CARLOS HENRIQUE VIÉGAS DE ROSIS

Application of agent based simulation to analyze the impact of tax policy on the Brazilian soy supply chain

Trabalho de Formatura apresentado à Escola Politécnica da Universidade de São Paulo para obtenção do Diploma de Engenheiro de Produção.

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Prof. Dr. Marco Aurélio de Mesquita

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Dedico este trabalho à minha avó
Luíza e sua trajetória admirável.

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“You don't have to be a mathematician to have a feel for numbers”

- Johm Forbes Nash

ABSTRACT

Agent Based Simulations is a relatively new tool if compared to Discrete Events Simulations or System Dynamics, as such, this approach does not yet have consolidated tools and methods, still, its applications have been growing in potential, number and notoriety over the years. In this context, this work seeks to demonstrate the feasibility of such method by applying to a relevant production engineering problem.

In this work, the mentioned method was applied to the evaluate the impact of the current tax policy in the soy supply chain efficiency because, even though this sector is growing rapidly and consistently every year, the current tax structure induces logistic and tributary tradeoffs, which contribute for an inefficient system. In addition, an almost exclusive use of grain infrastructure by soy, soy meal and corn, and great availability of information and data allow a good representation of reality with the development of a model. The conceived model allocates the production of corn, soy and soymeal in their respective supply chains, according to grains harvests over time, ports capacities, transportation costs and storage costs.

The insights given by the model point out that a path dependent tax system in Brazil's grain logistics contributes for inefficient allocation of grains, contributing for idle soy processing plants while increasing the seasonal character of grain flows in the infrastructure, thus increasing congestions at ports. Furthermore, this work shows that the chosen solution is adequate to simulate supply chains by balancing the model's complexity and accuracy.

Keywords: Agent Based Simulations, Soy, Logistic Systems Simulations, Supply Chain Analysis

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Abimilho – *Associação Brasileira das Industrias do Milho* – Bazilian Association of the corn Industries

ABIOVE – *Associação Brasileira das Indústrias de Óleos Vegetais* – Brazilian Association of the Vegetable Oil Industries

ALL – *América Latina Logística* – Latin America Logistics Railroad Company

ALLMN - *ALL Malha Norte* – ALL North Railroad Network

ALLMS – *ALL Malha Sul* – ALL South Railroad Network

ANTAQ – *Agência Nacional de Transportes Aquaviários* – Water Transport National Agency

ANTT – *Agência Nacional de Transportes Terrestres* – Ground Transport National Agency

API – Application Programing Interface

APROSOJA – *Associação dos Produtores de Soja e Milho de Mato Grosso* – Mato Grosso's corn and soy Producers Association

CEPEA USP – *Centro de Estudos Avançados em Economia Aplicada da Universidade de São Paulo* – Center of Advanced Studies in Applied Economy of the University of São Paulo

CNT – *Confederação Nacional do Transporte* – National Transportation Confederation

CONAB – *Companhia Nacional de Abastecimento* – National (Agriculture) Supply Company

EFC – *Estrada de Ferro Carajás* – Carajás Railroad

EFPO – *Estrada de Ferro Paraná Oeste* – Paraná Oeste Railroad

EFVM – *Estrada de Ferro Vitória Minas* – Vitória Minas Railroad

EMBRAPA – *Empresa Brasileira de Pesquisa Agropecuária* – Brazilian Agricultural Research Company

ESALQ LOG - *Grupo de Pesquisa e Extensão em Logística Agroindustrial da Escola Superior de Agricultura Luiz de Queiroz* – Agro industrial Logistics Extension and Research Group of the Luiz de Queiroz College of Agriculture

ESALQ USP - *Escola Superior de Agricultura Luiz de Queiroz da Universidade de São Paulo* - Luiz de Queiroz College of Agriculture of the University of São Paulo

FAO – Food and Agriculture Organization of the United Nations

FIFO – First In First Out

FNS – Ferrovia Norte Sul – North South Railroad

GDP – Gross Domestic Product

IBGE – *Instituto Brasileiro de Geografia e Estatística* – Brazilian Institute of Geography and Statistics

ICMS – *Imposto sobre Circulação de Mercadorias e Serviços* – Tax over the Circulation of Products and Services

IMEA – *Instituto Matogrossense de Economia Agropecuária* – Agricultural Economy Institute of Mato Grosso

LIFO – Last In First Out

MAPA – Ministério da Agricultura, Pecuária e Abastecimento – Ministry of Agriculture, Livestock and (Agriculture) Supply

MAPITOBA – Refers to the soy producing region in the Maranhão, Piauí, Tocantins and Bahia states

NCM - *Nomenclatura Comum do Mercosul* – Mercosul Common Nomenclature of products

PNLT – *Plano Nacional de Logística e Transportes* – Logistics and Transportation National Plan

Poli USP – *Escola Politécnica da Universidade de São Paulo* – Polytechnic School of the University of São Paulo

PPP – Public Private Partnership

SECEX – *Secretaria de Comércio Exterior* - Foreign Trade Secretariat

Sifreca – *Sistema de Informação de Fretes* – Freight Information System

SIG – *Sistema de Informações Gerenciais* - *Management Information* System

Sindirações – *Sindicato Nacional Indústrial da Alimentação Animal* - National Union of Animal Feed Industry

USP – *Universidade de São Paulo* - University of São Paulo

VBA – Visual Basic for Applications

SUMMARY

1 INTRODUCTION

Agent Based Simulation (ABS) is a relatively new class of computation models if compared to other approaches such as Dynamic Systems or Discrete Events. It works through the observation of the emerging behavior of a complex system composed by many autonomous and interacting individual entities (Macal & North, 2010). During the 1970s and 1980s, psychologists, sociologists and social scientists developed and studied Agent Based Models and Simulations (ABMS) in order to model hypotheses about social dynamics. Besides the fact that there is still no consolidated approach concerning this tool, it has proven itself useful and it is growing in the engineering field (Klügl, 2016). In this context, the present work aims to verify the suitability of Agent Based Simulation by applying it to a supply chain modeling and analysis.

The problem presented in this work is the evaluation of the impact of the current tributary policy in the soy supply chain in Brazil from the policy maker point of view. According to Santos and Abrita (2016), the current states' tax (ICMS – Imposto sobre…) configuration and the Kandir law (Brazil, 1996) generate negative externalities in the soy supply chain, deindustrializing the sector and increasing processing plants' idleness. This happens because the current tributary penalizes trades in between national players located in different states, making it costly for suppliers and consumers to interact and go further in the value chain by processing the grain and producing soy meal and soy oil. Therefore, there is a penalization of soy meal and soy oil trade in favor of soy *in natura*.

This chapter will first introduce the modeling tool, explaining the used framework, its steps, and usefulness, explaining why this tool may be suitable to the chosen problem. Later, it shall contextualize and explain the problem, defining its scope. Finally, it will outline the objectives for this work and explain its methodology, as well as briefly visit the structure of the next chapters.

1.1 Agent Based Simulation

In order to better examine this topic, it is necessary to define an agent based model, as such exemplifying it by using the model created by Thomas Schelling (1971), which is considered one of the first agent based models in concept. This model represented the formation and the dynamics of ethnical and culturally homogeneous neighborhoods. By using coins and a graph paper to represent autonomous agents, Schelling demonstrated how those agents, who had already belonged to two recognizable groups, would distribute themselves geographically over time by assuming a discriminatory behavior. The aforementioned model is a good explanatory example due its simplicity, and because it has all the components of an agent-based model as defined by Klügl (2016):

- Agents: each member of the two previously mentioned populations is an agent, the entities represented by the coins. These entities are active and autonomous in respect to the other agents in the simulated environment. Each agent may have a set of attributes representing the entity's characteristics such as age, income, gender, beliefs, inventory level, etc.
- Interaction and Organization: Defined as the rules permeating the agent's behavior and their relationships. The first item explains how each agent react to other agents and the environment, and the second shows how agents are linked. In Schelling's model (1971), the interactions and organization are given respectively by the discriminatory behavior and the links to adjacent agents (neighbors).
- The Simulated Environment: it is the idea of the environment underlying the entire model, the setting where the agents interact. In the previous example, it consists in the neighborhoods represented by the graph paper. Like the agents, the environment also may have parameters such as pressure, color, luminosity, etc., which also interact with the agents.
- The Simulation Infrastructure: Finally, there is the usually forgotten simulation infrastructure. As it provides the means to execute the model, it should not have any influence in the model's response, but, as agent based models may be computationally demanding, the Infrastructure might impose itself as an obstacle to the model's complexity. In this case, the coins, graph paper and the person placing them give the model's simulation infrastructure.

Considering the hypothesis tested by Schelling (1971), it is observable that agent based simulations are useful to understand an emerging pattern in a complex system with multiple agents with simple behavioral patterns. Thus being, this kind of model has already shown some interesting applications in the Industrial Engineering and Management Sciences. Holmgren (2008) studied the use of the multi-agent paradigm applied to manufacturing and transportation. Sudo and Matsuda (2012) used this framework to observe the effects of the mutual communication in the efficiency of assembly operations. In addition, Jamshidnezhad and Carley (2015) verified the link in between quality-engineering and organization productivity.

In the context of this project, the analysis of logistic and supply chain efficiencies in the grain sector are subjected to an inefficient tributary policy. There is a direct correspondence in between real life and the agent based model elements, therefore, suiting the studied problem to the chosen framework:

- There are many agents such as grain producers, traders, logistic operators, cooperatives and grain consumers responsible for decentralized decisions and affecting the system's overall behavior.
- The agents, i.e., the profit companies, may be approximated, by the concept of perfectly rational players, to the objective of maximizing their profits. These interactions are also subject to a transportation network, linking agents and organizing the system.
- In addition, there is an environment possessing dynamic and static properties that influence agents' decisions such as congestion levels, tax legislation and infrastructure capacities.

Most of the dynamics, properties and attributes of the aforementioned environment, agents and their respective organization and relationships can be modeled, estimated, or found in private and public databases. This condition, aligned with suitable simplifying assumptions, allows a good translation of real life events into an agent based model. Other few model parameters, not easily quantifiable through the mentioned means, may be as well obtained through a calibration process in a multi scenario analysis, using comparisons in between the model grain flows and real life events. Finally, the abundance of other studies and data concerning the underlying subject should provide enough material to validate the model and its results.

This procedure should draw conclusions about the use and feasibility of agent based modeling applied to supply chain problems, identifying roadblocks, advantages and deficiencies of the present method. Additionally, if the proposed method proves itself feasible, this work should result in a robust model, able to evaluate the effects of the current tributary policy in the soy supply chain. The model would also be able to support the decision making process concerning other public policies in the same environment, such as regulatory actions, incentives, and the construction of infrastructure projects through concessions and PPPs.

1.2 Grains' Supply Chains in Brazil

The Brazilian Agriculture is one of the most important sectors in the local economy – together with livestock –, it accounts for approximately 23% of the GDP and has grown at a 2,2% yearly rate from 1994 to 2013 (CEPEA - USP, 2015). Moreover, the sector presents itself as one of the most robust in Brazil as it has grown even under severe economic downturn, as seen in Chart 1.

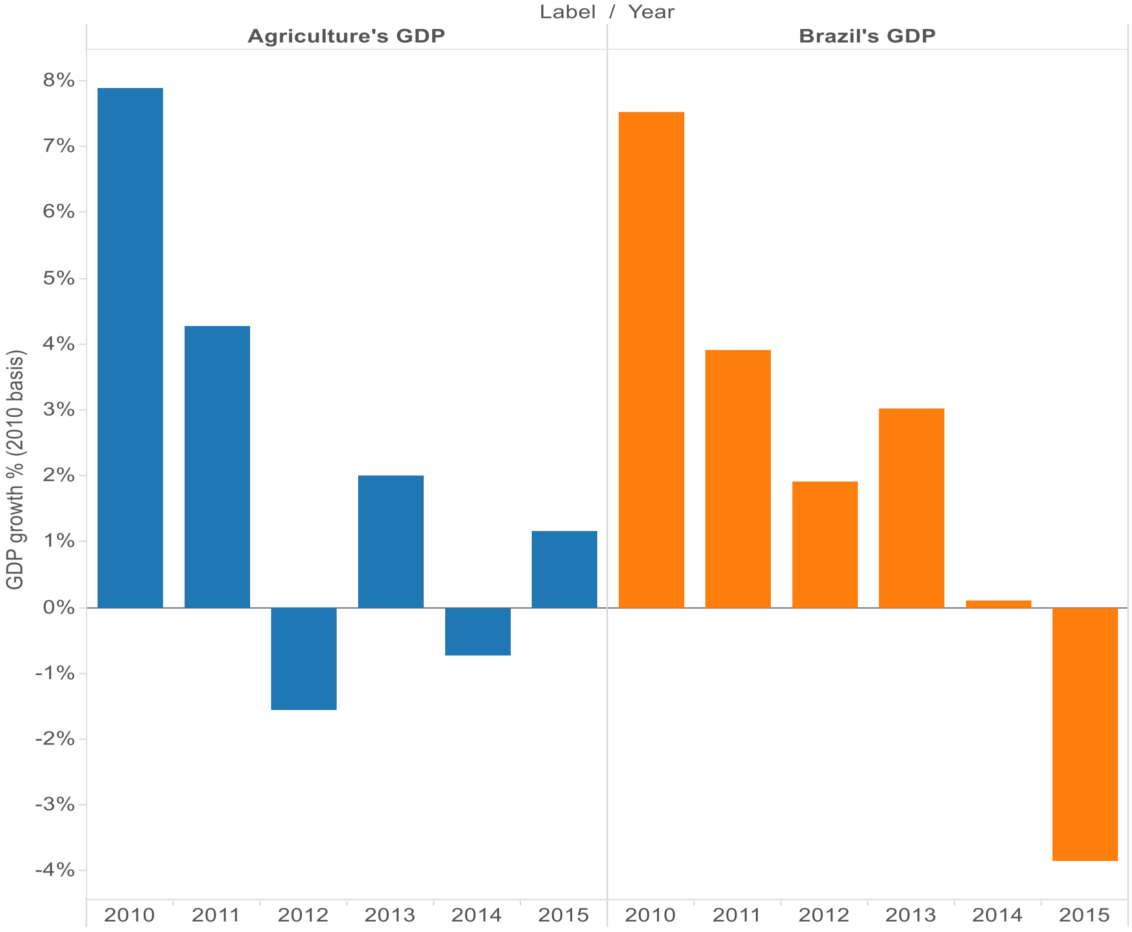

Chart 1 - Brazil's agro GDP vs GDP (CEPEA - USP, 2015)

One of the most important factors for this growth in the last decades is the development of new technologies, which enabled the expansion of crops, such as soy in infertile lands (Freitas, 2011) and corn production during the winter (Franco, Marques, & Filho, 2013). Thenceforth, those crops have gained a significant share of Brazilian arable lands, as we can see in the Chart 2, reaching 59% of the total harvested area among main commercial crops[1] in

[1] Crops considered: pineapple, cotton, garlic, peanuts, rice, oatmeal, bananas, potatoes, cocoa, coffee, onions, rye, barley, coconut, beans, tobacco, sunflower, guarana, jute, oranges, apples, mallow, mammon, cassava, corn, black pepper, sisal, soy, sorghum, tomatoes, wheat, triticale and grapes

2014 (IBGE, 2015). In addition to the high share of land used, the mentioned grains also use intensively other resources such as ports, roads, railroads, waterways and other transport infrastructure elements due to the high volumes and long distances in between producing areas, ports and the demand.

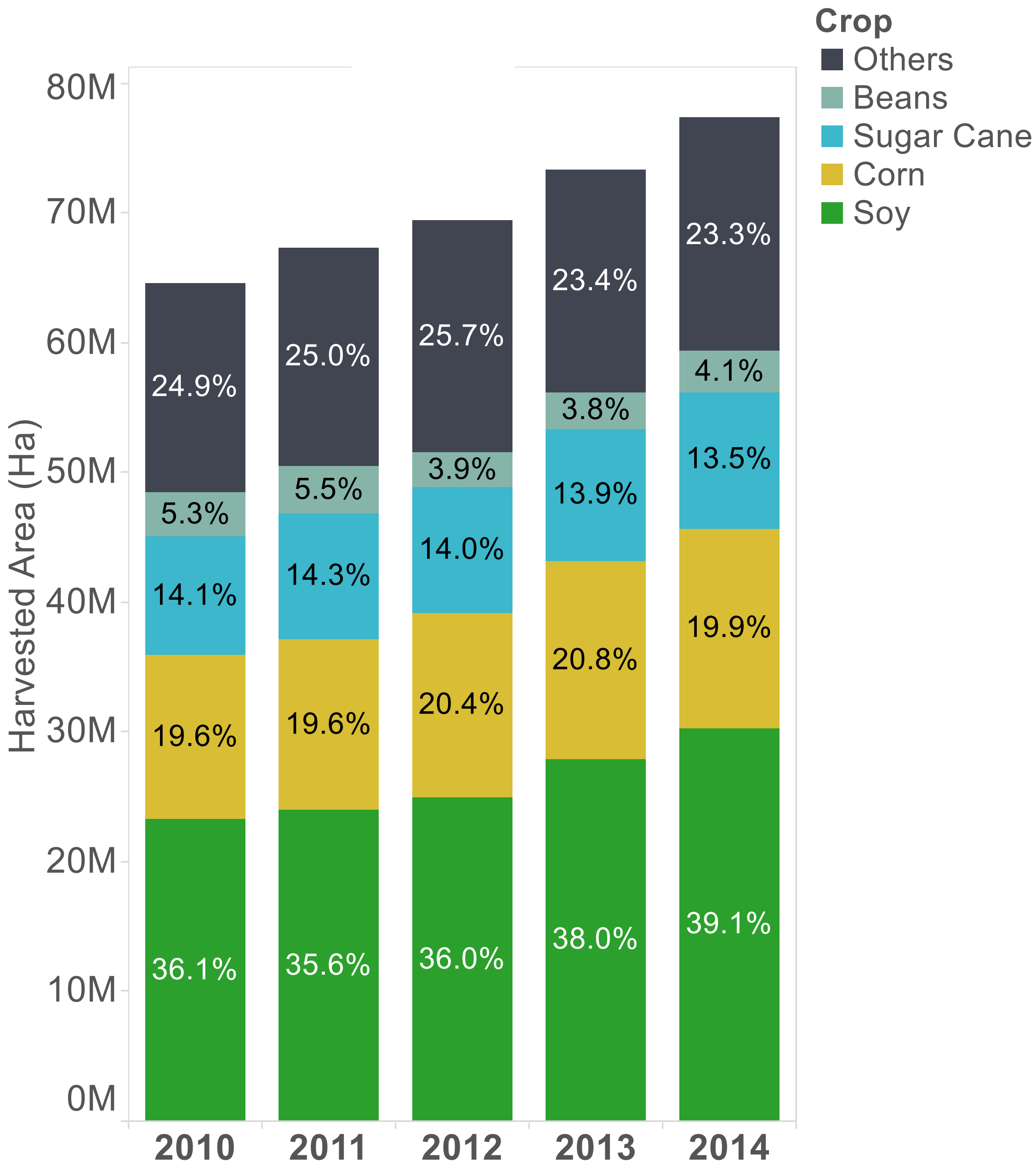

Chart 2 - Main commercial crops by harvested Area (IBGE, 2015)

The development of those crops has given Brazil a notorious position in the Global market of these commodities. In 2013, it was considered the second and third biggest producer, achieving 30% and 8% of the world production for soybeans and corn respectively (FAO, 2015). In addition, Brazil became the second largest soybean exporter in the world as the Chinese needed new sources of it in order to expand its meat production and continue to supply its households (Santos, Batalha, & Pinho, 2012). This situation explains the great importance attributed to the Agriculture in the Brazilian balance of payments, achieving 39% of its exports over the last five years, as in Chart 3.

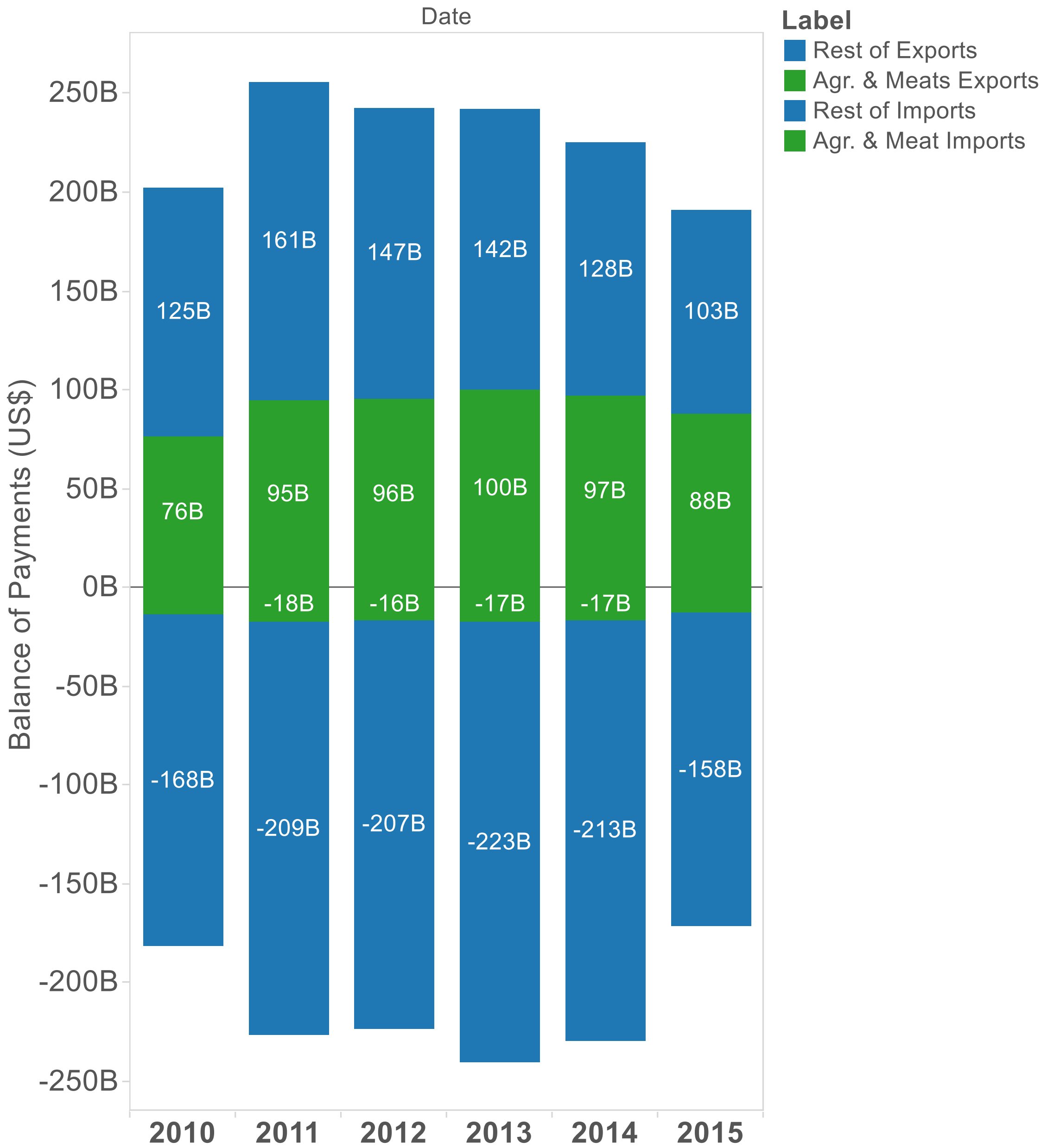

Chart 3 - Agriculture and meat exports' importance in the Brazil's balance of payments (MAPA, 2015)

Looking more closely into the Brazilian Agriculture's exports in terms of mass (Chart 4[2]), it is possible to see that soy, soy meal and corn represented approximately 76% of all Agriculture goods exported in 2015, therefore being the items responsible for most of the grain infrastructure utilization. This indicator is a good proxy for transportation infrastructure's share

[2] The products considered in this analysis are the ones presented in the chapters 6, 7, 8, 9, 10, 11, 12, 13, 17, 18, 20, 23, 24 and 52, of the Mercosur NCM table.

of utilization because exported goods usually are the ones that travel the most in the Brazilian territory. In addition, it is observable that those items grew in importance over time. This trend, even during an economic crisis, shows these grains economic resilience and growth possibility.

