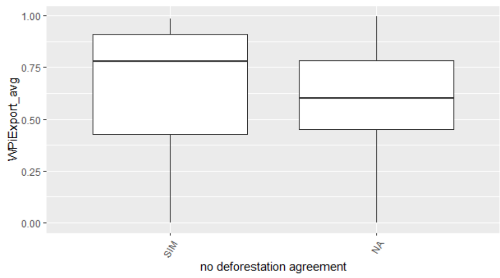
Fig. .C.: Map of the distribution of WPi coefficient of exporting municipalities.



(a) By states.



(b) By volume.



(c) By no-deforestation agreement.

Fig. .D.: Distribution of WPi coefficient of exporting logistic hubs

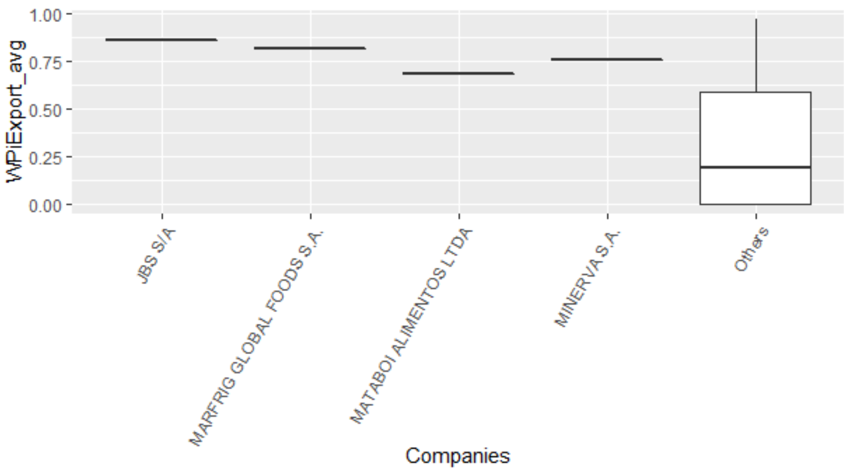
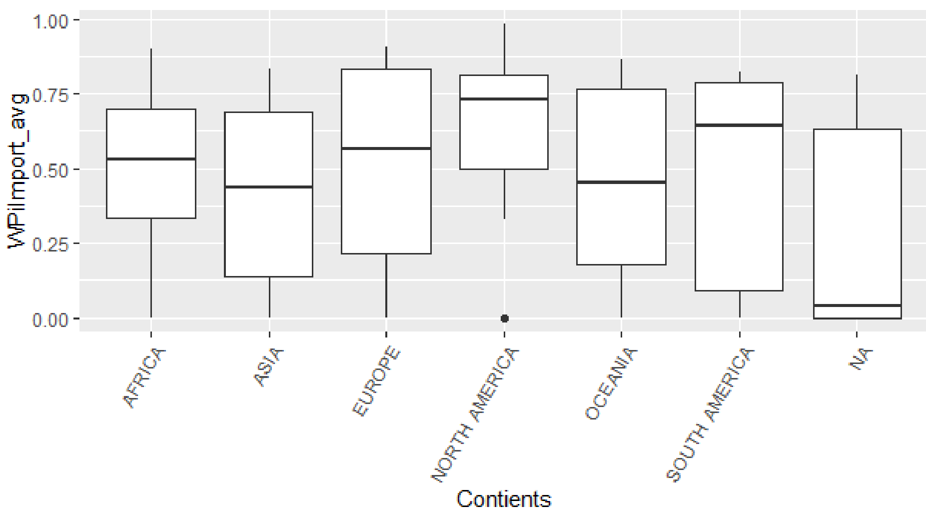
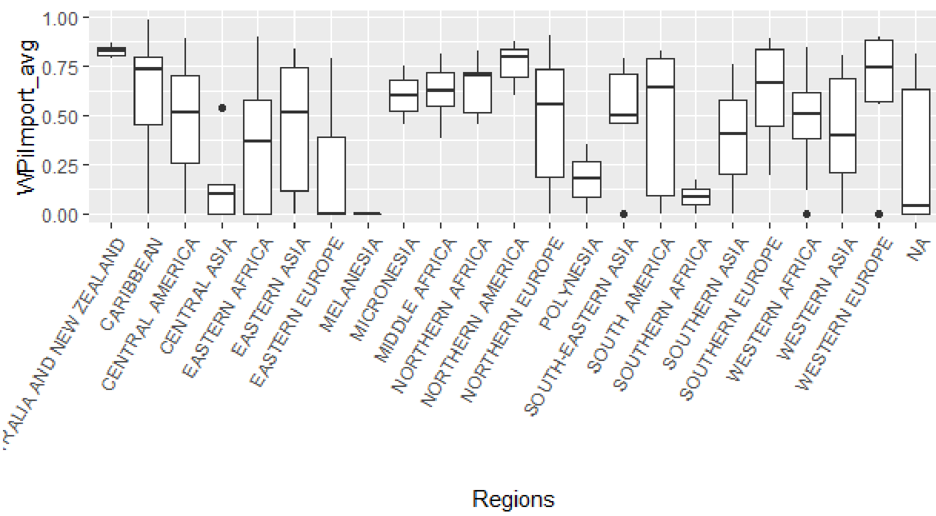


Fig. .E.: Distribution on WPi of exporting companies.



(a) By continents.



(b) By regions.

Fig. .F.: Distribution of WPi coefficient of importing countries

Colophon

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4 Rue nouvelle
7170 Manage
Belgium
+32 496/28.61.55
emicastin@gmail.com

Emilie Castin

Cursus

2014–2018 **Bachelor in Geography**, *Faculty of Sciences*, UCLouvain.
Relevant courses :
- Remote sensing
- GIS
- Statistical modelling

2018–Present **Master in Geography : General**, *Faculty of Sciences*, UCLouvain.
Relevant courses :
- In depth spatial statistics
- Geographic and environmental modelling
- Master thesis : Supply chain configuration and trade flows of beef from Brazil.

2019 **Six months Erasmus**, *Geography Department*, Exeter University.
Relevant courses :
- NIMBYism and the Low Carbon Transition
- Geopolitical cultures

Experience

2011–2014 **Youth leader**, *Espace jeunes*, Seneffe.
Organization and supervision of activities for youth.

2016-2018 **Student Job**, *Orange*, Bruxelles.

2019 **Translator**, *CEPS*.
Translation of written documents

2019 **Internship**, *Esri BelLux*, Wemmel.
Development of GIS technical skills, research skills and development of soft-skills

Skills

Languages French (mother tongue), English (C1 level, IELTS and OLS passed in 2018 and 2019), Dutch (A2 level).

Programming languages R , MATLAB, Octave

GIS ArcGIS, QGIS, R

Other softwares LaTeX, Office Suite

Soft-skills Teamwork, Adaptability, Problem Solving, Work ethics

Other

2013–2014 **Year Abroad**, *Senior year at Warsaw High School in Warsaw, New York, USA*.
Relevant skills :
- Empathy, Selflessness, Humility, Tolerance, Open-mindedness, Listening, Authenticity, Cultural intelligence, Initiative, Self-confidence

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Faculté des sciences
Place des sciences, 2 bte L6.06.01, 1348 Louvain-la-Neuve, Belgique | **www.uclouvain.be/sc**