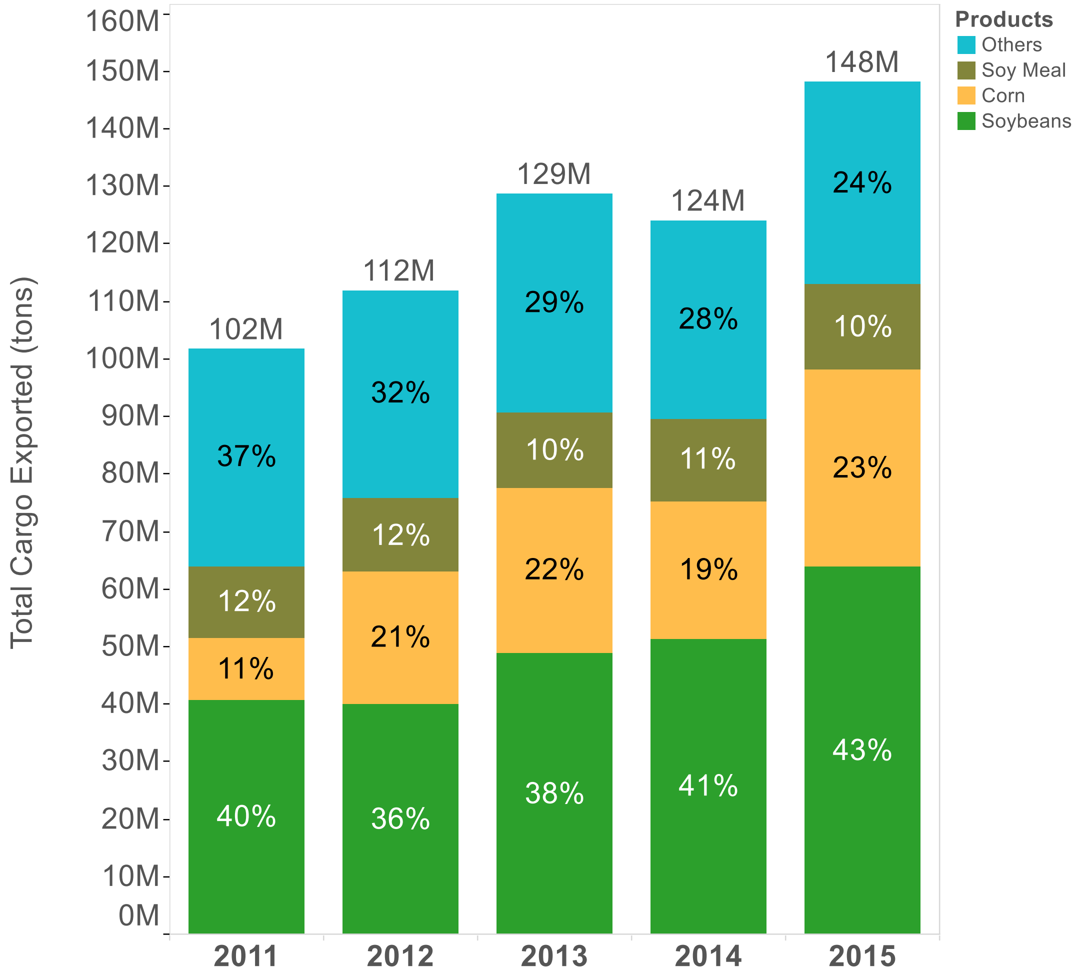

Chart 4 - Agriculture's exports through ports by mass (ANTAQ, 2015)

The growth in soy, soy meal and corn production seen in the last decades, however, is no longer sustainable because the investments in infrastructure, logistics and distribution of agricultural goods and inputs did not keep up with the increase of volumes. This situation leads to a loss of competitive edge as costs, lead times and losses throughout the supply chain increase (Trindade & Pacheco, 2015). In addition, prices around the world fall as global demand for commodities ceases to grow while China deaccelerates and other countries continue to increase production and diminish costs. This situation puts Brazilian farmers under pressure as logistics shows itself as a big competitive disadvantage while the Brazilian Government faces a fiscal and economic crisis, limiting the resources it could use for investments, subsides and incentives.

1.3 Motivation and Scope

The grain sector in Brazil faces several challenges in terms of logistics because infrastructure investments did not follow the increase in production over the last years, what may rise transportation costs and weak growth in the near future. Furthermore, commodities' prices fall as demand stagnates and production around the world increases. In order to maintain its competitive edge, the country would need to increase logistic infrastructure efficiency and/or expand it. The last alternative, however, usually requires a high amount of public resources through public funding or subsidized credit applied to new concessions or PPPs, which are unfeasible in a scenario of an economic downturn and budgetary public deficit. In this case, the policy maker should give more importance to the remaining alternative, seeking to optimize the use of the current infrastructure. In this context, this work shall model and examine how the changes in the current tax policy, presented in the Figure 1 below, can result in more efficient supply chain and logistic infrastructure as tradeoffs in between tributary and logistic optimization cease to exist.

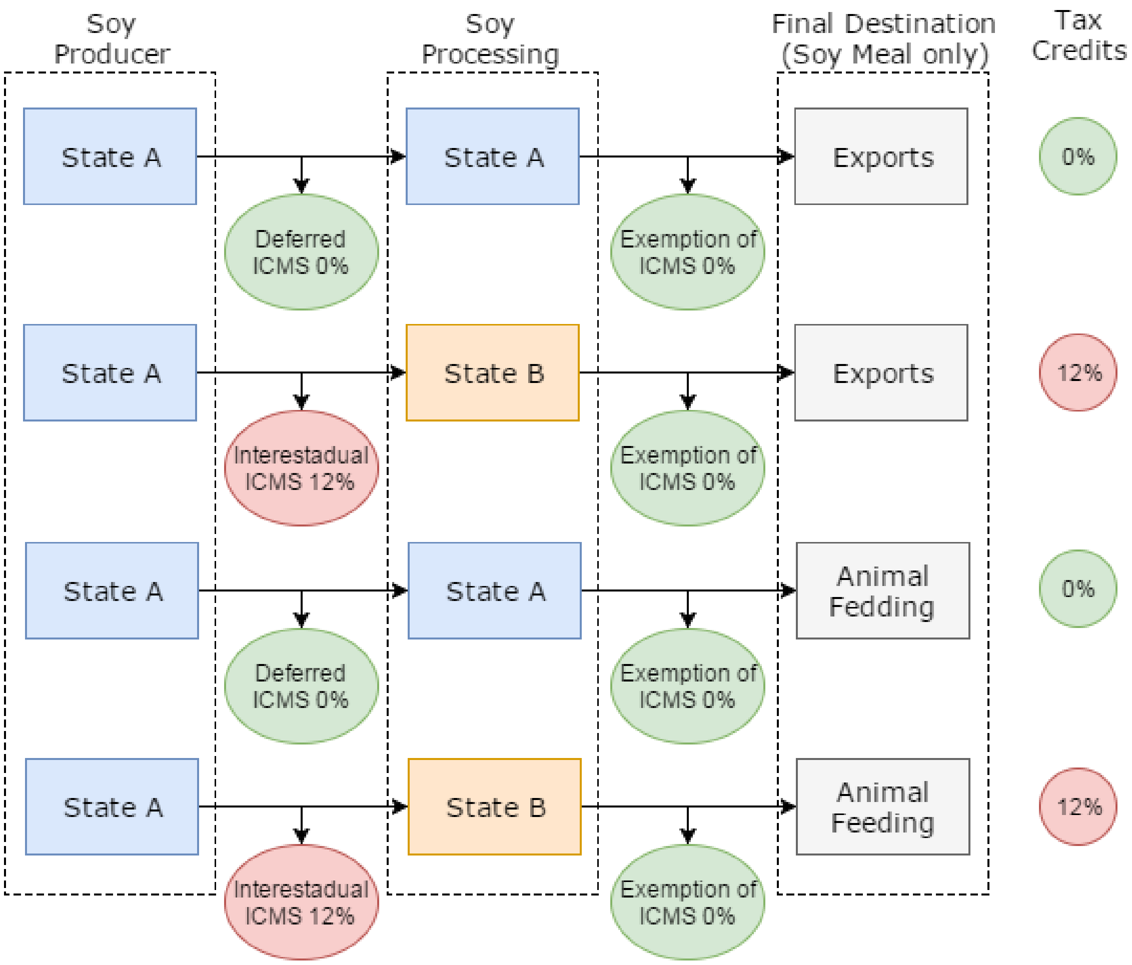

Figure 1 - Tributary policy for soy and soy meal

The Figure 1 synthesizes laws and policies concerning the trade of soy and soy meal between states. There are many important aspects regarding these laws. The first one refers to the fact that each state's tax code, according to ABIOVE (2016), exempt or defer tax related to the internal trade of soy, and exempt taxes concerning the trade of livestock inputs such as soy meal. Moreover, the Kandir Law (Brazil, 1996) exempts exports of soy and soy meal of the ICMS tax. On the other hand, the mentioned products pay taxes when traded between different states.

The situation above generates a path dependent tax system, in which a product pays taxes when stakeholders from different states trade it, even if they use it in tax-exempt activities, generating illiquid tax credits. A tributary path dependency, defined by a geopolitical criterion, usually does not coincide with supply chain and logistic efficiency, therefore, a logistic-tributary tradeoff emerges. In this case, decision makers may choose tax efficiency over logistics, contributing to a suboptimal system (Yoshizaki, 2002).

The consequent inefficiencies derived from emerging tradeoffs are reflected in the soy processing plants' low utilization rates and the sector deindustrialization as indicated by Santos and Abrita (2016) , and Fernandes Filho and Belike (2010) because it becomes expensive for processing plants to source soy from other states rather than their own. This issue is evident in the Chart 5 below, which shows how soy-processing plants become idle when they run out of soy in the months preceding the harvest season.

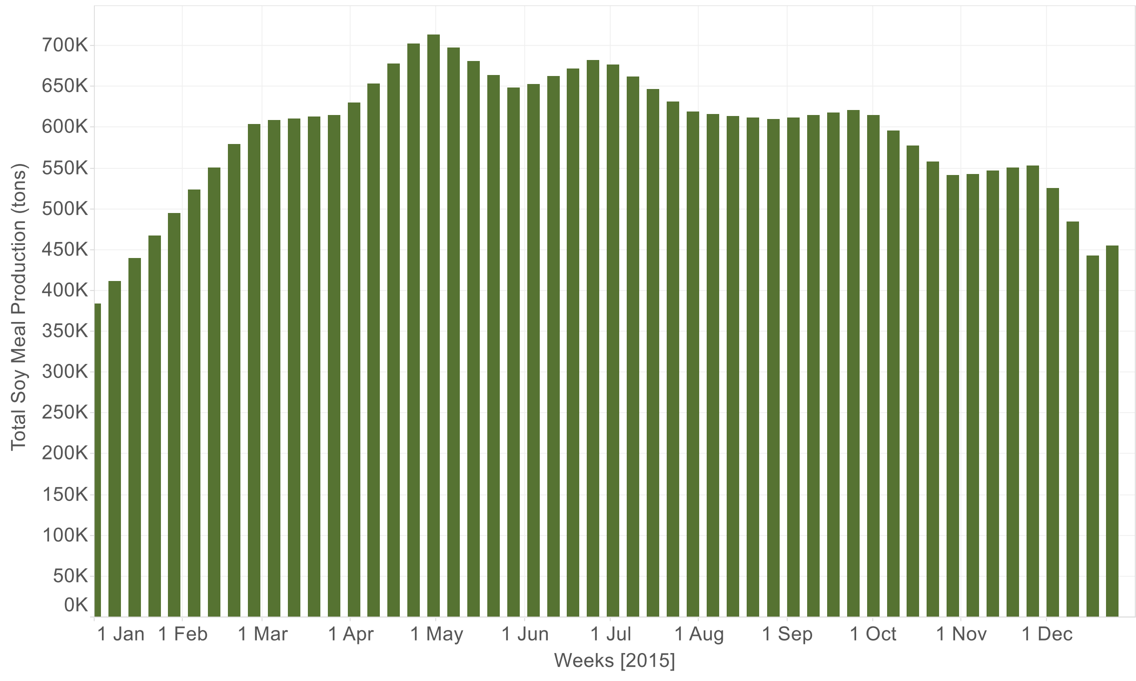

Chart 5 - Brazilian Soy Meal Production elaborated with data from ABIOVE (2015)

Additionally, the sector deindustrialization has a secondary effect over infrastructure efficiency because it increases the seasonal character of grains flows through ports, roads and railroads, rising congestions and idleness. Comparing Charts 5 and 6 it becomes evident that the processing industry absorbs the seasonality present in the grain harvests. Therefore, a tax system, which favors the circulation of primary products with a more seasonal behavior, such as soy and corn, instead of industrialized products like soy meal result in a more variable demand for transportation.

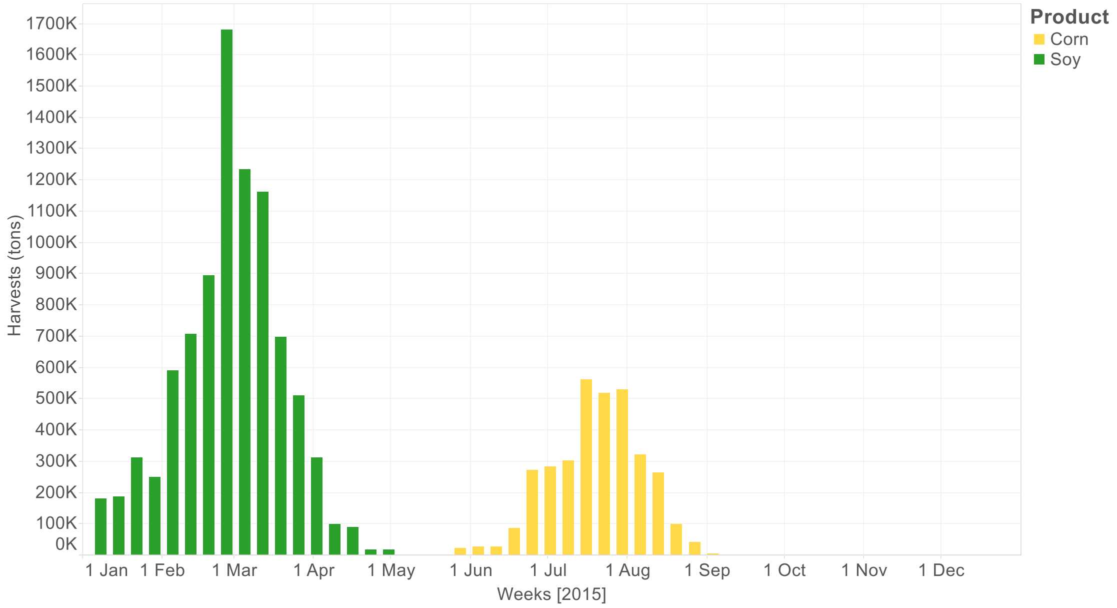

Chart 6 - Soy and Corn Harvests in Mato Grosso State, with data from CONAB (2016) and IMEA (2015)

We can clearly see the relationship in between grains seasonality and infrastructure efficiency by comparing Charts Chart 6 and Chart 7. The first chart shows the seasonality of soy and corn productions in Mato Grosso state while the second compares flows and congestion levels through selected berths in the port of Santos, responsible for a great share of Mato Grosso grains' exports. The congestions, represented by the ships' average time in line to dock peak in April and October, shortly after soy and corn harvests in March and August, respectively. For the same reason, the examined berths show lower utilization during the off-season periods, in January and July.

Moreover, the berths presented in Chart 7, responsible for 92% of Santos grain exports, are almost exclusively used to export soy and corn, with a relatively small participation of soy meal and an insignificant volume of other products. Such configuration raises the question if a substitution of soy exports for soy meal would result in a better port performance due to the reduction of the exports' seasonal character.

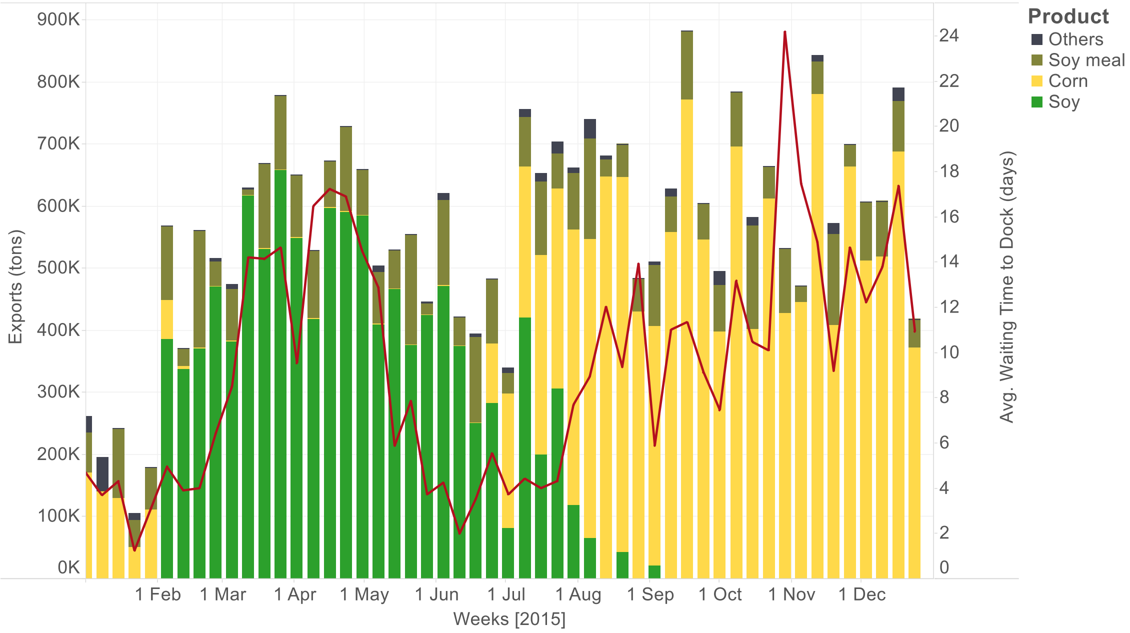

Chart 7 - Santos's port congestions and exports' seasonality[3]

This work seeks to answer the question above by modeling the present system through agent-based simulations, demonstrating the method feasibility. Therefore, it should somehow measure the effects of tributary scenarios over transportation and distribution efficiency of soy and soy meal, in order to stablish a comparison between them. Furthermore, the model should also take into account interactions with other relevant crops in terms of volume and common infrastructure. As such, corn should be included in the model due to the mentioned interactions in terms of land usage, as presented in the Chart 2, and infrastructure sharing shown in the charts Chart 4 and Chart 7. Additionally, these charts do not indicate the presence of other products with relevant impact in the resources usage.

Finally, beyond the studied grains, it is necessary to define the problem's scope within the grains supply chains. In this way, it is important to track soy and corn's most important products while they are still relevant in terms of volume and grain logistics without adding exceeding complexity. As such, corn is usually transported and traded *in natura*, being either transformed in industries close to its final destination or consumed by animals and humans as shown below in the Figure 2. In addition, soy is traded in form of soybeans or soy meal, used for animal feeding; or soy oil, which is used in the food industry and as an input for biodiesel. Among the mentioned products, soybeans, corn and soy meal, as vegetable grains, share exactly

[3] Elaborated with data from ANTAQ (2015), it consider the berths SSZ0942, SSZ0748, SSZ0803, SSZ0759, SSZ0412, SSZ0749, SSZ0627 and SSZ0626. These berths are responsible for 92% of Santos's soy, corn and soy meal exports.

the same infrastructure for storage, transportation and transshipment while maintaining a significant volume. Therefore, those products shall compose the scope of this problem.

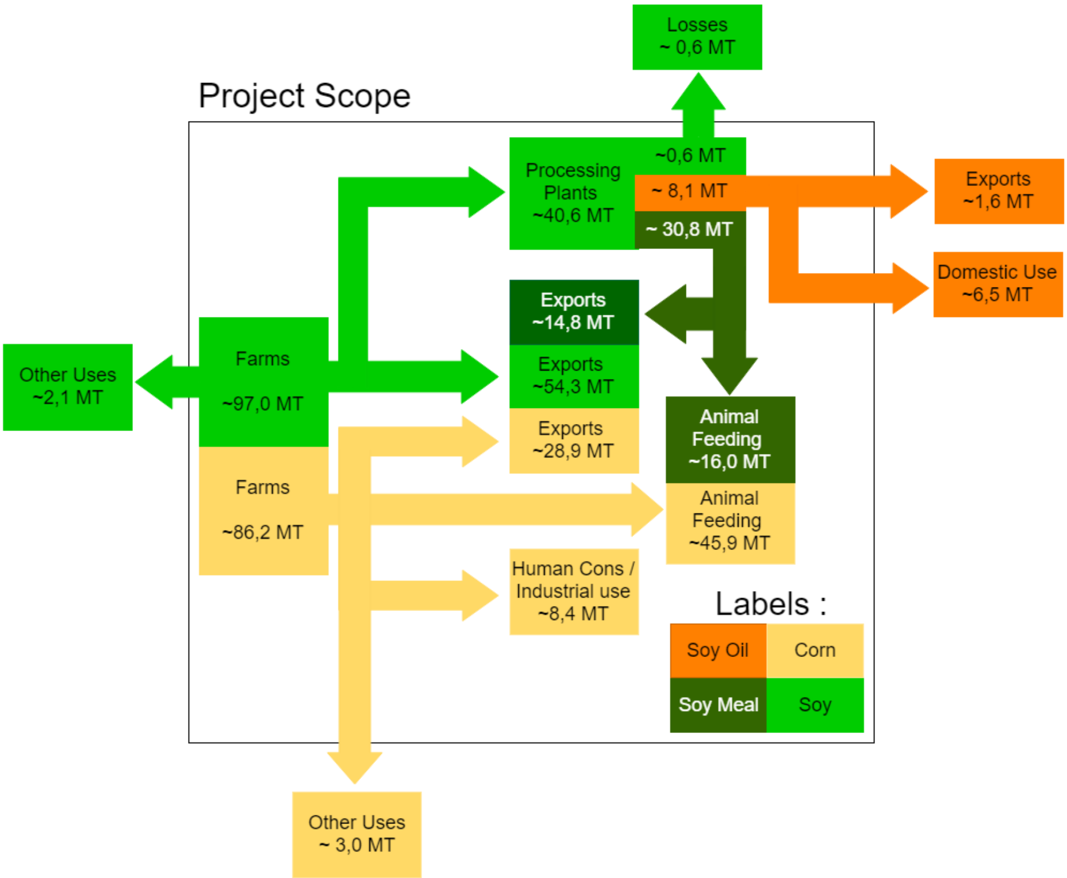

Figure 2 - Project Scope, elaborated with data from (ABIOVE, 2015) and (Abimilho, 2015)

1.4 Objectives

The main objective of this work consists in exploring and verifying the suitability of the agent based simulation tool through a practical application in which the impact of the current tax system in the soy supply chain efficiency is evaluated. This approach would allow an evaluation of the tool deficiencies, advantages and main roadblocks in its implementation. Likewise, this work has other adjacent objectives, of a more practical nature, as the framework developed and its corresponding answers found through the model would be useful in policy-making decisions in the agriculture sector. As such, the objectives of this work can be defined as it follows:

a) Exemplify and verify the feasibility and suitability of agent based modeling:
   i) Apply agent based modeling and simulation to a production engineering problem, evaluating if this tool is able to support the decision making process

   ii) Show how to develop an agent based model in a systematic and process, identifying major roadblocks, deficiencies and advantages relative to other methods presented in the literature.
   iii) Determine which characteristics are important in a problem as to make agent based simulations an adequate tool.

b) Use the agent based model as a public policy making decision support tool in the soy supply chain.
   i) Create a mathematical model able to mimic the main grains' flows in Brazil using agent based simulations.
   ii) Develop "what if ?" analysis in multiple scenarios to evaluate the effect of the current path dependent tributary policy in the soy supply chain.
   iii) Evaluate the feasibility of using the developed model to evaluate the impact of other policies such as investments in infrastructure, new concessions, PPPs, among others.

1.5 Structure of the work

The work is divided into eight chapters, plus references and annexes. The first chapter, the **Introduction**, gives a brief explanation of agent based simulations and the subject of this work, the soy supply chain. This chapter also introduces this work's motivation, the tributary system influence over soy's supply chain efficiency and scope. Moreover the chapter ends with this work's objectives and structure.

The **Literature Review**, in the next chapter, searches the literature for theory and practical examples concerning modeling techniques such as Dynamic Systems, Agent Based Simulations and Discrete Events Simulations. In addition, this chapter compares the studied techniques, identifying main strengths and weaknesses and advantages of Agent Based Simulations in the scope of this work. This chapter ends by exposing other works with the same object of study.

Following to the **Methodology** chapter, we have the general framework for the rest of the work, with an explanation of the techniques used in the subsequent chapters, showing the conception, implementation and evaluation of the model and the evaluation of results as well.

The fifth chapter, **Conceptual Modeling**, goes through the model conception and presenting a preliminary and simple prototype of the model by defining each one of its agents, their behaviors, organization and characteristics of the environment in which these agents are inserted. This procedure will use some concepts presented in game theory and some qualitative information concerning grains supply chains functioning and structure.

The next chapter, **Data Gathering and Parameters Estimation** explains how corn and soy supply chains were mapped, presenting numbers concerning production and processing of grain over time, demand, prices, main routes, infrastructure capacities and freight costs. These numbers and parameters were then translated into model's parameters and inputs, which were then used in the next chapter: **Model Implementation and Validation**, which presents the process used to implement the model computationally showing the used software. Moreover, this chapter presents the model's validation, both at micro level, given by the agents, their behavior, organization and environment and at macro level, given by the emerging behavior of the system.

Proceeding to the next chapter, **Results and Discussion**, this work will then analyze the outputs given by different tributary scenarios inserted in the model in order to quantify the effects of the current tax system over soy supply chain by observing soy processing plants utilization, a proxy of congestions at ports and transportation demand. Finally, the **Conclusion** summarizes main insights found on the previous chapter and makes a qualitative evaluation of the chosen method applied to the subject of this work.

2 LITERATURE REVIEW

This chapter will look into the key concepts used in mathematical simulations from the points of view of many different authors, visiting and comparing the main modeling paradigms: dynamic systems, agent based modeling and discrete events simulations. This analysis shall provide some inputs about these models development and comparisons in strengths, weaknesses and overlaps concerning each modeling method, indicating key characteristics for the application of each one of them.

Besides the modeling concepts, this chapter will also give some insights about other works involving public decision making, tributary impacts over the soy sector, infrastructure and grains supply chains. This chapter is organized as it follows: it begins introducing agent based models, discrete events and dynamic systems simulations, then, it will give an overview of other works in the same field or with similar purposes.

2.1 Agent Based Modeling

As a relatively new tool, the Agent Base Modeling is not mature and does not have a consolidated approach for conception and implementation (Klügl, 2016), especially when dealing with geospatial data (Andrade, 2010). However, there are theoretical works presenting frameworks of how to engineer an agent based model with many commonalities among them. Andrade (2010) presents a framework for spatial agent based models fed by geospatial data. Klügl (2016) developed a general framework for agent based simulations engineering in a step by step process with a best practices guide from model conception to implementation with examples. In addition, Macal and North (2010) published a short tutorial on how to develop such models. The conception of an agent based model, as cited in these works can be summarized as understanding a complex system and breaking it into agents and the environment, translating the agent's actions and behaviors into simple programmable patterns.

Agent Based modeling has a very wide scope of applications, ranging from manufacturing and logistics systems to social interactions and biology. In this work's scope, it is important to observe agent based modeling in the infrastructure, production and management contexts. As such, in the production and management fields, there are the works by Pokahr *et al.* (2016), which explore the possibility of modeling and implementing logistics networks using multi-agent tools. Holmgren (2008), Sudo and Matsuda (2012) and Monostori (2006) discuss the possibility and formulate frameworks for the utilization of the mentioned technique into various industrial engineering problems such as logistics, manufacturing and assembly operations. Cicogna and Ribeiro (2012) use agent based simulations to study the production and pricing strategies of companies in a duopoly. Finally, Jamshidnezhad and Carley (2015) discuss questions related to quality management, productivity and the organization.

Considering the Infrastructure field, the United States government has built a dedicated laboratory, the National Infrastructure Simulation and Analysis Center (NISAC), to apply the agent based framework towards policy making (Schoenwald, Barton, & Ehlen, 2003). The main objective of the laboratory would be to test the country's infrastructure interdependency and elaborate plans on how to deal with multiple economic shocks and disruptions. In addition, there is an extensive use of agent based models in urban infrastructure applied to transport policy (Holmgren, Ramstedt, Davidsson, & Persson, 2011) and in smart grids: (Babic, 2016), (Chassin, Fuller, & Djilali, 2014) and (Kremers, Durana, & Barambones, 2013). Among the cited works, the one developed by Kremers *et al.* (2013) is especially pertinent because it shows how to model a network in many different layers, using agent simulations. Similarly to the model exposed in the next chapters, Kremer *et al.* (2013) designed the network as a graph and attributed autonomous agents to each of its nodes. Each node would, then, control the flows in the adjacent links of the graph.

2.2 System Dynamics Simulations

Conceived in the mid-1950s by Professor Jay Forrester, the System Dynamics Simulations (SDS) approach is described as a method to policy analysis and design applied to dynamic problems in any system characterized by interdependence, mutual interaction, information feedback and circular causality, which, then, are translated in mathematical models. In those terms, a system dynamics model works as a set of coupled, nonlinear, first-order differential equations, which are then simulated by partitioning time into small discrete intervals, and stepping the system of equations through it at one interval at a time (System Dynamics Society, 2016).

Systems with the presence of circular causality, interdependence and mutual information feedbacks, as described in the last paragraph, are present literally everywhere, thus allowing the system dynamics approach in a broad range of problems. Since its creation, this approach in applied in many fields, from education, as proposed by Forrester (1994) himself, tourism (Das, 2012), strategic planning (Adeniran, 2010) to infrastructure (A. Ganjidoost & C. T. Haas, 2015), among others.

Considering other applications more closely related to this work's scope, there is the model proposed by Osorio (2009), in which system dynamics are used in the agriculture sector to identify cycles in the coffee market. Grothedde (2000) observes the interactions in between spatially separated markets using freight costs and logistics dynamics. In addition, Soehodho (2001) presents a system dynamics model for commodity distribution in a supply network. Finally, Jiang (2010) applied system dynamics in order to access and evaluate transportation infrastructure investments with the motivation of developing tourism in two historic villages in China.

2.3 Discrete Events Simulation

The Discrete Events Simulation (DES) paradigm has its start during the second half of the 1950s with the first efforts targeted to develop concepts linked to model representation and facilitation needs in simulation modeling. Those efforts resulted in the forerunners of major simulation programming languages in the 1960s, such as GPSS and SIMULA (Nance, 1993). Those programming languages were supposed to model the operation of a discrete sequence of events in time, describing changes of states in a system, being applied to the simulation of queues in the logistics and production environments.

Currently, the DES paradigm has a widespread use in the Production engineering field, not only with a consolidated approach, but also with consolidate best practices and a multiple offer of accessible softwares and platforms. Matloff (2008), for instance, describes the use of Discrete Event Simulations using SimPy, an environment based on Python, an open source language. Mesquita and Henandez (2006) show how to deploy models and teach the Discrete Events Simulations using simple spreadsheet software. Karnon *et al.* (2012) show best practices and applications of the DES paradigm using a practical example in the healthcare sector.

Moreover, other than methods and applications, the Discrete Events Simulation paradigm has consolidated itself as a simulation method with a broad range of practical cases. Ribeiro *et al.* (2008), for example, use the mentioned technique to evaluate the effects of an unexpected maintenance in healthcare equipment in hospitals, Rangel, Teixeira *et al.* (2001) successfully used the same tool as a resource in order to teach Physics for the High School level. Again, in the medical field, Wang, Jiang and Yu (2012) apply DES to evaluate the capacity of a hospital to handle a large amount of victims in case of biochemical terrorist attacks. In addition, adjacent to the scope of this work, Asio (2011) uses DES to plan a grain delivery terminal.

2.4 Comparison in between Simulation Paradigms

In order to verify if the chosen tool, agent based simulations, is the most adequate in the studied context, it is necessary to resort to comparison in the literature with the other modeling paradigms and observe if ABS's comparative strengths and modeling feasibility are aligned with the behaviors presented in the modeled environment, the soy supply chain. In addition, it is necessary to observe if the three paradigms are necessarily mutually exclusive or if this project can resort to features provided by the other modeling tools.

Compared to Dynamic Systems, commonly applied to systems from an overall (macroscopic) point of view, ABS has some advantages in terms of applicability due to its bottom-up nature, reaching more levels of abstraction. This is endorsed by Maidstone (2016), which mentions that all DS models belong to a strict subset of all ABS models. This advantage, however, comes at the cost of greater development complexity a lower computational efficiency. Considering this trade-off, the ABS method is more suitable to represent systems with features not fully captured by the Dynamic Systems paradigm; this is especially true in systems with a many heterogeneous players' acting according to decentralized decisions.

For that author, the same relationship is not true between ABS and DES because, while elements in the first paradigm are predominantly active, DES elements have a passive behavior, providing a complementary role to both methods. Nevertheless, both tools have similarities such as the stochastic nature and ability to model random behavior, as such, there are systems which can be accurately modeled by both methods as executed by by Majid, Aickelin and Siebers (2009). Still, besides being more complex and heavy, agent based simulations can reach systems with a higher level of abstraction while DES is best suitable for simple systems presenting discrete states, passive elements, events and any sort of queue, like a production line.

According to Borschev and Filippov (2016), the three modeling paradigms are not necessarily exclusive, an ABS model can be built from an existing DES or SDS model, enhancing them as and capturing more insights from the system being modeled. As such, Borschev and Filippov (2016) exemplify many hybrid models using AnyLogic^{TM}, which is able to simulate the three paradigms concomitantly, allowing the mentioned approach (Figueredo, 2011). Analogously, Zankoul (2015) uses a combination of DES and ABS methods to model construction earthmoving operations.

There are also many works concerning the choice of the best modeling paradigm for every system: Figueiredo (2011) uses both System Dynamics and ABS to model the growth of a cancer tumor, looking for tradeoffs in among both methods. Sweetser (1999) makes extensive comparisons in between both System Dynamics and Discrete Events in order to understand strengths, weaknesses and overlaps. Considering the purpose of this work, we have similarities with the work presented by Behdani (2012), in which he evaluates different modeling paradigms in order to model a supply chain. In the mentioned study, the author suggests the use of the ABS method to model supply chains, because this is the method, which can best capture the complex socio-technical nature of the system.

2.5 Studies about grains supply chains, infrastructure and logistics in Brazil

It is important to survey other works in the scope of grain logistics infrastructure in Brazil in order to compare results and recommendations, therefore, finding common opinions towards public measures about the studied subjects in the research community. This review is also useful in giving insights on how to deal with eventual roadblocks because projects with similar scopes usually face the same challenges. In addition, eventual discordances in between works could be useful to identify potential flaws made by other authors.

Fernandes Filho and Belike (2010) trace a direct relationship in between the deindustrialization of the soy supply chain in Brazil due to tributary reasons, comparing Brazil's tributary decisions to those taken in Argentina and observing their impacts in each country soy processing industry. Following the same argumentative line, Santos and Abrita prove that the Kandir law and the deindustrialization of the soy sector have generated negative externalities, therefore, supporting the problem raised in the introductory chapter of this work.

ESALQ – LOG (2014) has developed a diagnose project called Benin, in which it evaluated logistics' inefficiencies concerning Paraná state's agriculture. The project is divided in three parts; the first one evaluates storage conditions; the second looks into transportation itself: and the third observes inefficiencies at the Paranaguá Port.

In the first volume of the research, ESALQ – LOG (2014) identified that the main problem with grain storage in Paraná state concerns transparency and the lack of knowledge about legislation and optimum conditions to store grain. Furthermore, stakeholders might store grain in inferior conditions to save costs, and then mix or hide it among other grain of higher quality in order to sell them at premium prices. Other issues may also concern vicious sampling and the lack of quality control, thus enabling situations in which some individuals can take advantage over others.

In its second volume, ESALQ – LOG (2014) analyzed transportation through roads in Paraná state, and, even though the main roads are in very good conditions, they have not received enough investments for expansions in order to cope with the transported volumes, resulting in congestions. Moreover, ESALQ – LOG (2014) realized that the freight market is very competitive and its prices vary a lot in between harvest (higher prices) and off season (lower prices). In such situation, it was concluded that many transportation companies do not fully evaluate transportation costs before placing a bid, consequently, having serious losses.

Lastly ESALQ – LOG (2014) observed the Paranaguá port and identified many problems, ranging from losses of grains to the high amount of sulfur in the fuel offered by Petrobras, the monopolist in the bunker oil market in Brazil. However, among all problems the most grieve ones concern congestions at the port as it operates very close to its maximum capacity. This situation generates long lines of ships, peaking at 110 days, increasing significantly sea freight prices and generating penalties, such as the demurrage.

Castellani (2013) has developed other notable work about this context. Firstly, he evaluated the current flows, routes and infrastructure for soy exports in Brazil. Then, by considering expansions of the agricultural frontier, infrastructure projects in the planning and construction stage, he created a forecast for Brazil's soy exports in 2023 by port and producing region and compared it with the current situation, identifying the most critical infrastructure projects. Finally, he concluded that the most important projects would improve either northern ports' capacity or access, increasing their share of soy exports from 18% in 2011 to 41% in 2023.

At last, there is the work developed by Stupello (2011), in which he evaluated the current logistics infrastructure projects in the planning stage from the strategic point of view using the Analytic Hierarchy Process method. According to his analysis, the *Plano Nacional de Logistica e Transportes* or PNLT (Brazil, 2015) was not conceived through a strategically coherent framework. In addition, he stablished a list of infrastructure projects, which should be prioritized in order to better develop the agriculture in Brazil's Midwest region. In his list, four out of all six projects (including the first two) concern improvements in the northern ports' access.

3 METHODOLOGY

This chapter discusses the project's methodology, describing the work's development process, the used tools and methods, justifying their uses and observing their relationships. First, it shall evaluate the method's suitability to the problem proposed in the introductory chapter. Second, this chapter outlines the model development process, describing the conception of the agents, the translation of their behaviors into programmable patterns, the study of their relationships and organization, the creation of a conceptual model and other procedures. Then, there are the model verification and validation process, which shall be done in two levels: the micro, defined by the agent's and their behaviors, and the macro, outlined by the emerging behavior. Lastly, there is the delineation of scenarios and their discussions.

In order to use such method, we need to justify it, as such; we shall resume the first objective proposed in this work: to test and verify the feasibility of agent based simulations as a tool in the industrial engineering field. This, *per se*, is enough to support the application of the mentioned method; nevertheless, it is important to understand in which aspects the analyzed problem is aligned with the method's properties and if the used tool is the most indicated for such cases. Therefore, concerning the studied problem, we should observe that grains supply chains consist of a vast network of active players, such as producers, consumers and dealers acting independently and seeking their own benefit. In this case, the simulation of many decentralized processes, such as the proposed model, is key to generate insights about the system behavior.

Moreover, other works, such as the one presented by Bedhani (2012), indicate that Agent Based Modeling is the best way to capture and simulate the socio-technical nature of supply chains. This situation derives from the fact that both Discrete Events Simulation and Dynamic Systems have gaps considering the studied problem: the first method is not suitable to simulate active elements, while the second does not replicate decentralized systems very well, as highlighted by Maidstone (2016).

3.1 Agent Based Simulations Framework

Following the justification, this section explains the used framework, observing inputs and guidelines from works proposed by the literature, adapting them to the current case. In this context, the tutorials and methods explained by Macal and North (2010) and Klügl (2016) are especially useful as they provide complete descriptions for an agent based model development. As such, this section proceeds by explaining the model's elements definition, the conceptual model development, estimation of inputs and parameters and the final model deployment.

According to Macal and North (2010) and Klügl (2016), the definition of the elements of an Agent Based Model follows a defined sequence, which starts with the identification of the agents as programmable objects, continues with the translation of their interactions and behavior into routines and attributes, and finishes defining the interactions of these players with the environment. Thus being, this work will first refer to the grains' supply chains literature in order to define the agents in the model. Then, it shall visit some concepts in commodity pricing and game theory in order to define these agent's behaviors and organization. Finally, some studies about logistic costs, the influence of taxes in logistics and hinterland's configuration will provide information about the environment and its influence over the agents.

After defining and understanding the agents, the environment, their behaviors and relationships, this work show proceed to the development of a conceptual model, an exercise, which simulates the behavior of a simple system in an illustrative way. This conceptual model shall follow two guidelines about best practices in Agent Based Modeling given by Klügl (2016): KISS (Keep it simple, stupid), and TAPAS (take a previous model, add something). The first guideline suggests specifically that the agent's behavior must be as simple as possible, while the second states the value of leveraging previous models. Therefore, the conceptual model will use simple rules to define the agent's behaviors and it will be conceived upon models with a similar configuration.

Following to the next step, it is necessary to map soy and corn supply chains in Brazil and translate this information in such way that it could be used as inputs in a final model that describes the flows of the mentioned commodities in Brazil. As such, this project relates to governmental and institutional sources to gather data concerning soy and corn productions quantities and seasonality, soy processing plants' installed capacities, ports' capacities, soy meal and corn demand, taxes, main transportation routes and their respective distances, transshipments costs, and railroads, roads and waterways freight prices.

Finally, the mentioned information and the conceptual model shall be combined in order to develop a final version of the model, able to replicate commodity flows in Brazil. This will be done by grouping production and demand into centroids that will act as individual agents with behaviors described in the conceptual model. Those agents, together with ports will be organized in the nodes of a network, where connection in between two nodes is given by a freight cost. This model will be implemented using Excel 2013, for two reasons. First, spreadsheet modeling is a more suitable tool than icons based programming tools in order to deal with a very large number of elements. Second, the objective of this work has a didactic component; therefore, the tools used to build this model should be as accessible as possible for the public.

3.2 Model Verification, Validation and Calibration

This section deals with aspects concerning the assertiveness of the model. It shall explain which procedures are going to be used to verify the results given by the model altogether with the validation of the model itself. These procedures are going to focus on three aspects of the model: the first, the model verification, certifies that the results given by the model do not violate constraints that are fundamental for the reality representation, showing that the grain flows are conservative and that modeled prices do not show strange behaviors. In addition, producers and consumers are the only entities that can alter the balance of grains in the system. The second aspect, the validation of the model at the micro level, should verify and confirm the behavior of the agents and their disposition. Finally, the emerging behavior validation, will focus on validating the overall output given by the model, comparing the exports and other indicators in the model with the reality

In order to verify the model, it is necessary to certify that the flows are conservative, in other words: the final stock of grains in the model must be the difference in between the whole production, exports and grains consumed. Other agent's properties must also be considered, for instance, prices must remain inside of a certain range and inventory positions must be non-negative. Finally, the model must verify if any formula or input result in errors or invalid values. Therefore, the model will have checks that evaluate each one of the mentioned conditions.

Moreover, this work counted with a meeting with a specialist in order to validate the agent's behaviors, as recommended by Klügl (2016). This meeting intended to check if the behaviors and relationships of the agents are consistent with the conceptual model. In addition, it sought for possible improvements for the model and tried to evaluate the impact of other factors that may affect the behavior of the agents in the real world, which were not captured by the model.

Finally, in order to validate the model at the macro level, the emerging behavior of the agents, this work shall make comparisons with the exports' historic, as these are the best-documented flows of commodities in Brazil. Other numbers, such as soy, soy meal and corn balances, soy processing industry monthly production and soy meal consumption indicators should be confronted with the model in order to validate it. Eventual inconstancies in between the results shown by the model and the reality should be small and explainable by factors not captured by the model, such as infrastructure quality, interference of other products, and presence of return cargo or tributary characteristics at the local level. These factors will, then, be included through a calibration process where some routes would receive penalties or bonuses in terms of costs.

3.3 Scenario Analysis and Discussions

In this section, we shall discuss the methods used to develop and analyze scenarios in order to provide answers for the proposed problem in the first chapter. As this project seeks to evaluate the impacts of taxes' path dependency in the efficiency of soy supply chain, this work should propose scenarios that differ in terms of tributary assumptions. In addition, it is necessary to choose which indicators would be the most suitable in order to evaluate the impact of the mentioned scenarios,

In terms of scenarios, this work shall proposes two possibilities. The base scenario, which tries to depict reality in the best way possible, replicating current commodity flows. The Second Scenario, in which taxes are not path dependent for soy, as such, it should penalize all sorts of decisions equally, not influencing agents' decisions.

The best choice indicators to evaluate all scenarios would be the logistic efficiency indicators. As such, it would be interesting to verify the variation of transportation demand over time, because a more efficient scenario would result in a lower and more stable transportation demand, because agents would choose routes that are more efficient logistically rather than in tributary terms. The total inventory of grains at ports would give a picture of congestions at ports, and soy processing plants utilization would reflect assets' efficiency.

4 CONCEPTUAL MODELING

This chapter studies the model deployment process, translating the conceptual model into one able to describe the reality discussed in the introductory chapter. The first section indicates commodity flows and information flows as proposed by the conceptual model. In addition, it explains the algorithm, which dictates agents' behaviors and decisions. The second section will analyze the model's preliminary results, confronting them with the reality and proposing a calibration process. Finally, this chapter finishes presenting the final version of the model and introducing the analysis presented in the next chapter.

4.1 Description of the model's elements

Continuing with the guidelines provided by Macal and North (2010) and Klügl (2016), this section will use the literature to define the model's elements, tracing stablishing relationships to those proposed in the micro-smart grid model (Kremers, Durana, & Barambones, 2013). Therefore, similar to a smart grid, the elements presented in a supply chain naturally align to an agent based model configuration, as such, each consumer, producer or distributor take the place of agents as individual decision makers, reacting to each other with selfish goals. Those players are placed over nodes of a logistic network characterized by attributes such as distances and freight costs, defining these agents' configuration and simulated environment, which will be better defined as follows:

4.1.1 *Agents*

This work seeks to model grains supply chains through an agent based method, therefore, it requires a good understanding of the agents in the supply chain and their decision making behavior. In this section, we shall review works which look into the cited supply chains and divide it into agents, attributing roles and giving information about their decision making process. Then, we shall compare the agents structures found and summarize them in a structure pertinent to this work.

The literature presents many works that map the agents in the soy and corn supply chains in a regional and national context, defining their interactions and organization. Fuganti (2016) shows the soy supply chain defined by four players: inputs suppliers, producers, originators, the processing industry and the final consumers. The first is given by providers of seeds, chemicals, fertilizers and equipment. The producers use those inputs to pant and harvest soy, the originators buy the producer's grains and conduce the distribution process (storage and transportation). The processing industry transforms soy in soy meal and soy oil, finally, the final consumers are given mostly by the livestock industry, and soil oil to produce biodiesel or use in the food industry and households.

Other authors such as Machado *et al.* (2013), Roberti *et al.* (2016) and Silva *et al.* (2010), also present a similar configuration to the one mentioned above. In addition, Martha Junior (2012) provides a similar model to represent the corn supply chain, consisting of: suppliers, corn producers, originators, processing industry and final consumer. Summarizing the agents and their relationships given in the aforementioned works in both supply chain, we have the Figure 3 below:

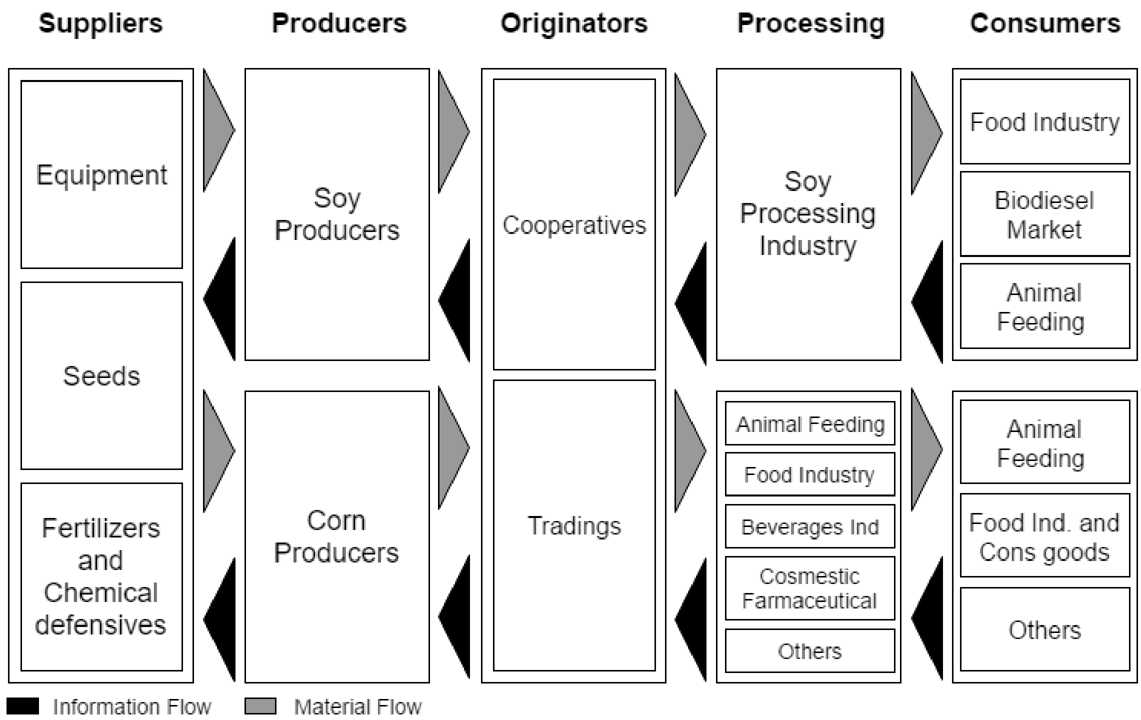

Figure 3 - Soy and corn supply chains' agents and their interactions

The diagram above demonstrates the material flows, given by agriculture inputs, grain or their subproducts, and information flows, given by cash, future contracts, or prices, exchanged among agents. These flows give inputs about the behavior of each agent, as such; players can act as distributors, producers, consumers, or a combination of those roles for a given product. In the scope of this project (presented in Figure 2, in the first chapter), considering the roles of the producers, originators, processing industry and consumers towards soy, soy meal and corn, we have four types of agents, as presented in the Figure 4.

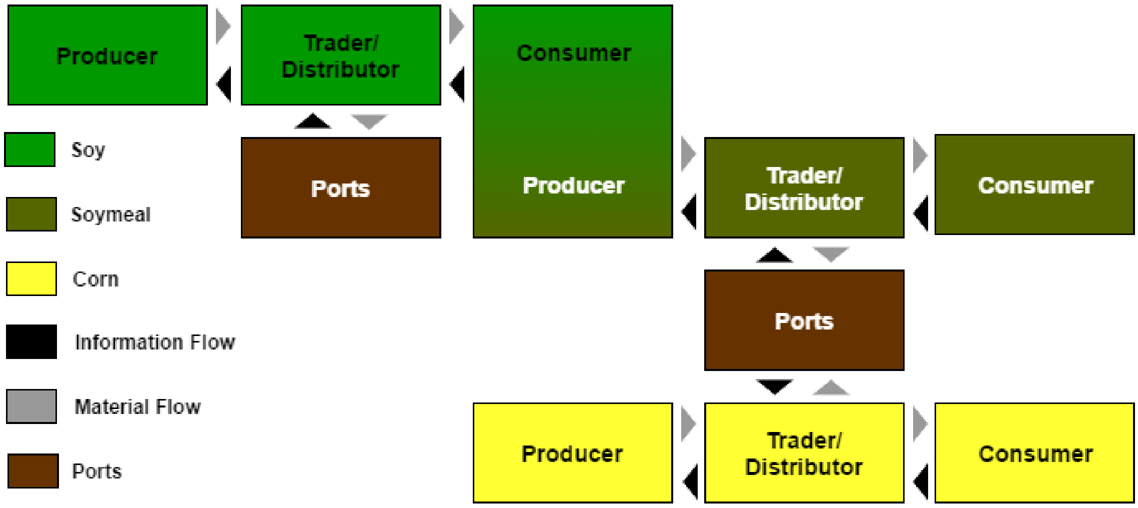

Figure 4 - General overview of the modeled agents

First, there are the producers, characterized by an endogenous curve of production over time, simulating the harvests or output of the processing industry, this production flow is, then, allocated to nearby traders, which will distribute the commodity across ports and consumers by evaluating the trade off in between logistics costs and prices paid by each entity. Finally, ports and consumers will present a price curve, which is related to each agent current inventory level, consumption rate and seasonal factors. In addition, it is important to notice that the processing industry is not represented by a single individual agent because it has been broken into a consumer of soy and a producer of soy meal, where the exiting flow of soy meal is conditioned by the inventory level and the incoming flow of soy.

4.1.2 *Agents Interactions and Organization*

In this section, we will refer to the literature in order to find inputs to describe the agent's behaviors and try to reproduce it mathematically. Departing from the assumption that players behave rationally, game theory may provide valuable insights about the originator's behavior. In addition, commodity pricing is a valuable tool in order to simulate the behavior of consumers, and the concept of hinterlands is very useful in order to understand the relationship among originators and ports.

<u>Congestion Games</u>

In the model proposed in this work, a congestion game is a simple programmable behavior very similar to the actions practiced by traders. Thenceforth, it would be interesting to define a congestion game and, then, search for practical applications of such game to model player's behaviors in other contexts.

A Congestion Game, as introduced by Rosenthal (1973), is a game in which each player has to choose to use one or more resources from a set of common resources. The payoff function associated with each resource and player is a decreasing function, depending on the number of players using that very same resource. As stated by Monderer and Shapley (1996), congestion games are equivalent to potential games, therefore, possessing pure Nash equilibria, reached through iterative best response.

In such way, a congestion game is a suitable model to represent scarcity of common resources. Arthur (1994) presents a notable example of these problems: in this case, a number of costumers decide independently whether to go to a bar that offers live music on a certain night of the week or to stay home. As the bar has a finite amount of space, if the number of people deciding to go to the bar surpasses a certain threshold, it becomes crowded and unpleasant, and similarly, if the bar is empty, it offers quite an amusing show. Finally, Arthur suggests a solution using dynamic simulations.

Concerning this project, originators would be constrained by the scarcity of resources such as ports capacities or local consumer's demand. Therefore, each of the agents would weight freight and price of the commodity before choosing where to sell their products at every simulation step. This behavior is very close to the a iterative best response algorithm and it has the same result if the model assumes atomic players acting in a sufficiently small time interval. In addition, the use of Congestion Games to model agent's behavior implies in a network organization.

Commodity Pricing

One way to understand this model, especially when it concerns the production allocation against national demand, is through the congestion game presented by Selten and Güth (1982). In this model, many players can choose to enter in one or more markets of a set of markets. In each market, the cost to each player is fixed but the price of the sold items in each market depending on the number of players accessing that very same market. Similarly, in this work, a producing city (or player) can choose whether to send its production to one or more cities (market) where the transportation cost is fixed, but the price offered for each unit of commodity sent varies according to the total offer of that commodity at that market by all other players.

In this context, it is important to study models for the estimation of commodity prices. According to Low (1974), the market price of a certain product is affected by the inventory of goods held by the manufacturers rather than the rate at which manufacturers are supplying those goods. If the manufacturers were supplying goods at a rate equal to the consumer demand, characterizing an equilibrium in the static classical theory, In case of a tremendous surplus in the store supply rooms, the manufacturers will lower the price and/or decrease production to return inventory to a desired level. Therefore, prices are dependent on the relationship in between the current and the desired inventory level. This relationship becomes especially important in the agriculture sector, because producers cannot adjust their production to the market demand in the short term, being able only to change prices and plan their production quantity for the next season.

Frankel and Rose (2010) have pointed out the importance of inventories in commodities price determination, because storage costs rise with the extent to which inventory holdings strain existing storage capacity. If the level of inventories is close to its maximum capacity, storage prices must be high, therefore having a negative effect on commodity prices. In addition, the authors consider the logic that inventories are bounded below by zero and above by their peak capacity, therefore, concluding that a logistic function is appropriate to describe the price as function of inventories.

Hinterland Definition

As this work aims to assess and provide insights about the current conditions of the Brazilian infrastructure system, it is import to identify how flows in between producing regions and ports work since exports are the destination of approximately half of the total grains produced in Brazil. Therefore, this section focuses on understanding the concept of area of influence of ports and the main important factors in their definition.

According to Winden and Klink (1998), a hinterland is the main port's market, composed by the continental area of origin and destination of the cargo traffic through the port. Therefore, defining a port's hinterland is of pivotal importance for its marketing strategy because the port would have little influence outside of it. In addition, Winden and Klink also point out that a port hinterland is identified by the region where that specific port is the first option in terms of total logistics costs.

Other authors such as Notteboom (2009), Stupello (2011), Pizzolato, Scavarda and Paiva (2010), also used similar ideas to define a hinterland as the region with the best access to the port in terms of total logistic costs. Therefore, considering the high volumes involved, the high demand for cost efficiency in dealing with a commodity and the long distances concerning the grain logistics in Brazil, it is reasonable to adopt the concept of hinterland as defined by the total logistic costs in the terms done by Castellani (2013).

4.1.3 *The Simulated Environment*

This section concerns the simulated environment's attributes that may influence agent's decisions and cannot be directly attributed to the modeled agents, such as logistic costs and taxes. These two elements are very important in order to simulate the relationships in between agents, because they have a direct impact over their interactions.

Logistics Costs

In order to calculate players' payoffs, other than product prices, this work must also take into account costs, in the case of agriculture, as production costs are compromised before the harvest season; they must be seen as sunk costs. Therefore, the logistics cost becomes the most important costs factors in the players' decision-making process.

According to the Council of Supply Chain Management Professionals, logistic management can be defined as a set of activities including:

> "inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution--strategic, operational and tactical. Logistics management is an integrating function, which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology." (Council of Supply Chain Management Professionals, 2016)

In agriculture, as players deal with large volumes of commodities of low aggregate value in business-to-business context, many of the activities described above become insignificant whereas others gain importance. As such, it is necessary to look for a suitable methodology to calculate total logistics costs in this context. Reis (2011) presents a convenient method for this work as he looked into different techniques used in the United States, South Korea, South Africa and Brazil to calculate total logistics costs, proposing an adapted version best suited to the Brazilian reality.

In the methodology proposed by Reis (2011), the total logistic cost, TLC is composed by the transportation cost TC, storage costs, SC, and administrative costs AC:

$$TLC = TC + SC + AC$$

$$TC = \sum QT_{kl} \times ATC_{kl} \times D_{kl}$$

$$SC = OC + SMC = \sum \overline{QS_k} \times \overline{V_k} \times r \times \Delta t + \sum \overline{QS_k} \times \overline{V_k} \times USC_k \times \Delta t$$

$$AC = W + IS + IC$$

Whereas:

- QT_{kl} is the quantity of product k transported in the modal l
- ATC_{kl} is the transportation cost per kilometer of the product i in the modal l
- D_{kl} is the average distance traveled
- OC is the opportunity cost of the cargo
- SMC is the stock management cost of the cargo
- $\overline{QS_k}$ is the average inventory of the cargo k during the period Δt
- $\overline{V_k}$ is the average value of the cargo k during the period Δt
- r is the capital opportunity cost of the product stored
- Δt is the time interval considered
- USC_k is the unitary storage cost of the product k per unit of time
- W corresponds to the wages of the administrative personnel
- IS is related to the costs of the equipment and information system used
- IC is related to other intangible costs such as legal requirements and bureaucracy

ICMS

As one of this project's objectives, the evaluation of current tributary policy in the soy supply chain requires an assessment of the current policy for the studied commodities (already presented in Figure 1, in the first chapter) and a review of studies concerning the impact of tributary policies over logistics and distribution of products. Concerning this last topic, we shall view the work developed by Yoshizaki (2002) and subsequent discussions. In addition, it is important to review case studies of tax impact over logistics in the agribusiness sector. Lastly, we should identify studies about the impact of current tax configuration in the soy industry.

The study conducted by Yoshizaki (2002) subsidized the generation of many others researches about the impact of the ICMS tax over the logistics of goods, ranging from the environmental impact point of view (Carraro & Yoshizaki, 2009) to the impact of tax law actualizations, as it may be seen in Yoshizaki and Andrade (2012) and Yoshizaki (2008). In these papers, the authors evaluate the distortions caused by the misalignment of logistic costs and tax policy. This is done by the evaluation of different scenarios, which consider the effects of different factors such as tax evasion and tributary incentives, using linear optimization models to seek the optimal total cost solution to design distribution channels. The studied scenarios are, then, compared to the optimum logistic solution in order to verify the mentioned distortions, which result in negative outcomes such as higher logistic cost, increase in greenhouse gases emissions and loss of competitive edge.

Furthermore, there are other studies in the literature concerning the distortions of the ICMS in the agriculture sector. Junqueira and Morabito (2006) use a similar methodology in a case study concerning the production planning and logistics of a corn seeds production company. The mentioned work concluded that tax policy has a great impact over the decision making process in this kind of activity. Other works such as the ones conducted by Fernandes Filho and Belike (2010) and Santos *et al.* (2016) also highlighted the negative distortions caused by a poorly designed tax policy. Finally, institutions representing the soy processing industry have issued documents pointing out the negative impacts of the current tributary configuration as verified in ABIOVE (2016).

4.2 Conceptual Model Prototype

The previous chapters, sections and the reviewed literature have given enough input for the conception of a time discrete model that represents the system behavior. According to this approach, we shall first have a high-level overview and then look at each element more closely, defining each agent behavior.

Applying the best practices guidelines indicated by Klügl (2016) such as KISS (Keep it simple, stupid), and TAPAS (take a previous model, add something), mentioned in the third chapter, we can look for the simulation of systems similar to the grain supply chains and conceive a model derived from them. Agent Based Simulation applied to Smart Grids fit this role well, because, like in the grains supply chains cases, there are multiple agents allocating flows of commodities through a network subject to regulatory and capacity constraints. Ringler *et al.* (2016) studied many previous cases of Agent Based Modeling to electricity grids, observing the consistent development of this method applied in the sector, Babic *et al.* (2016) address the ABS method as the best form to model an electricity market in order to provide insights for the decision making process of the main affected stakeholders. Finally, and most important, there is the work presented by Kremers *et al.* (2013), in which it is described a method to model a micro smart grid based on multiple layers, in those layers there is the circulation of energy or information, influencing the agents' behavior (placed on each node). This representation was adopted in this work and it is very useful in order to show this work's subject in a higher level, as shown in Figure 5 and Figure 6 in the next page.

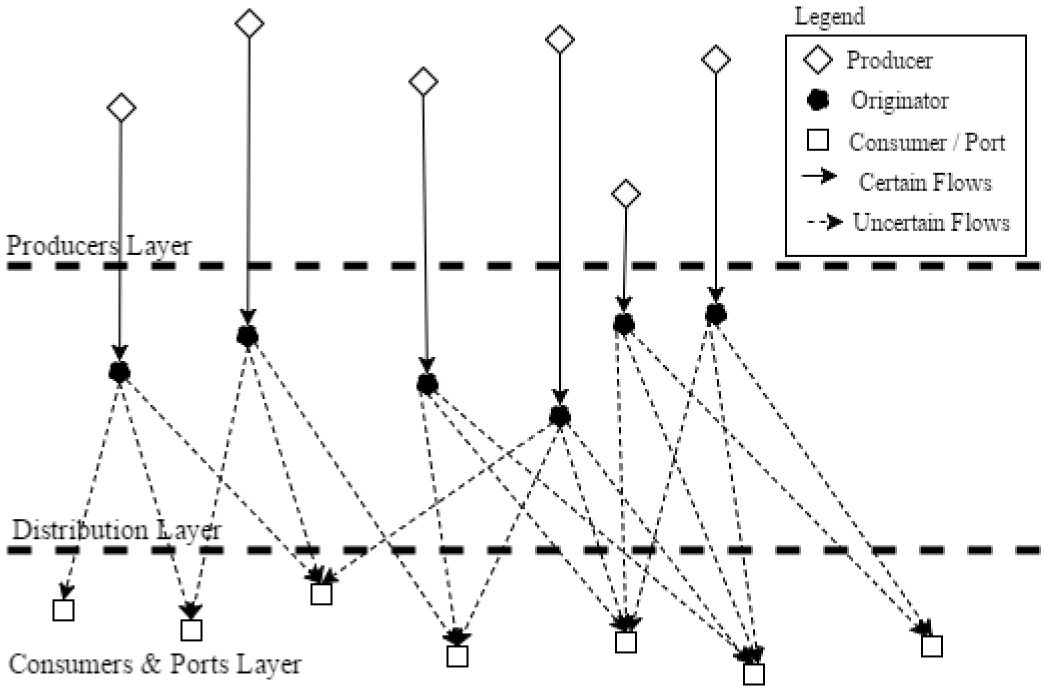

Figure 5 - Commodity flows representation overview

According to Figure 5, the modeled commodity transits through several layers, one is dedicated to its production, defined by the producers, other is used for its circulation, occupied by originators, and the third layer is occupied by consumers and ports. The continuous arrows define flows of commodities that will certainly occur, while dotted arrows define flows of commodities, which may or may not occur depending on the player's decisions. In addition, there is an information layer, presented in Figure 6, which defines flows of information in the opposite direction of the commodity flows, linking consumers to originators and closing the feedback loops. Besides the layers, the model presents classes of agents, which dictate part of those entities behaviors. These classes are defined as producers, traders or originators, consumers and ports.

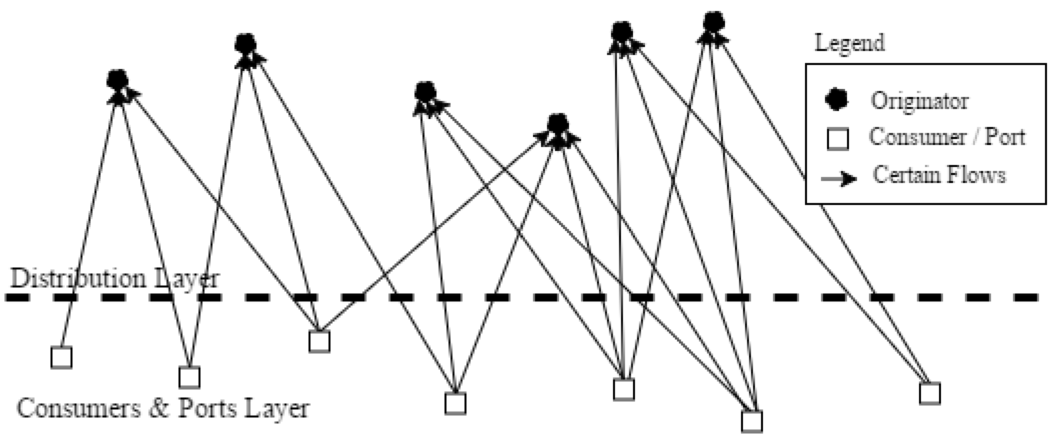

Figure 6 - Information flow representation overview

Starting from the producers, the model considers that productions have been already planned and negotiated through future contracts (IMEA, 2016) before the model starts. In this context, producers act passively, transferring their productions to nearby originators some time after the harvests, as if they were fulfilling the previously negotiated contracts. In the model, each producer is linked to only one exclusive trader in its geographic position. This behavior is explicit in the Figure 7, where producer G harvests some of its production at time t, at this same time step, this producer transfers a certain amount of commodity that was harvested in time $t - x$ to the originator H. In addition, it is important to observe that there are no logistic costs related to the edge GH because these two agents have the same geographic position.

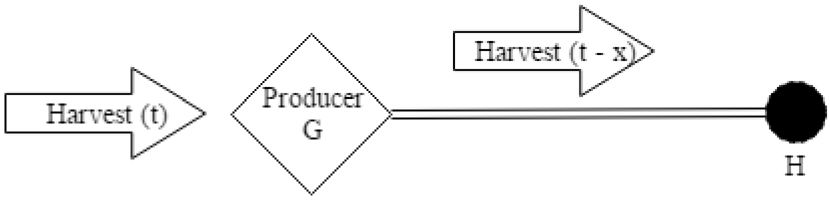

Figure 7 - Producer behavior

Having a central role in this model, originators explain most of its behavior because they allocate the commodity flows in the model. They do it by receiving the producer's grain and, then, directing it to a consumer or port after evaluating prices and logistics trade-offs. In a more detailed process, each originator would receive an amount of a generic commodity from their respective producers at the beginning of each simulated period; these originators would then consult the commodity prices and logistics costs related to every consumer inside a certain radius. Finally, each originator would allocate the received production to the port or consumer related to the highest payoff. Figure 8 and Figure 9 exemplify the mentioned dynamic:

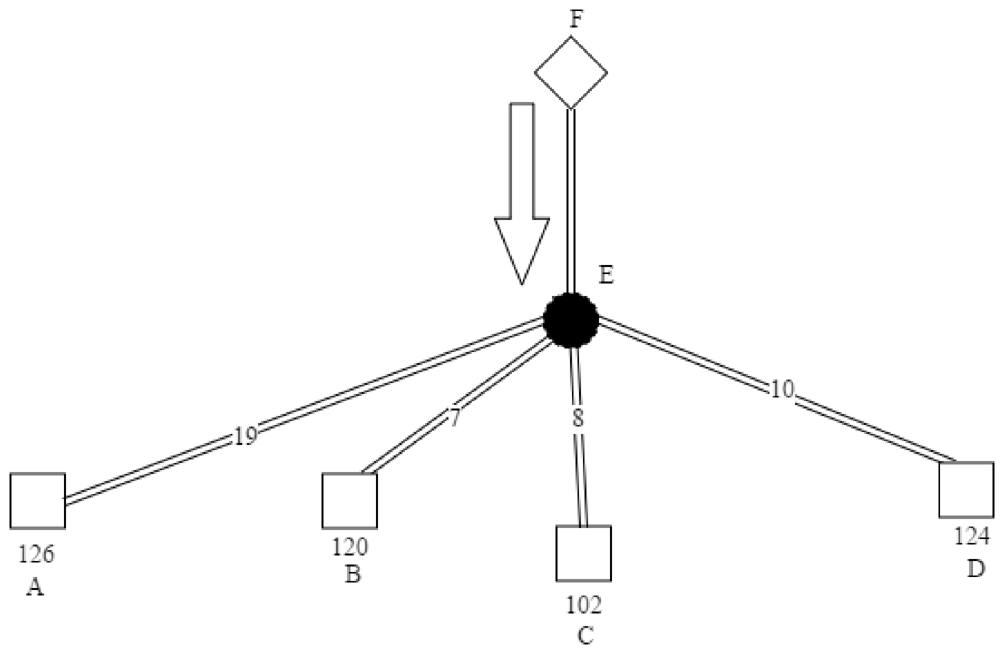

Figure 8 - Originators representation I

In the example given above, the producer F sends a certain amount of a generic commodity to trader E at the beginning of a simulated time period. This trader E will then evaluate the payoffs related to selling a unitary amount of the generic commodity to consumers A, B, C and D. This evaluation is done by subtracting each logistic cost, in the graph edge, from its respective vertex. In the case above, consumers A, B, C and D would have payoffs of 107, 1013, 94 and 114 respectively. Therefore, at the end of the simulated period, trader E would transfer the production received from F to D.

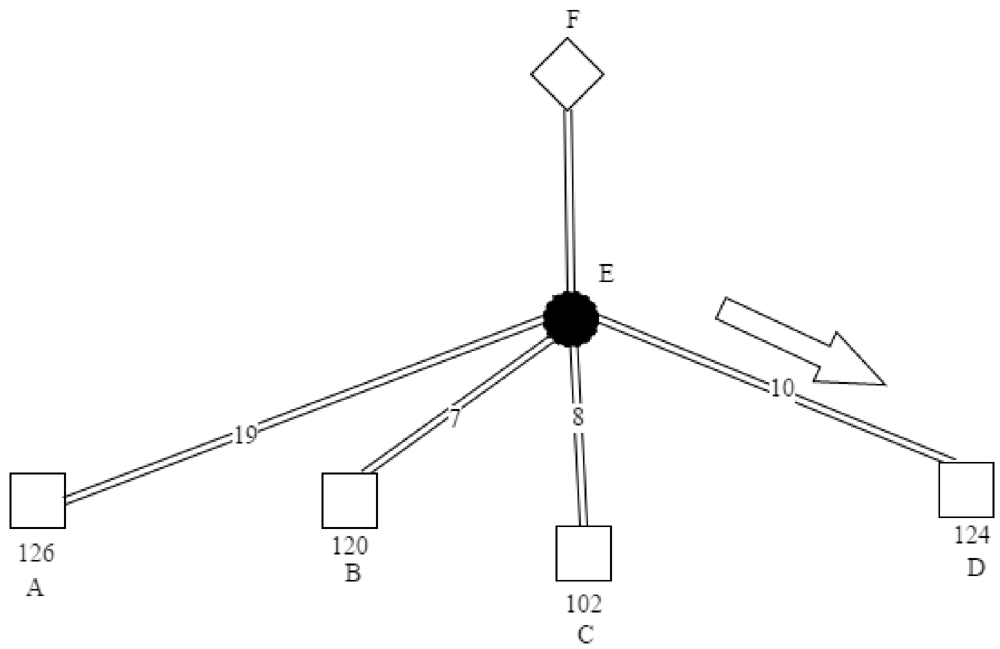

Figure 9 - Originators representation II

Proceeding to the last set of agents, there are the consumers and ports in Figure 10 and Figure 11. These agents have very similar behavior, as they divulgate prices to adjacent agents in order to influence incoming commodity flows. The mentioned agents also have an exit flow representing the consumers demand rate or the ports capacities. The only difference among the mentioned players are the functions defining their prices. The consumer's prices are defined by their current inventory position and the expected inventory, given by a seasonal curve, following this assumption, prices at ports are given by the total storage costs subtracted from the commodity prices practiced internationally. In this case, the total storage costs would be given by the current inventory position (in days) multiplied by the unitary storage costs.

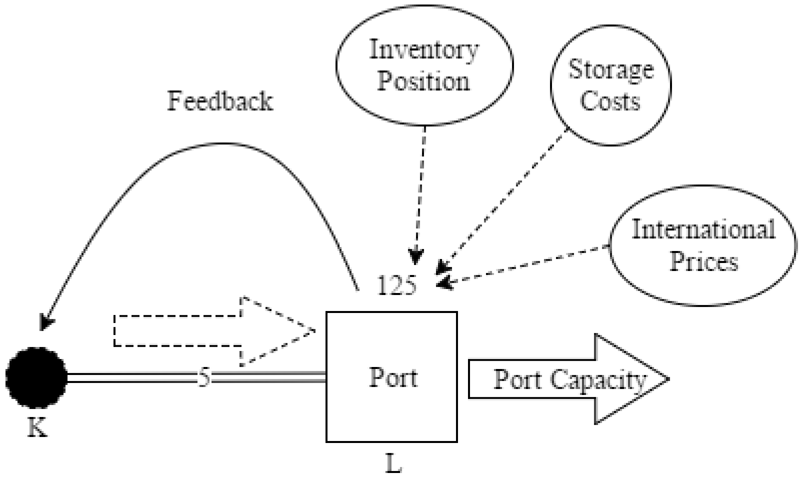

Figure 10 - Ports' behavior representation

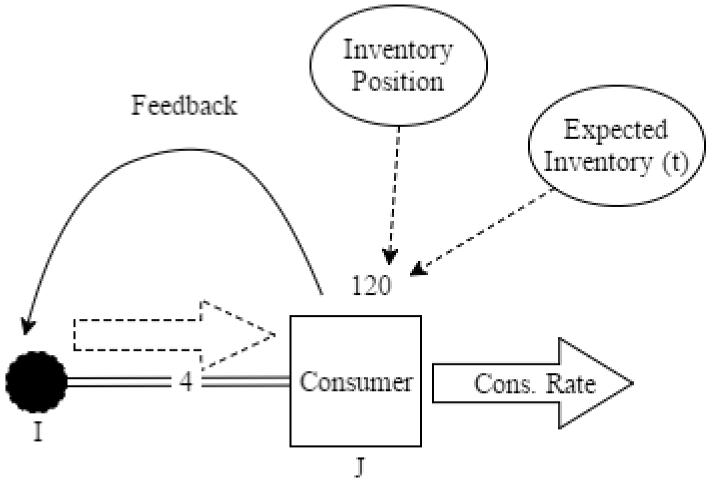

Figure 11 - Consumers' behavior representation

Applying multiple iterations in this model described above, we have that information (prices) and the modeled commodity travel in opposite directions, stablishing multiple balancing feedback loops, therefore making it difficult for consumers or ports to have excessive stocks or run out of the modeled commodity.

5 DATA GATHERING AND PARAMETERS ESTIMATION

The final model in this work requires a considerable amount of data as input, varying from the distribution of the grain production over time by location to freight costs, ports capacities and consumer's demand rates. These numbers are not always available in a convenient format, thus, it is necessary to either translate them into an adequate format or estimate them. Therefore, this chapter presents the data sources, their conversion and other inputs estimation. In addition, in order to better organize the process, we shall use the following indexes:

- i is an index related to the geographic origin of a route or commodity
- j is an index related to the geographic destination of a route or commodity
- k is an index related to a commodity (soy, corn or soy meal)

5.1 Soy and corn Productions Estimation

For the purpose of the conceived agent based model, Brazil's soy and corn productions can be described according to three parameters: geographic position, quantity and time. The first two would represent the production distribution in space and the last one identifies at which time of the year the production is harvested.

In this work - in order to represent production geographically with enough accuracy, while still being able to process the model without any special hardware or software - Brazil's soy and corn productions were distributed in 66 regions and all of the production of each region would be concentrated in a centroid according to the state borders and geodesic distances. The total production considered was the 2015 production by state, presented by CONAB (2016), this total production was then divided among all cities using the cities registered production in 2013, as provided by IBGE (2015). The mentioned representation is shown in the maps in the next page, which covers 97% of Brazil's soy and corn combined production, a table with all cities, latitudes, longitudes and their respective regions is provided in the Attachments.

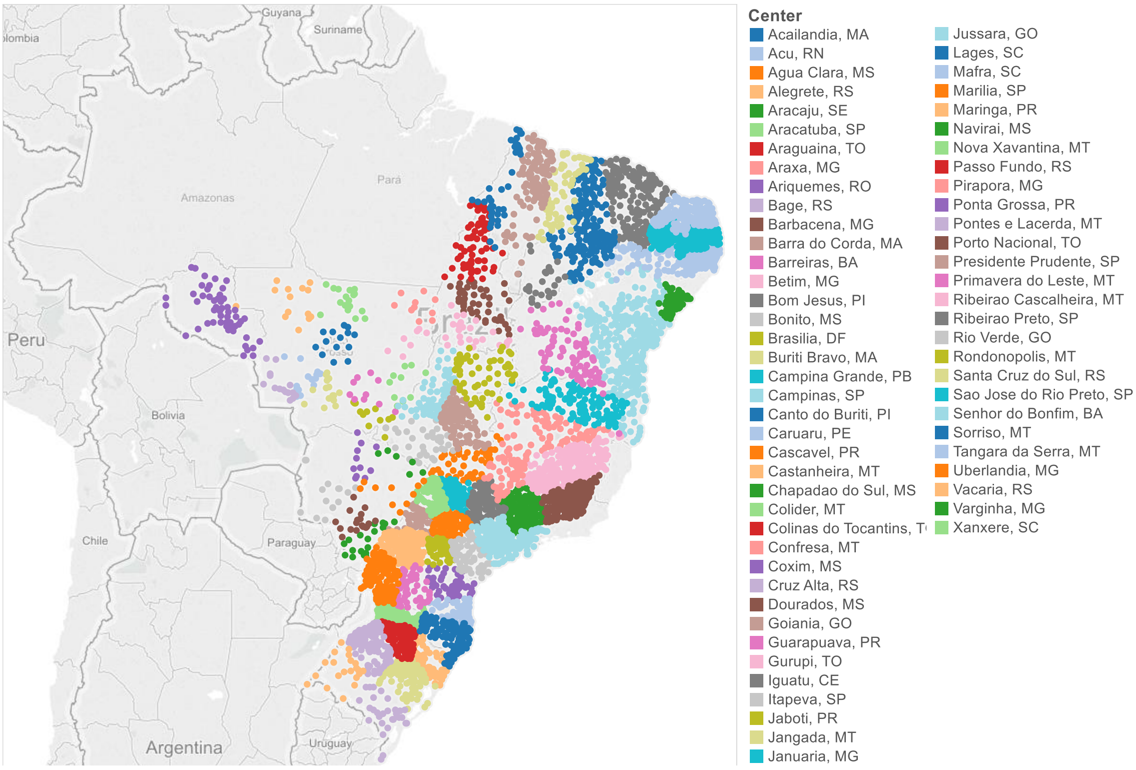

Figure 12 - Geographic division of production in the model

The maps with the production distribution are quite similar in terms of volumes concentration; especially outside Santa Catarina and Rio Grande do Sul states, in the South region. This curious effect happens because those crops compete for land in those states as corn cannot be planted during the winter, being substitutes for the producers. In other states, where the winter corn is feasible, the behavior is the opposite as the synergies presented by the combined production of soy as the primary crop with the winter corn generates positive correlations in between those productions.

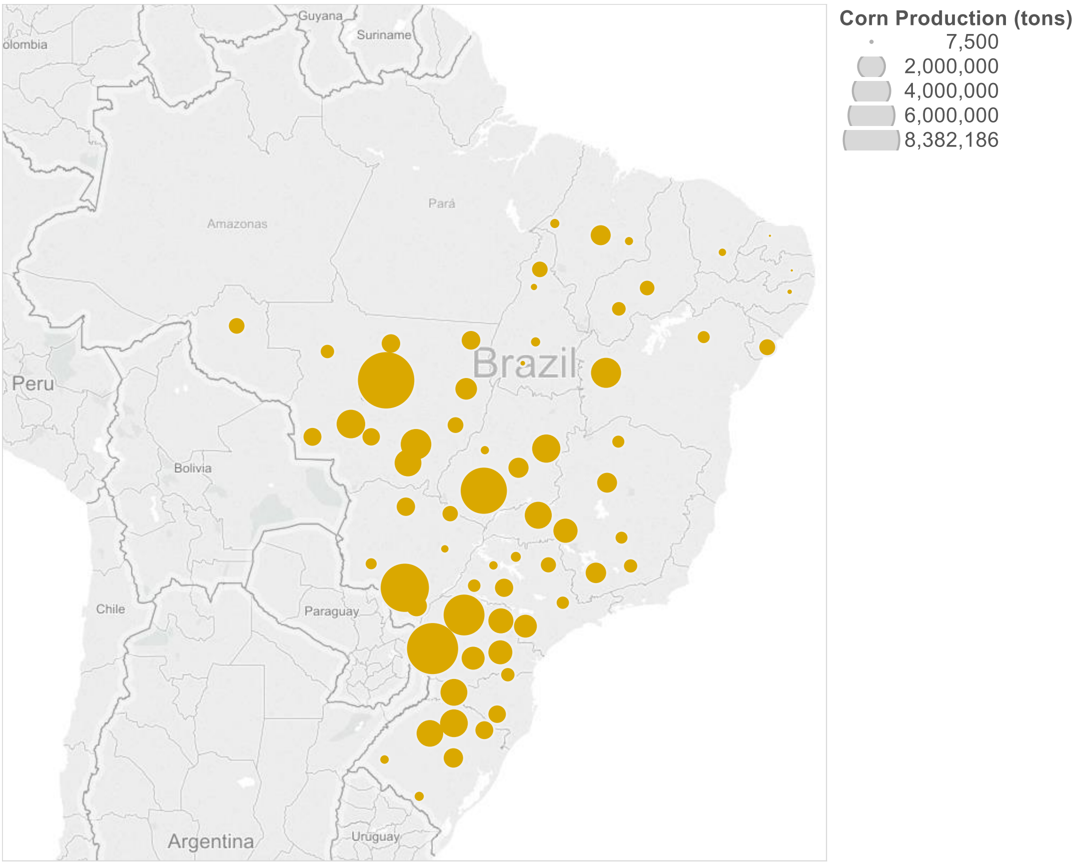

Figure 13 - Geographic distribution of corn production

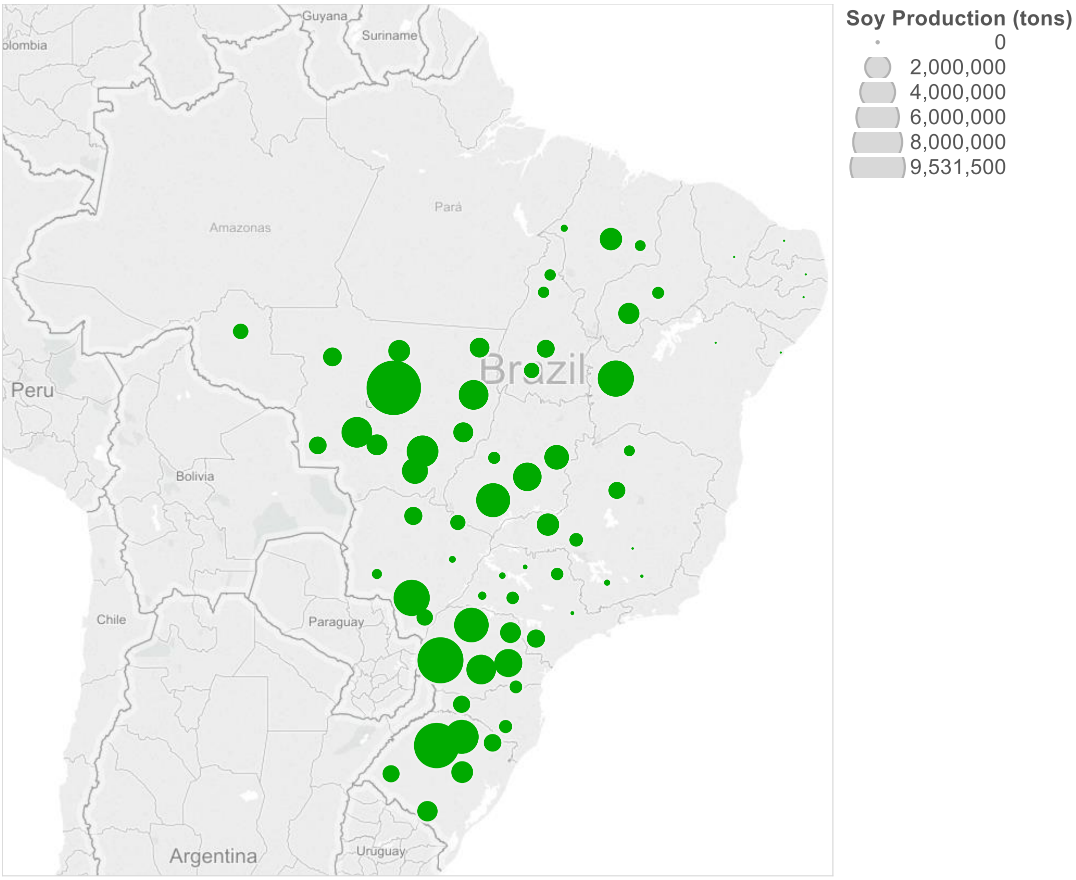

Figure 14 - Geographic distribution for soy production

In order to represent production over time, it is necessary to look at harvest season's dates by region, as harvests seasons in each region vary according to geographic and climatic conditions. Therefore, harvests shall be modeled according to the harvests calendar, which are presented in the Gantt chart below :

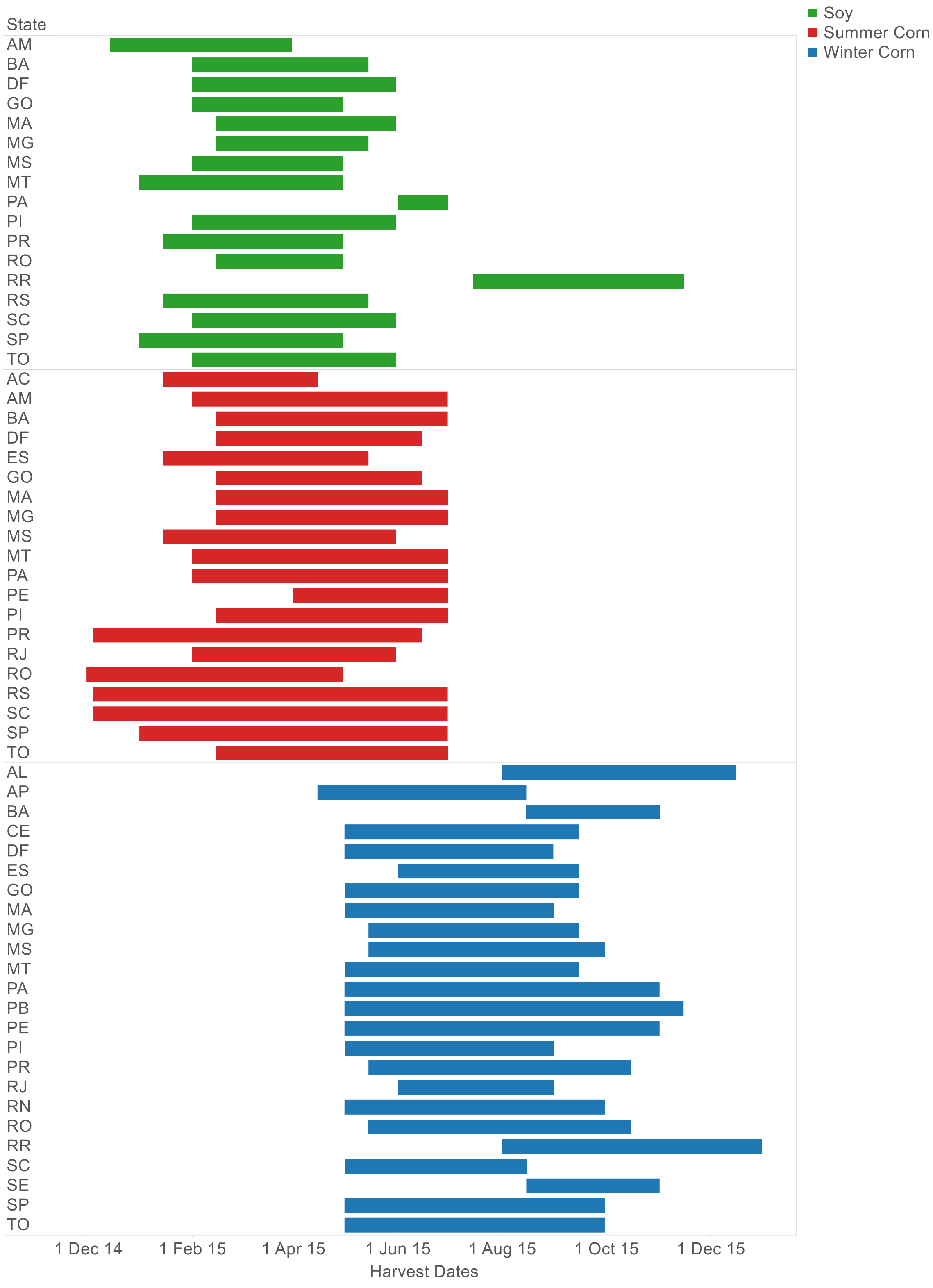

Chart 8 - Gantt chart representing all harvests seasons in Brazil by state (Sifreca, 2015)

Besides the harvest dates, it is also necessary to verify how production is distributed along harvest seasons, which is not available for all states. Nevertheless, IMEA (2015) has divulgated harvests by week in many Mato Grosso cities, totaling 74% of all harvest area in the State during 2015 harvest season, which is represented and compared to a logistic regression in the chart below:

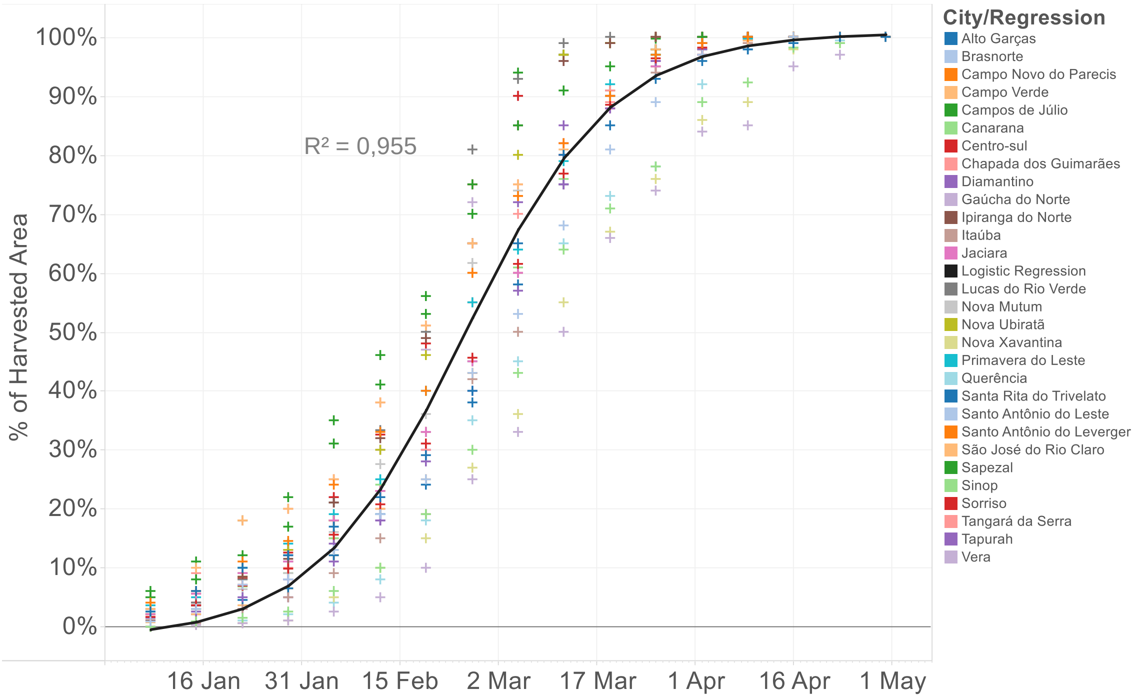

Chart 9 - Soy harvests in Mato Grosso and its logistic regression

Thus, in order to extrapolate this model to the harvests in other States, the distribution of harvests $H\%_{ik}(t)$ shall be calculated as follows:

$$H\%_{ik}(t) = \frac{1}{1+e^{k\left(\frac{t-\overline{t_{ik}}}{t_{fik}-t_{0ik}}\right)}}$$

$$\overline{t_{ik}} = \frac{(t_{fik} + t_{0ik})}{2}$$

Where $k = -10{,}56$ as found in the Model shown for Mato Grosso's harvests, t_0 is the harvest start date and t_f is the harvest end date as presented in the Chart 8, while i and k are indexes related to centroid and crops identifications respectively. Therefore, combining the model above with Brazil's production distribution across geographies, we have the production over time by state as presented in Chart 10 for corn and Chart 11 for soy.

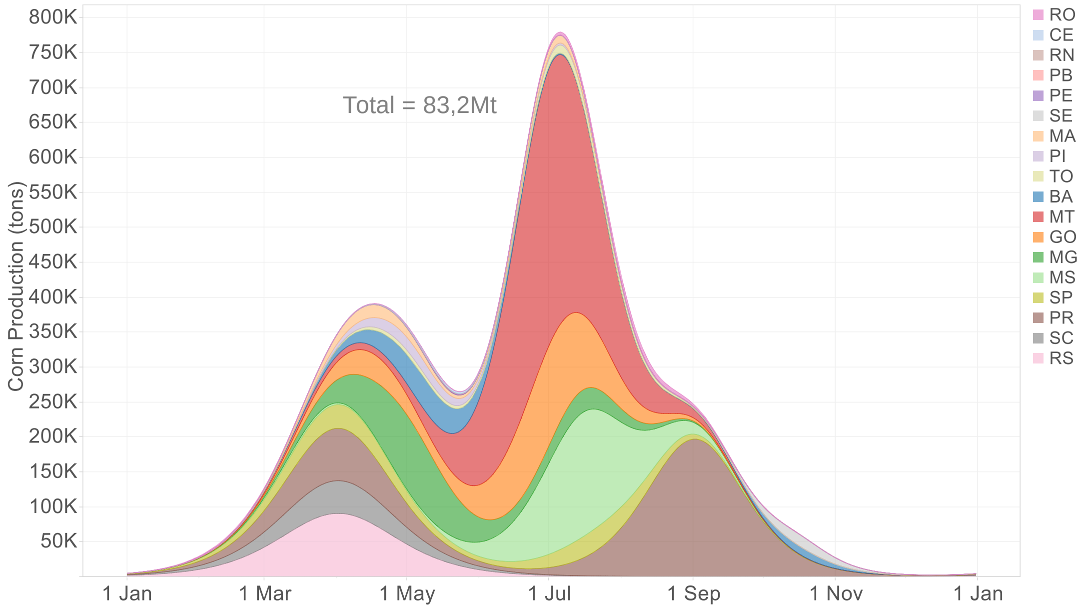

Chart 10 - Model of Brazil's corn harvests over time in 2015

It is noticeable that most of corn production peaks in April (for summer corn) and in July (for winter corn), but overall, corn production is much better distributed than soy's, as it peaks at 780k tons/day in the beginning of March while the last one peaks at 1,8M tons/day by mid-March. This high concentration of production around March-April probably is one of the main reasons for congestions at ports.

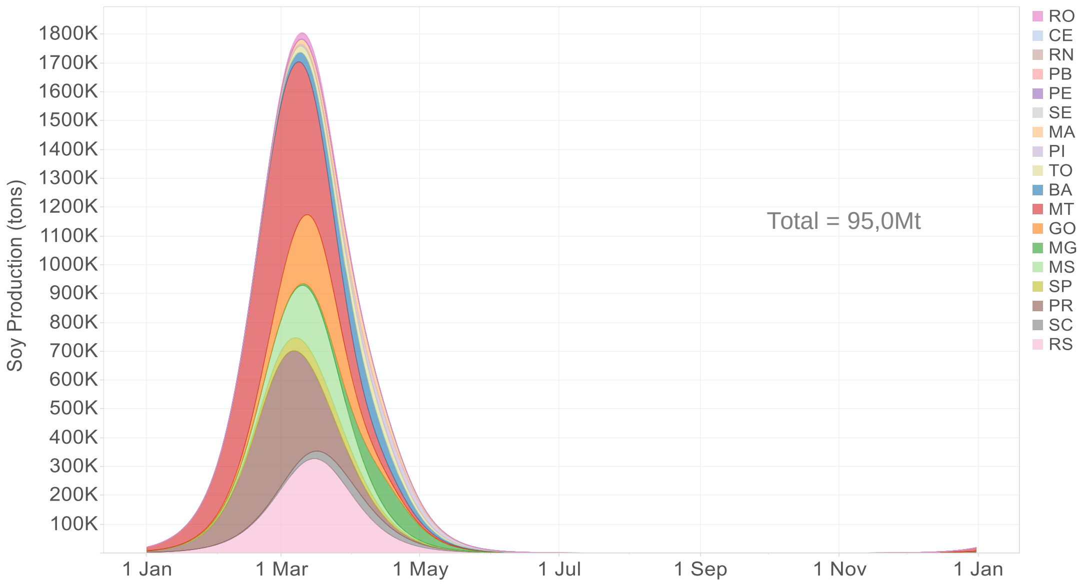

Chart 11 - Model of Brazil's soy harvests over time in 2015

5.2 Routes, Exports Corridors and current Infrastructure

In order to estimate freight costs and provide a good overview of all routes, this section begins by selecting and identifying important routes thorough waterways, roads and railroads in the grain transportation context in Figure 15 and Figure 16 below. Then, both infrastructure maps shall be examined more closely, providing insights about routes, ports and hinterlands.

Figure 15 - Important roads in the grain transportation context

According to the map above, some ports such as Itacoatiara and Santarém, in the north region, and Vitória, in the southeastern region, are not accessible directly through roads, therefore relying on other modals of transportation such as railroads and waterways.

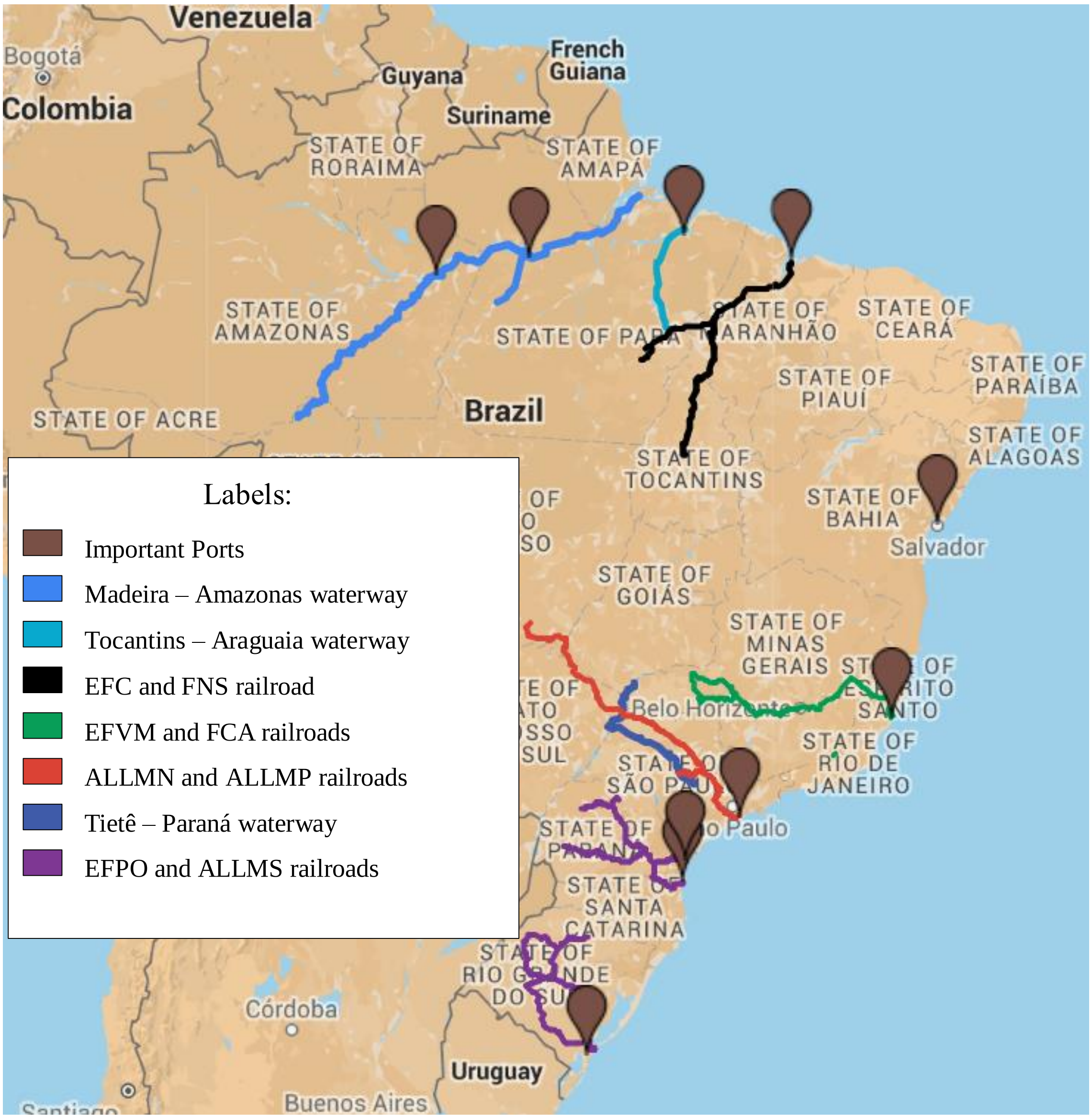

Figure 16 - Important railroads and waterways in the grain transportation context

Comparing both maps, it is noticeable that the highway infrastructure is much more prominent than the railroads in grain logistics. It derives from the fact that, even though Brazil possesses continental dimensions and a great waterway network, its transportation infrastructure is based mostly on roads. This condition presents itself as a big disadvantage relatively to other import grain exporters such as Argentina and United States, which have most of their productions transported through railroads and waterways (Castellani, 2013).

The South Corridors, comprised by Rio Grande, São Francisco do Sul, Paranaguá ports, and their respective infrastructure, are represented in the Figure 17 in the next page:

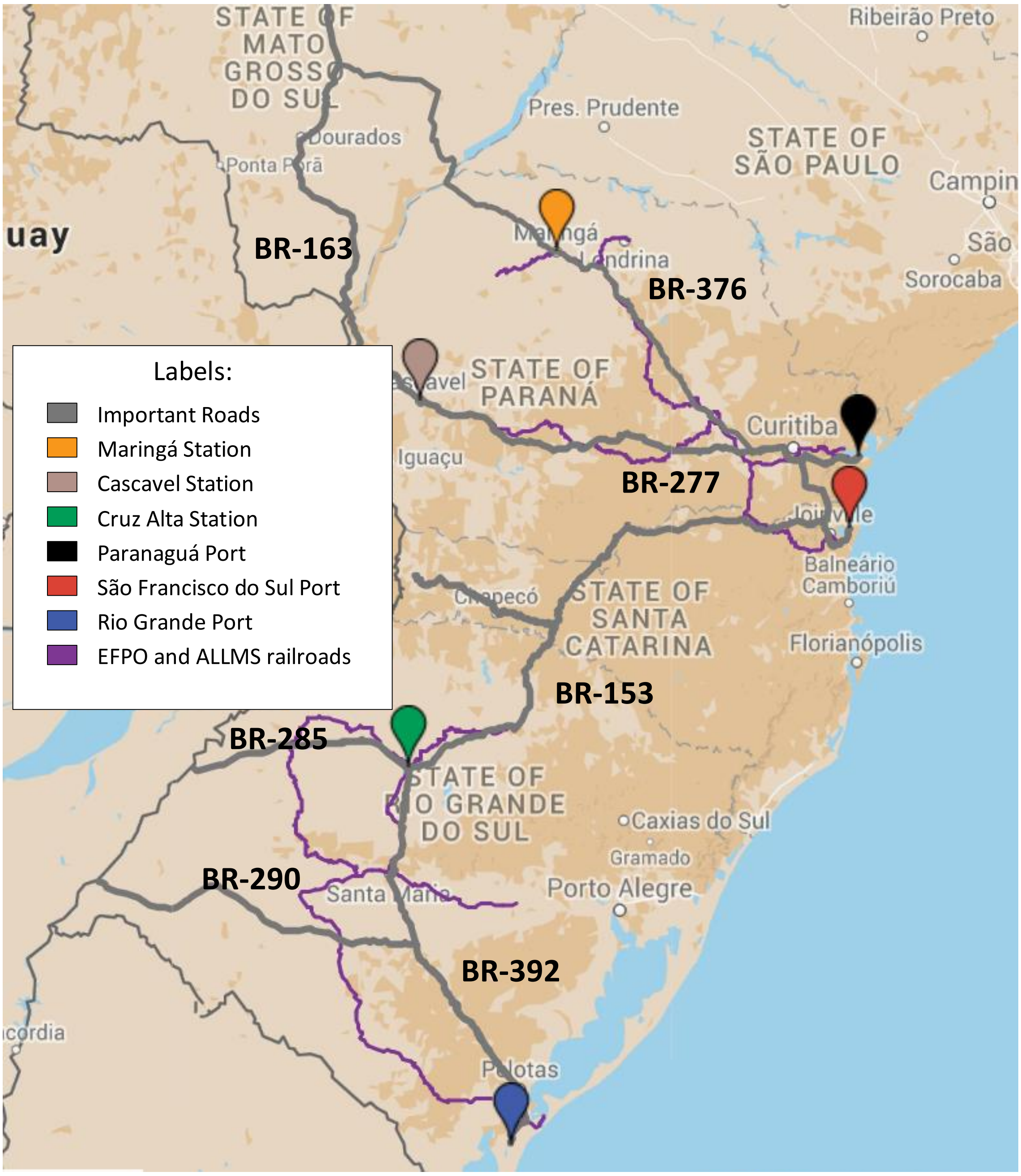

Figure 17 - South exports corridors

The ports represented in the map above receive most of their cargo from the South region itself and some from the Mato Grosso do Sul State, in the Midwest, through the roads BR-376 and BR-163, linked to the ALLMS railroad in Maringá and Cascavel. While the port of Rio Grande has a strong influence over Rio Grande do Sul State, both Paranaguá and São Francisco do Sul port share the same hinterland in the rest of the South region as their proximity and similar infrastructure contribute for akin total logistic cost in the areas surrounding them.

The Southeast corridor consists of the Santos and Vitoria ports and all the roads, waterways and railroads linking them to Mato Grosso, Mato Grosso do Sul, Goias and Minas Gerais states, as we can see in the map below:

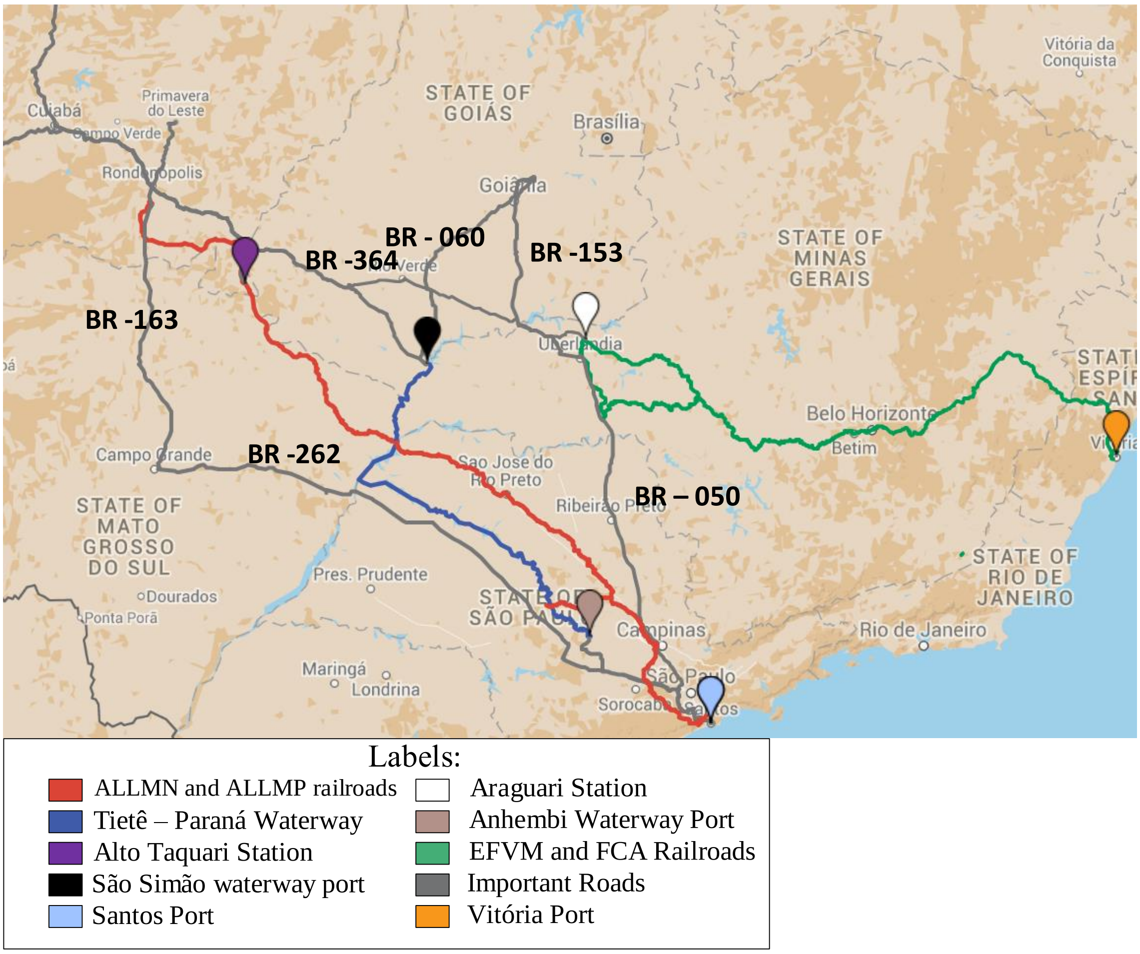

Figure 18 - Southeast exports corridors

In the Southeast corridors, Santos receives its cargo from Mato Grosso do Sul, Mato Grosso, Minas Gerais and Goiás while Vitoria receives its cargo from all the cited states, except for Mato Grosso do Sul.

In order to access the Vitoria Port, the cargo must be sent through Araguari where it uses the FCA/EFVM railroad to reach the port. In the case of Santos, there is a wider range of options: cargo from Goiás or Minas Gerais can arrive through BR – 050; Mato Grosso and Goiás can access Santos port by using Tietê Paraná Waterway from São Simão to Anhembi; and there is the BR-262 route, with grains coming from Mato Grosso and Mato Grosso do Sul.

Next, there are the North Ports, accessible through the Amazon river basin. Those ports receive grains almost exclusively from the eastern and northern portions of Mato Grosso State, as we can see in the Figure 19 in the next page:

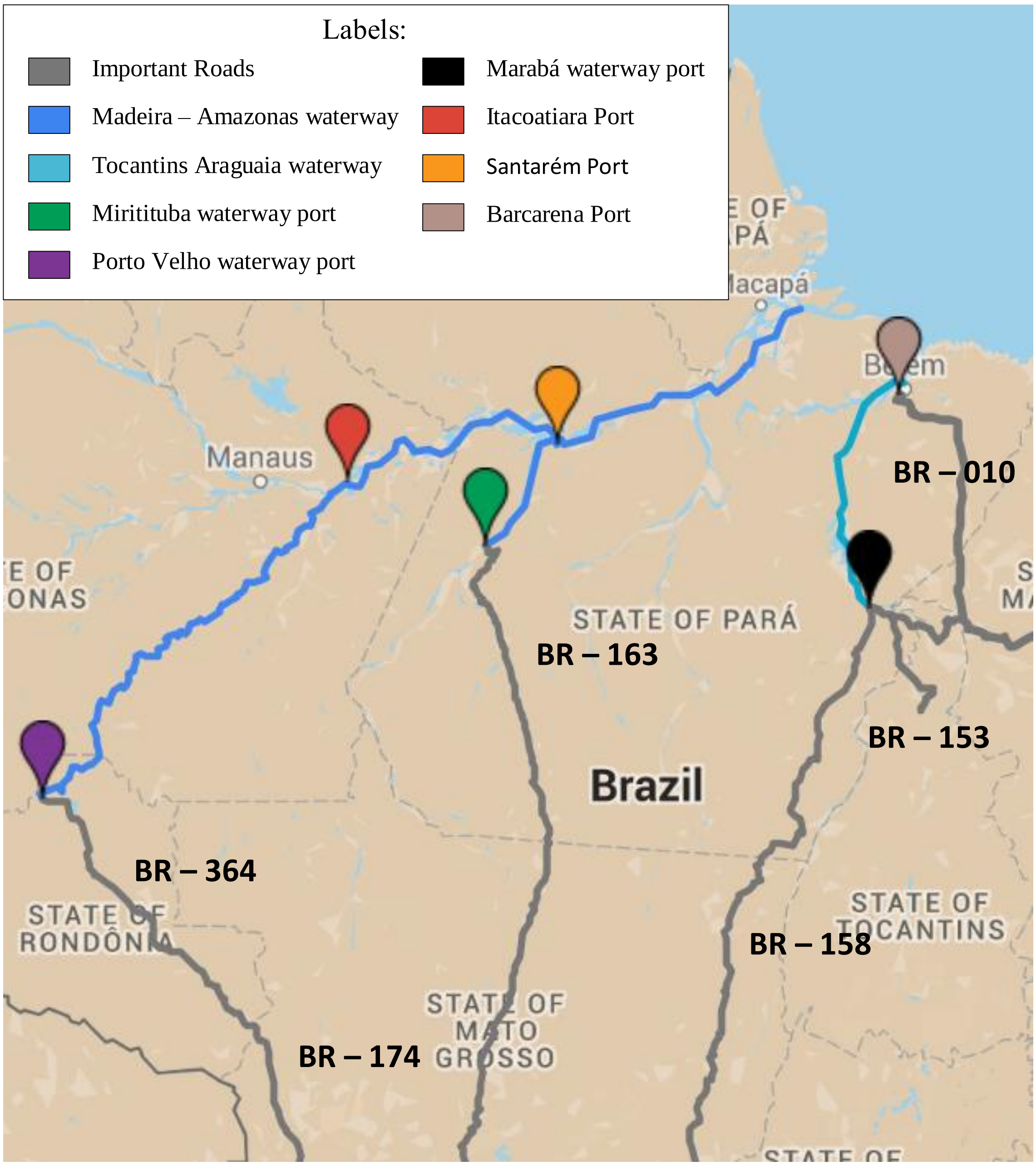

Figure 19 - North exports corridors

According to the map above, it is possible to observe that the grains need to travel long distances either through BR-158, BR-163 or BR-364/BR-174 in order to reach the river ports in Marabá, Itaituba (Miritituba) or Porto Velho respectively, from where the grain follows to Itacoatiara, Barcarena (Vila do Conde) or Santarém Ports. It is important to highlight that all these three routes have many unpaved parts. Besides that, the humid climate and the lack of maintenance are responsible for those roads bad conditions. As it is indicated by CNT (2014), all of the aforementioned roads have sections present among the ten worst roads in the country. This situation significantly increases the total freight costs through those ports.

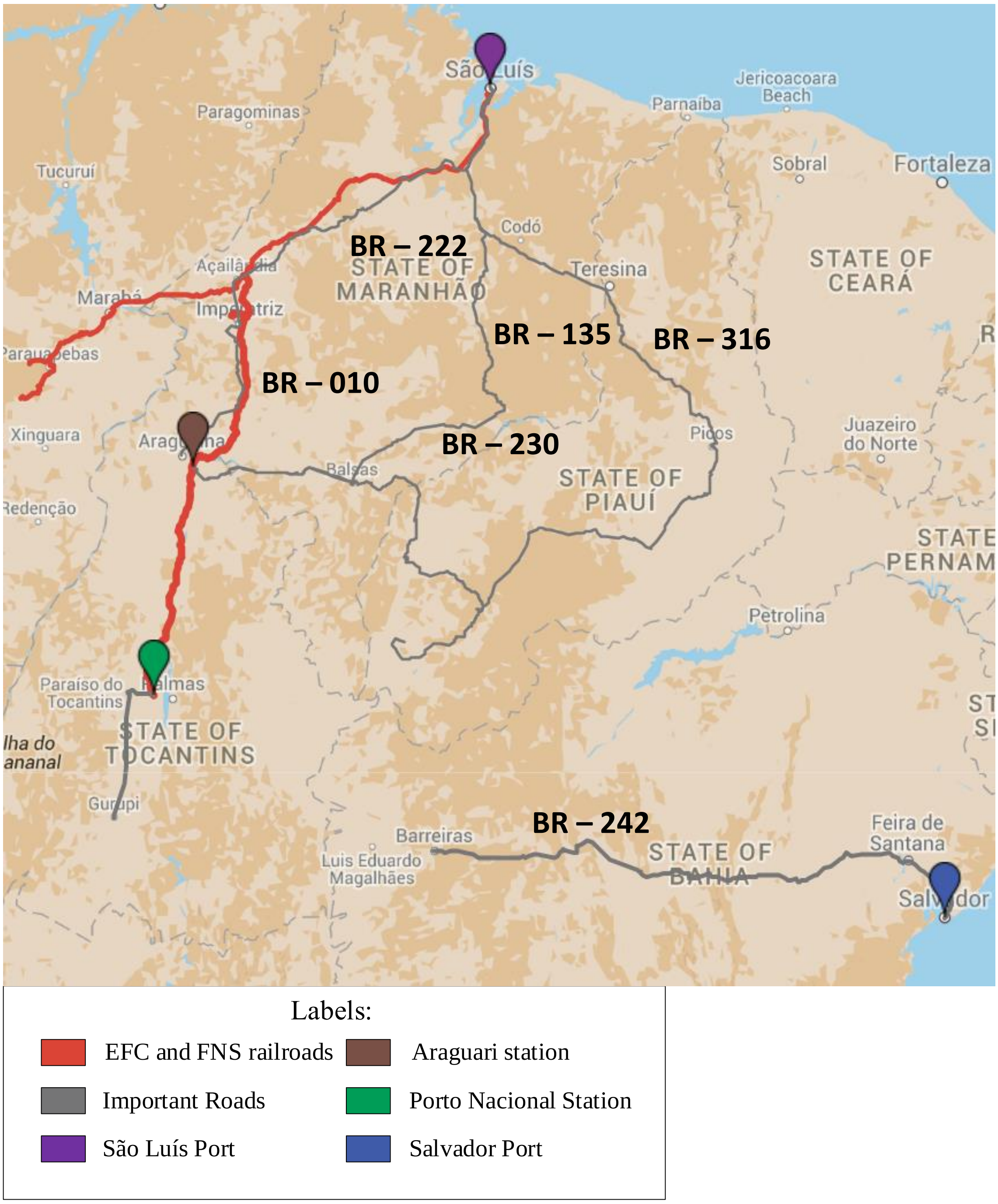

Figure 20 - Northeast export corridors

Finally, we have the Northeast export corridors, influenced by two ports: Salvador, which draws its cargo from the Eastern part of Bahia State through BR-242; and São Luís (Itaqui) port, which is accessed from Tocantins state through the EFC and FNS railroads, and from Maranhão and Piauí states through the roads BR-316, BR-135, BR-230 and BR-222. Due to the proximity in between the producing regions and their respective ports, this region has a competitive edge in terms of logistics costs if compared to other producing regions, such as the Midwest.

5.3 Logistic Costs

According to the logistic cost calculation proposed by Reis (2011), first it is necessary to identify the modals used and their respective tariffs per kilometer. In this context, we shall look more closely to the freight and transshipment prices of the modals used in the Brazilian grain industry, which are, in order of importance: roads, railroads and waterways. The modals, in order of importance are: Roads, Railroads and Waterways. Therefore, the model used to estimate each routes' costs consists in the sum of costs in each modal plus transshipment costs, taxes and inventory (if applicable).

Some of these costs are easily found online as Railroads operators have their fares fixed by law, they also present estimates of the average transshipment costs. On the other hand, fragmented companies, such as water and road transport companies, which do not disclose prices unless quotations are asked, give the prices provided for other means of transportation. Therefore, the accuracy and precision of each cost estimate may vary according to the abundance and public access to the prices data.

In the case of road costs, the pricing data was obtained through a monthly paid subscription to the Sifreca online database (ESALQ - LOG, 2015), which provided samples of freight costs each month during the entire year of 2015. All the data gathered was, then, inserted in a linear regression model in which prices were the dependent variable and distances the independent variable.

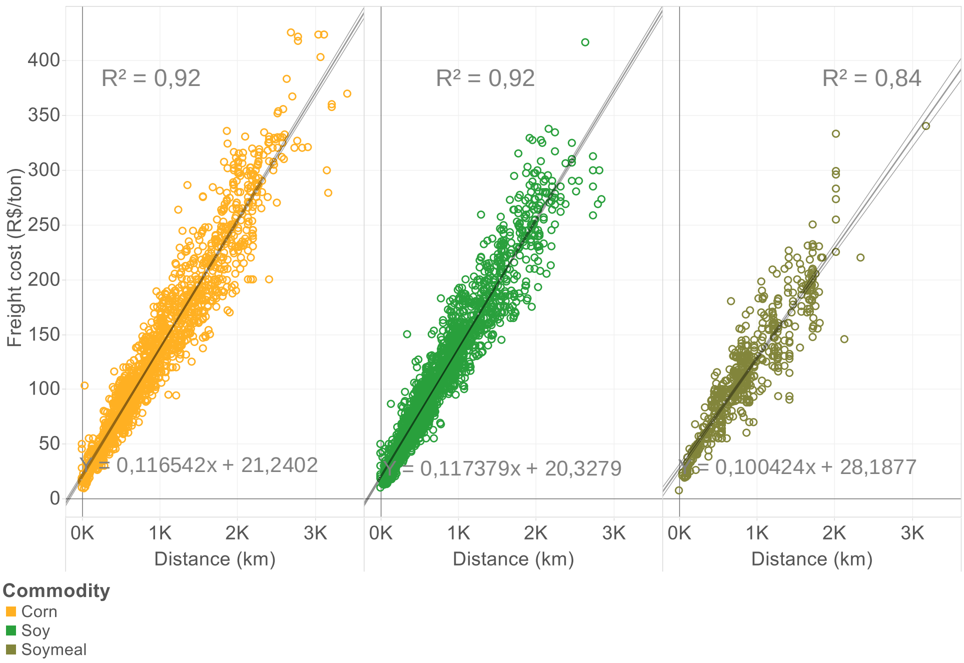

Chart 12 - Road freight coefficients estimation through regression analysis

The coefficients found were used to estimate the model's freight costs in roads, even though those parameters fail to identify other effects such as infrastructure quality, waiting times, probability of losses and the presence of synergies such as return cargo, that could contribute to increase or reduce freight. However, as demonstrated through the Chart 12, the regression model presented fits well the data analyzed. Still, this imprecisions must be taken into account when interpreting the results.

Finally, the road transportation costs were estimated by inserting the distances of the routes used into the model. The used routes will be determined by the infrastructure linking each producer or processing plants to the 3 closest ports and the 10 closest demand centroids in geodesic terms, still, additional ports and demand centroids may also be considered if distances are similar. These criteria generated a large number of routes, (1098 for soy meal, 1305 in the corn model and 811 for the soy model), therefore, an automated method to collect the distances was required, which motivated the development of a Google Maps API programed in VBA (source code in attachment 1). This method may generate other inaccuracies because, as routes were retrieved from Google Maps, it is plausible that some of them may not be in working conditions.

In the case of railroads, as it was already commented, fares are divulgated in the ANTT (2015) website through freight simulators, which calculate freights maximum prices based on distances between origin and destination stations. Those distances were calculated using the network declaration, also provided by each railroad operator in ANTT's website. Therefore, tables 1 and 2 below present railroad fares and the estimated distances between the most important terminals:

Table 1 - Estimated distances in between railroad terminals based on network declarations

Origin/Destination	Railroad	Vitória, ES	Santos, SP
Uberlândia, MG	FCA	1457	704
Pirapora, MG	FCA	1049	2479
Anapólis, GO	FCA	1791	1092
Araguari, MG	FCA	1411	757
Santa Luzia, MG	FCA	646	2076

Origin/Destination	Railroad	Santos, SP
Itiquira, MT	ALLMN	1353
Rondonópolis, MT	ALLMN	1492
Alto Taquari, MT	ALLMN	1140
Alto Araguaia, MT	ALLMN	1238
Chapadão do Sul, MS	ALLMN	1028
Pederneiras, SP	ALLMP	560
Campinas, SP	ALLMP	94

Origin/Destination	Railroad	São Francisco do Sul, SC	Paranaguá, PR
Rolândia, PR	ALLMS	718	612
Cascavel, PR	EFPO	955	736
Guarapuava, PR	EFPO	706	487

Origin/Destination	Railroad	Rio Grande, RS
Tupanciretã, RS	ALLMS	683
Girua, RS	ALLMS	888

Londrina, PR	ALLMS	738	631
Maringá, PR	ALLMS	758	652
Ponta Grossa, PR	ALLMS	354	230
Sarandi, PR	ALLMS	743	636

Origin/Destination	Railroad	São Francisco do Sul, SC	Rio Grande, RS
Cruz Alta, RS	ALLMS	1228,46	738
Passo Fundo, RS	ALLMS	1035	1134
Vacaria, RS	ALLMS	619	1137
Carazinho, RS	ALLMS	1174	1188
Julio de Castilhos, RS	ALLMS	1308	659

São Gabriel, RS	ALLMS	407
Santa Maria, RS	ALLMS	593
Estrela, RS	ALLMS	964
Cacequi, RS	ALLMS	482
Santo Ângelo, RS	ALLMS	846
Santa Rosa, RS	ALLMS	911

Origin/Destination	Railroad	São Luis, MA
Porto Nacional, TO	FNS	1245
Palmeirante, TO	FNS	973
Porto Franco, MA	FNS	722

Table 2 - Railroad fares for each operator, distance range and commodity

			Variable Fares (R$/t km)			
Railroad	**Product**	**Fixed fare (R$/ton)**	**0 to 400 (R$/ton km)**	**401 to 800 (R$/ton km)**	**800 to 1600 (R$/ton km)**	**greater than 1600 (R$/ton km)**
ALLMO	soy	17,860000	0,11196	0,10080	0,07817	0,05548
ALLMP	soy	29,630000	0,11112	0,11112	0,11112	0,11112
ALLMS	soy	16,950000	0,10580	0,09526	0,07387	0,05243
EFPO	soy	9,400000	0,08850	0,07970	0,07080	0,05310
FNS	soy	20,457114	0,06424	0,06424	0,06424	0,06424
ALLMO	soy meal	17,860000	0,11196	0,10080	0,07817	0,05548
ALLMP	soy meal	29,630000	0,11112	0,11112	0,11112	0,11112
ALLMS	soy meal	16,950000	0,10580	0,09526	0,07387	0,05243
EFPO	soy meal	9,400000	0,08490	0,07640	0,06800	0,05100
FNS	soy meal	20,457114	0,06424	0,06424	0,06424	0,06424
ALLMO	corn	17,860000	0,11196	0,10080	0,07817	0,05548
ALLMP	corn	29,630000	0,11112	0,11112	0,11112	0,11112
ALLMS	corn	16,950000	0,10580	0,09526	0,07387	0,05243
EFPO	corn	9,400000	0,08850	0,07970	0,07080	0,05310
FNS	corn	20,457114	0,06424	0,06424	0,06424	0,06424

			Variable Fares (R$/t km)			
Railroad	**Product**	**Fixed fare (R$/ton)**	**0 to 500 km (R$/ton km)**	**501 to 1000 km (R$/ton km)**	**1001 to 2000 km (R$/ton km)**	**greater than 2000 km (R$/ton km)**
FCA	soy	14,37	0,0706	0,0618	0,0530	0,0353
FCA	soy meal	13,93	0,0720	0,0630	0,0540	0,0360
FCA	corn	20,58	0,0737	0,0645	0,0553	0,0368

In addition to the fares charged, railway operators and port also charge fees related to the reception and expedition of cargo. For FCA, FNS railroad, this fee ranges from R$4,30 up to R$9,91 with average values ranging from R$5,94 to R$6,36 per ton of soy, corn or soy meal according to VLI (2015). As the reasons for those variation are not specified, the model will contemplate the average value of R$6,15.

Therefore, adding up all presented costs, we have the total cost model for railroads:

$$TR_{omjk} = F_{o0k} + TSS_J + \sum_a F_{oak}.min(max(D_{mj} - d_{a-1}, 0), d_a)$$

Where o represents the railroad operator, m represents the reception terminal, F_{o0k} is the fixed cost for the commodity k, D_{mj} is the distance in between the terminal m and the port j, F_{oak} is the fare charged by ton.km in the range a, in between d_{a-1} and d_a and TSS_J is related to transshipment costs.

Lastly, there are the waterway freight prices estimates. As already seen in the literature review, the relevant waterways in grains logistics are Tietê-Paraná, Tapajós, Madeira-Amazonas, and Tocatins Araguaia. Those prices are not accessible online, but ANTAQ has published online a list with contacts of all companies authorized to navigate Brazilian rivers (ANTAQ, 2015). After contacting those companies, one of them has responded with the fares in between São Simão, GO - Pederneiras, SP and Simão, GO – Anhembi, including transshipment costs. Those two fares were used to find the fixed and variable coefficients, and were then extrapolated to all waterways. The values found are consistent with the fact that waterways are, in general, more efficient than railroads and roads. The distances in each waterway were found using Google Earth measuring tools. Therefore, we have freights in the Table 3 below:

Table 3 - Waterway freight estimates

Origin	Destination	Waterway	Fixed Fare (R$/ton)	Variable Fare (R$/ton.km)	Distance (km)	Total (R$)
Sao Simao, GO	Pederneiras, SP	Tietê - Paraná	15,00	0,05	650	47,50
Sao Simao, GO	Anhembi, SP	Tietê - Paraná	15,00	0,05	800	55,00
Itaituba, PA	Santarem, PA	Tapajós	15,00	0,05	280	29,00
Maraba, PA	Santarem, PA	Tocantins - Araguaia	15,00	0,05	1220	76,00
Maraba, PA	Barcarena, PA	Tocantins - Araguaia	15,00	0,05	515	40,75
Porto Velho, RO	Itacoatiara, AM	Madeira - Amazonas	15,00	0,05	1100	70,00
Porto Velho, RO	Santarem, PA	Madeira - Amazonas	15,00	0,05	1620	96,00

Concerning storage costs, applicable only to ports in this work, we shall continue to use the model presented by Reis (2011), in which total inventory costs are the sum of the costs related to management $SMC_i$and the cargo opportunity cost OC_i. Some ports also divulgate specific values per ton for the reception, storage (for up to 30 days) and expedition of grains (SMC_i), as we can see in the table 4, in the next page. As those values do not vary much and are in line with the storage costs presented by CONAB (2016), average values per ton shall be extrapolated to all ports. For the opportunity cost OC_i, as it is a product of the cargo value $V_{jk}(t)$ (or $Pint_k$), the time it remains stored Δt, and a real interest rate r of 6%, which is similar to the premium paid by the government bonds indexed to inflation in Brazil (2015).

Table 4 - Reception, storage and expedition costs at ports (R$/ton)

Port/Terminal	Region/ City	Min soy (R$/ton)	Max soy (R$/ton)	Min corn (R$/ton)	Max corn (R$/ton)	Min soy meal (R$/ton)	Max soy meal (R$/ton)	Additional storage costs	Source
Terminal de Cotegipe	Salvador, BA	40,22	52,29	40,22	52,29	41,38	53,8	R$5,75/ton per 10 days after 20 days in stock	Porto Cotegipe, 2015
Terminal Cargill	Paranaguá, PR	34,00	40,00	34,00	40,00	38,00	45,00		Cargill, 2015
Terminal Bianchini	Rio Grande, RS	29,00	30,00	36,00	37,00	35,00	36,00	R$6,30/ton per 15 days after 30 days in stock	Bianchini, 2015
Terminal de Granéis do Guaruja	Santos, SP	33,00		33,00		37,00			TGG, 2015
Terminal de Tubarão	Vitória, ES	40,00		40,00		40,00			Vale, 2015
Average		37,15		38,55		40,31			

Considering the way fares are proposed, we have the total Stock Costs defined below:

$$IC_k = SMC_i + Pint_k(t) \times \Delta t \times r + \max(0, \Delta t - at) \times ASC$$

Extrapolating the contract proposed by Terminal Bianchini (2015) to other ports, we have agreement at time of 30 days, and the Additional Stock Cost ASC of R$6,30 every 15 days, and the SMC_i, which is the cost related to reception, storage and expedition of grains for the first 30 days.

Therefore, we have the total logistics costs:

$$TTC_{ijk} = TR_{omjk} + TRo_{ijk} + TW_{ijk}$$

$$TLC_{ijk} = (TTC_{ijk} + IC_k)/(1 - TX_{ij})$$

Where TTC_{ijk}, TR_{omjk}, TRo_{ijk} and TW_{ijk} are the total transportation cost and transport costs by railroads, roads and waterways respectively and TX_{ij} is related to tax rates, depending on the origin and destination according to the ICMS table (Brazil, 1996).

5.4 Soy meal Production and soy bean demand

As soy processing plants are, by far, the main destination of soy beans, both production of soy meal and demand for soy are naturally linked, so, one of the outputs of the soy model is an input of the soy meal model and the soy meal production in time could be estimated after quantifying the geographic distribution of soy demand. Therefore, we have the relationship:

$$Prd_{ik_{sm}}(t) = c.\min\left(\frac{C_{jk_s}(t)}{dt}, D_{jk_s}\right),$$

Where: $i = j, k_{sm}$ and k_s represent soy meal and soy, respectively, and $c = 76\%$, which is the percentage in between the quantity of soy processed and the soy meal produced according to ABIOVE (2015).

In order to estimate the geographic distribution of soy processing plants, it is necessary to find plants capacities and their locations. That information can be accessed through an oleaginous plants processing capacity ranking by city in Brazil published in 2011 by ABIOVE (2011). As ABIOVE also publishes total processing capacity by state every year (ABIOVE, 2015), the 2010 ranking could be updated with the presumed capacity of each city for 2015, as shown in the figure below:

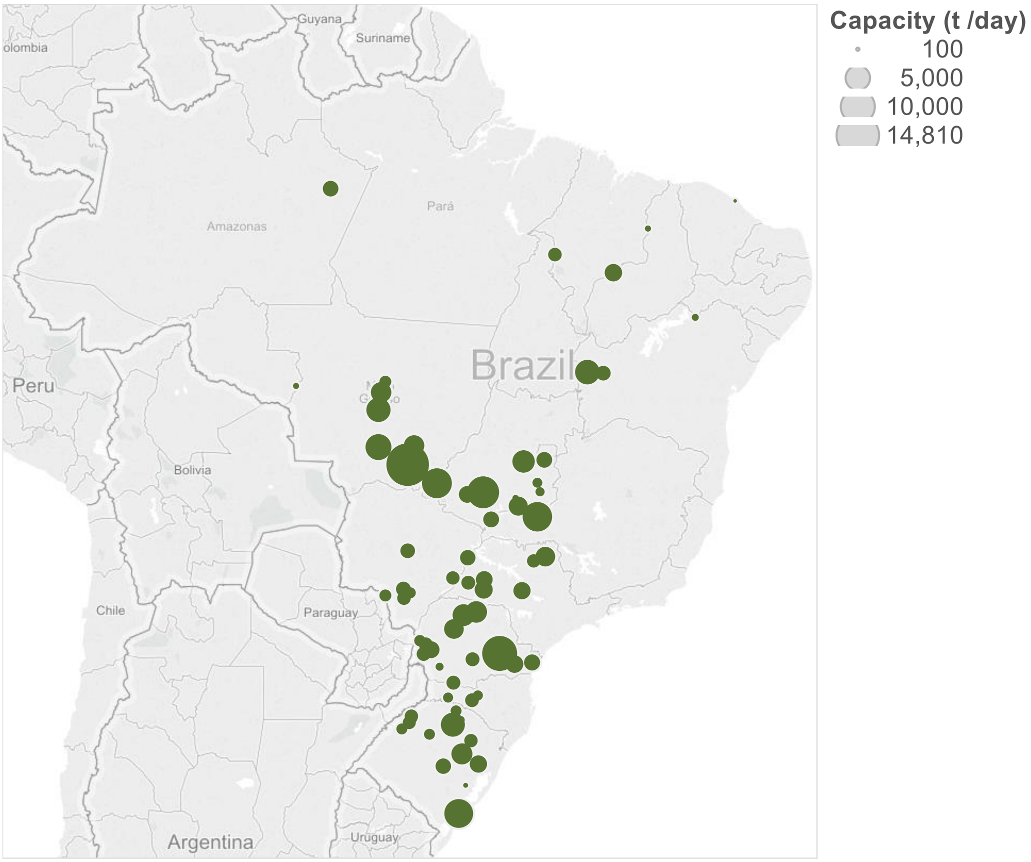

Figure 21 - Brazil's soy processing capacity distribution estimate

5.5 Corn and soy meal demand

Following the same approach used for the production of soy and corn, first, the main drivers of soy meal and corn consumption were identified and mapped, as presented in the chapter 3. So, according to Abimilho (2015), Sindirações (2015) and ABIOVE (2015), we have the 2014 and 2015 balance for those products in the following table:

Table 5 - Balance for soy meal and corn in Brazil

M tons	Corn		Soy meal	
Supply	**2014**	**2015**	**2014**	**2015**
Initial Stocks	**14,08**	**17,88**	**0,99**	**1,12**
Total Production	**82,76**	**86,20**	**28,75**	**30,77**
Imports	**0,79**	**0,37**	**0,00**	**0,00**
Use of substitutes	**2,00**	**2,00**	**0,00**	**0,00**
Total Supply	**99,63**	**106,45**	**29,74**	**31,89**
Demand	**2014**	**2015**	**2014**	**2015**
Animal Feeding	**47,18**	**49,45**	**14,10**	**14,54**
Poultry	27,44	28,65	8,84	9,05
Pork	12,56	13,25	3,28	3,45
Cattle	3,98	4,16	1,60	1,65
Others	3,21	3,40	0,39	0,39
Industrial / Human Use / Others	**13,91**	**14,75**	**0,70**	**1,47**
Exports	**20,66**	**28,92**	**13,82**	**14,80**
Final Stock	**17,88**	**13,33**	**1,12**	**1,08**
Total Demand	**99,63**	**106,45**	**29,74**	**31,89**

Combining the data above with the population split by city according to the 2010 census, and the animal population split by city (IBGE, 2015), it is possible to infer the total corn and soy meal consumption by city. Those values were then aggregated in 72 the centroids shown in the map below, in order to reduce software and hardware requirements to run the model

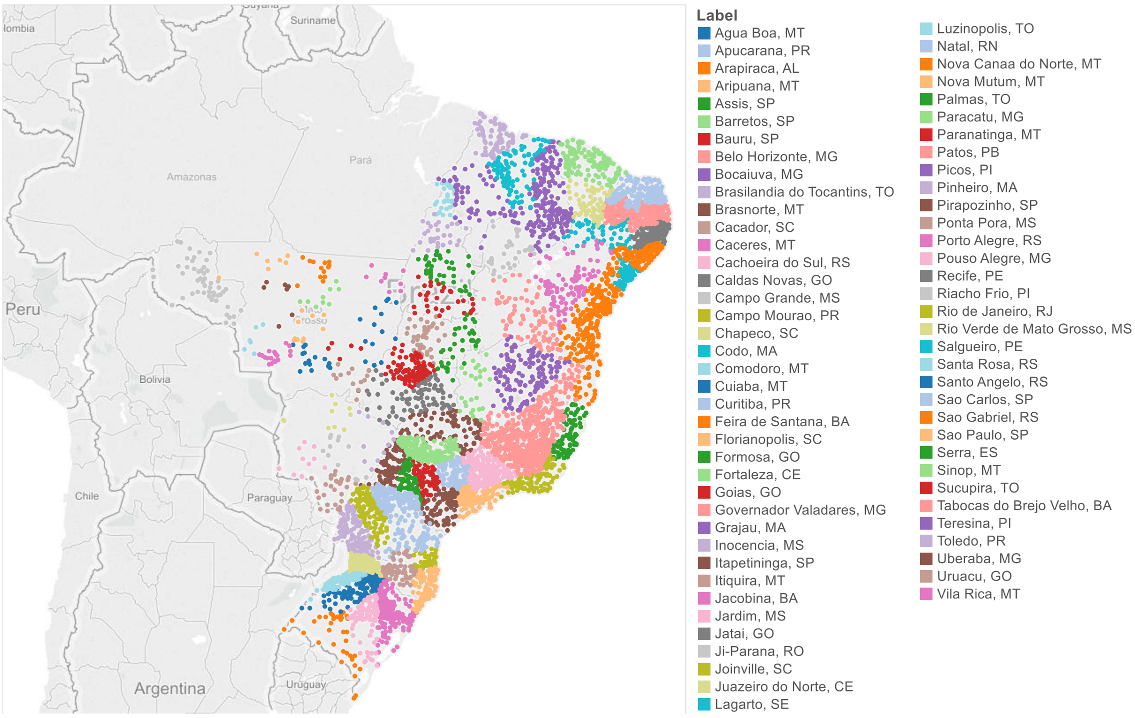

Figure 22 - Centroids used to concentrate soy meal and corn demands

From the centroids used, we have the geographic distribution of soy meal and corn demands across the Brazilian territory in the following maps:

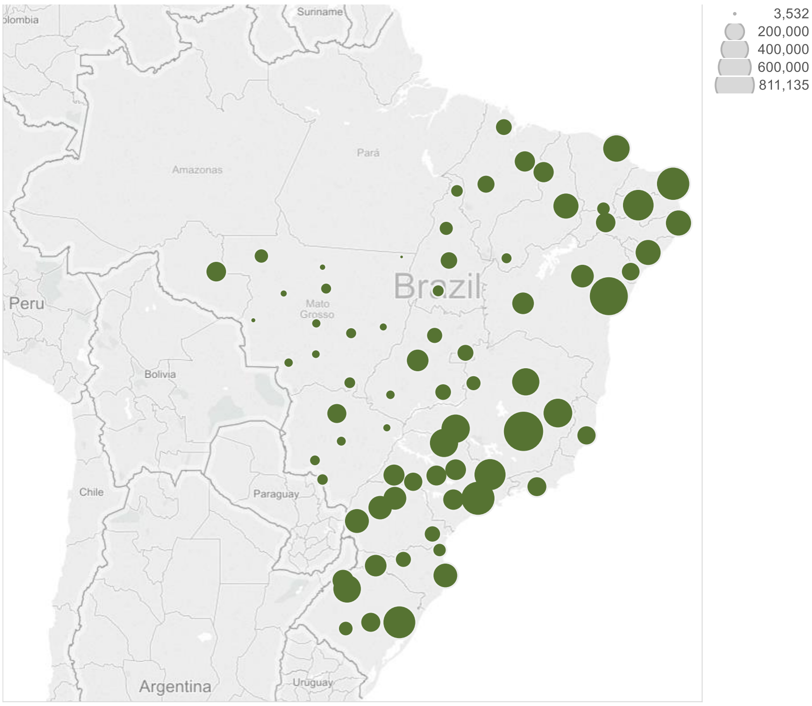

Figure 23 - Soy meal yearly potential demand estimated distribution

As both commodities have basically the same consumption drivers, it is noticeable that both distributions are quite similar, being more concentrated in the coastal area. Additionally, those two maps cover 95% of all combined potential demand.

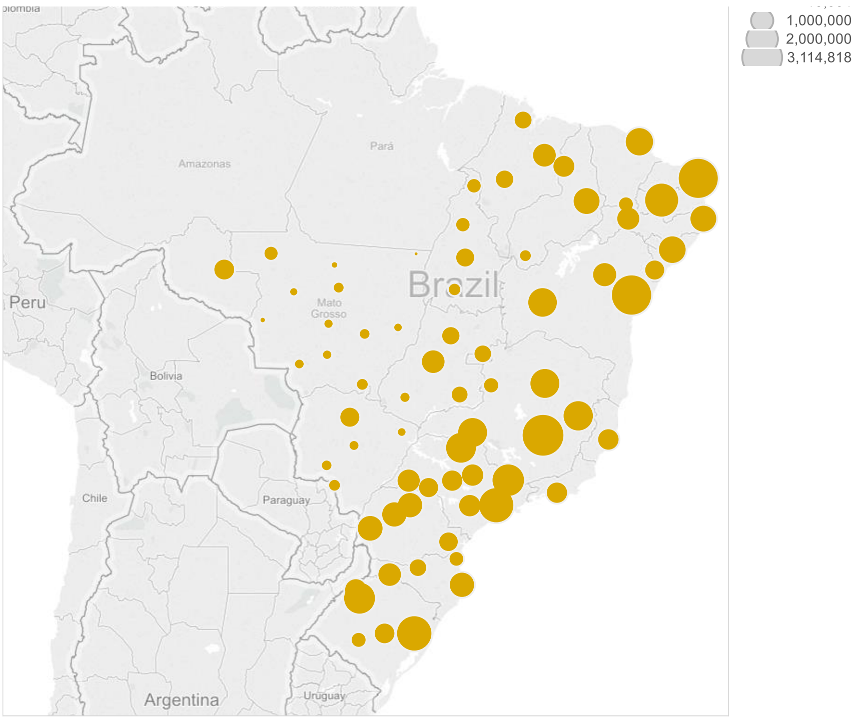

Figure 24 - Corn yearly estimated potential demand estimated distribution

Those estimations do not take into account average corn/soy meal consumption by animal, which varies across geographies according to many factors, such as land availability for pastures, use of intensive or extensive animal creation, repressed demand, use of substitute products and climate, as animals are raised indoors during cold periods. Therefore, the rates of consumption will be defined as follows:

$$D_{jk} = A_{jk}.ED_{jk}$$

Where ED_{jk} is the estimated demand already presented in the previous maps, k refers to corn or soy meal and A_{jk} is an arbitrary adjustment variable that fluctuates around 1,0, being slightly higher in states with more intensive animal creation.

5.6 Ports capacities

For the purpose of this work, we shall consider ports as the only way in which crops are exported as they account for approximately 99% all grain exports (SECEX, 2015). Nevertheless, it is still possible to eliminate the ports with the lowest representability, thus simplifying the model without significant losses in reliability by covering 98% of all exports. The map below identifies the geographic location of the ports considered and an estimation of their hinterland based on the origin of previous exports, as such, each city on the map was colored based on the port with the biggest share of grains exported, according to SECEX (2015), in all cities in a 200 km radius:

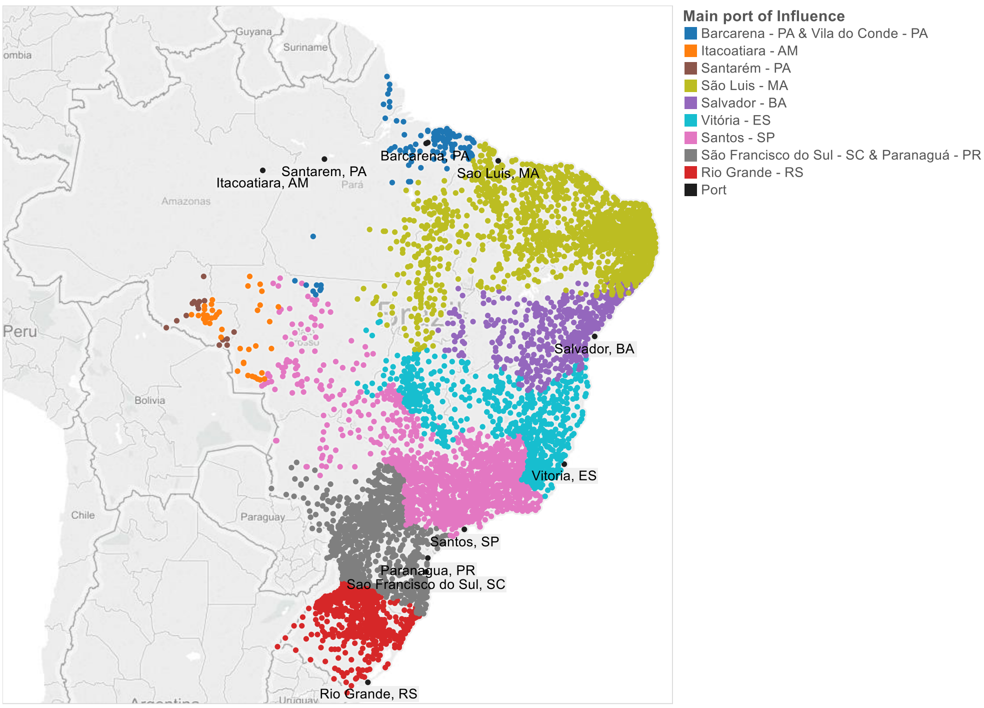

Figure 25 - Ports' hinterlands

ANTAQ (2015), has provided data and indicators through SIG, in its website, enabling a deep analysis of Brazil's ports in order to estimate their capacities. One interesting insight about ports' capacity estimation is that 30 berths transport around 88% of all grain exports. Those berths also work almost exclusively with the grains studied (95%), as we can see in the chart below. Therefore, to assume that there is no interference of other products in the ports capacities is reasonable.

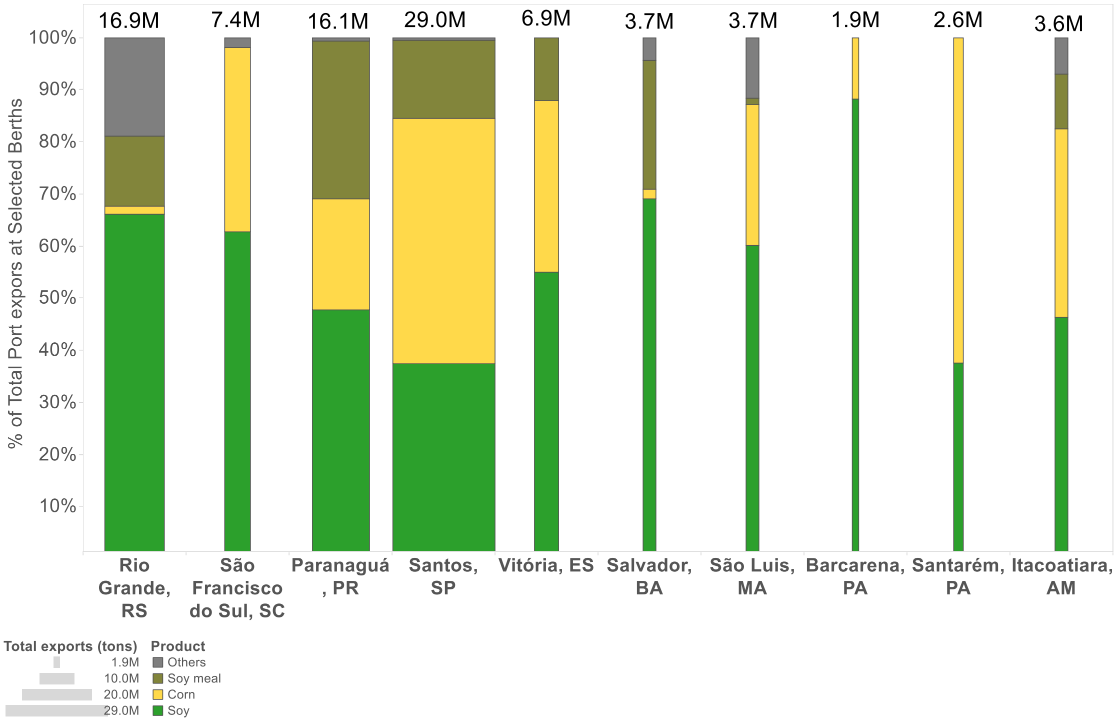

Chart 13 - Exports by product and port at selected berths, elaborated with data from ANTAQ 2015

In order to define the capacity of a port, it is necessary to define the capacity of its bottleneck, which can be attributed to many causes such as deficient port access, handling equipment, lack of storage space and personnel, among others (Adam, 2009). During peak season, as the bottleneck works at full capacity, the port output gets close to its potential (ESALQ - LOG, 2014); therefore, it is a reasonable assumption that the average slope of the curve of the accumulated exports can approximate the port capacity over time during the peak months. Following this approach for the São Francisco do Sul (the remaining estimates will be shown in the attachments), we have its peak months in July and August, according to the Chart 14:

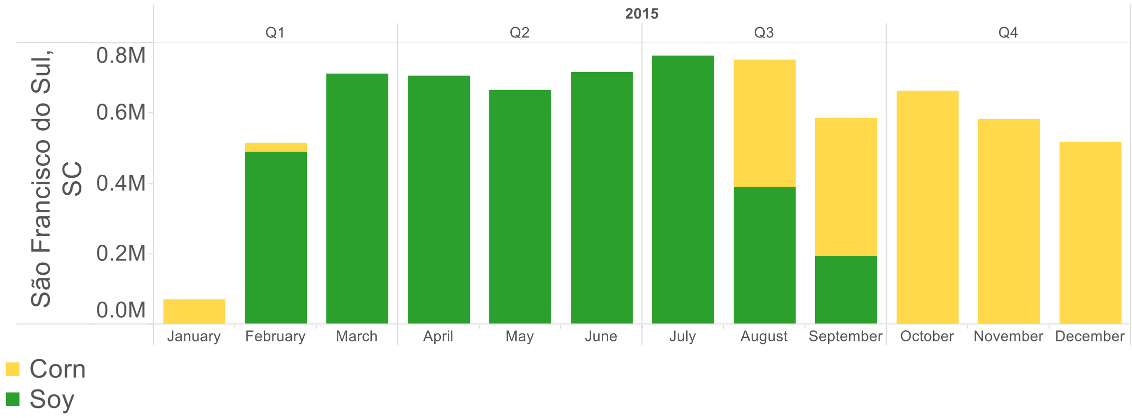

Chart 14 - São Francisco do Sul's port grain exports by month (ANTAQ, 2015)

Using this information, we can plot its accumulated exports during peak months and estimate its capacity using a linear regression analysis as we can see in the Chart 15:

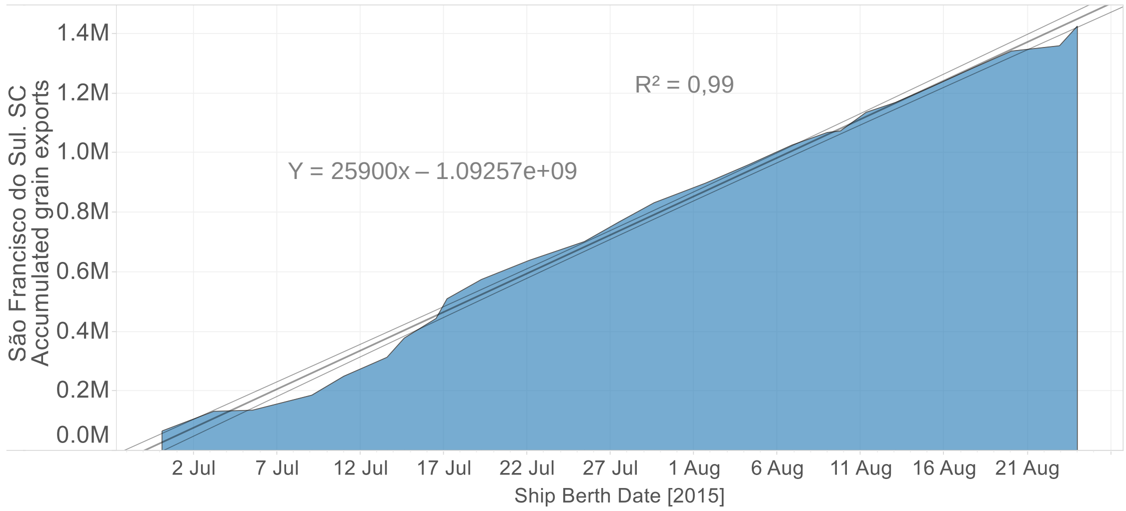

Chart 15 - São Francisco do Sul's port capacity estimation, elaborated with ANTAQ, 2015

5.7 Consumer's target stock and Pricing parameters

The objective of this part of the model is to mimic the stock regulation of consumers as those players would act through prices in order to prevent shortage of products. As those products' demands are quite inelastic (there are no competitive substitutes up to a certain price), it is reasonable to estimate the demand curve through an S-curve where the maximum and the minimum values are related to historic peaks and valleys.

The target stock variable would be considered as the desired stock level at the eyes of the consuming cities. Assuming a constant use of resources, it would have its bottom at the beginning of the harvest and increase linearly until it peaks at its end, then it would decrease until the next harvest starts but never falling below a safety stock parameter, therefore, the target stock formula is defined by:

$$EI_{jk}(t) = \left(\frac{(t - t_{0jk})(365 - t_{fjk} + t_{0jk})}{t_{fjk} - t_{0jk}} + SS\right) D_{jk} \text{ if } t > t_{0jk}$$

Else:

$$EI_{jk}(t) = (t_{0jk} - t + SS) D_{jk}$$

In the other case, as soy meal production is almost flat:

$$EI_{jk}(t) = SS.\, D_{jk}$$

Where t_{0jk} and t_{fjk} are the first and last harvest days for commodity k and SS is the safety stock parameter, which ranges from 10 to 35 days.

6 MODEL IMPLEMENTATION AND VALIDATION

The conceptual model in the fourth chapter presents commodity and information flows in a simple supply chain spread geographically. In the following model, this simple structure is reproduced in such way to represent the flows of multiple products with dependency and interference relationships as shown in the Figure 26 and Figure 27.

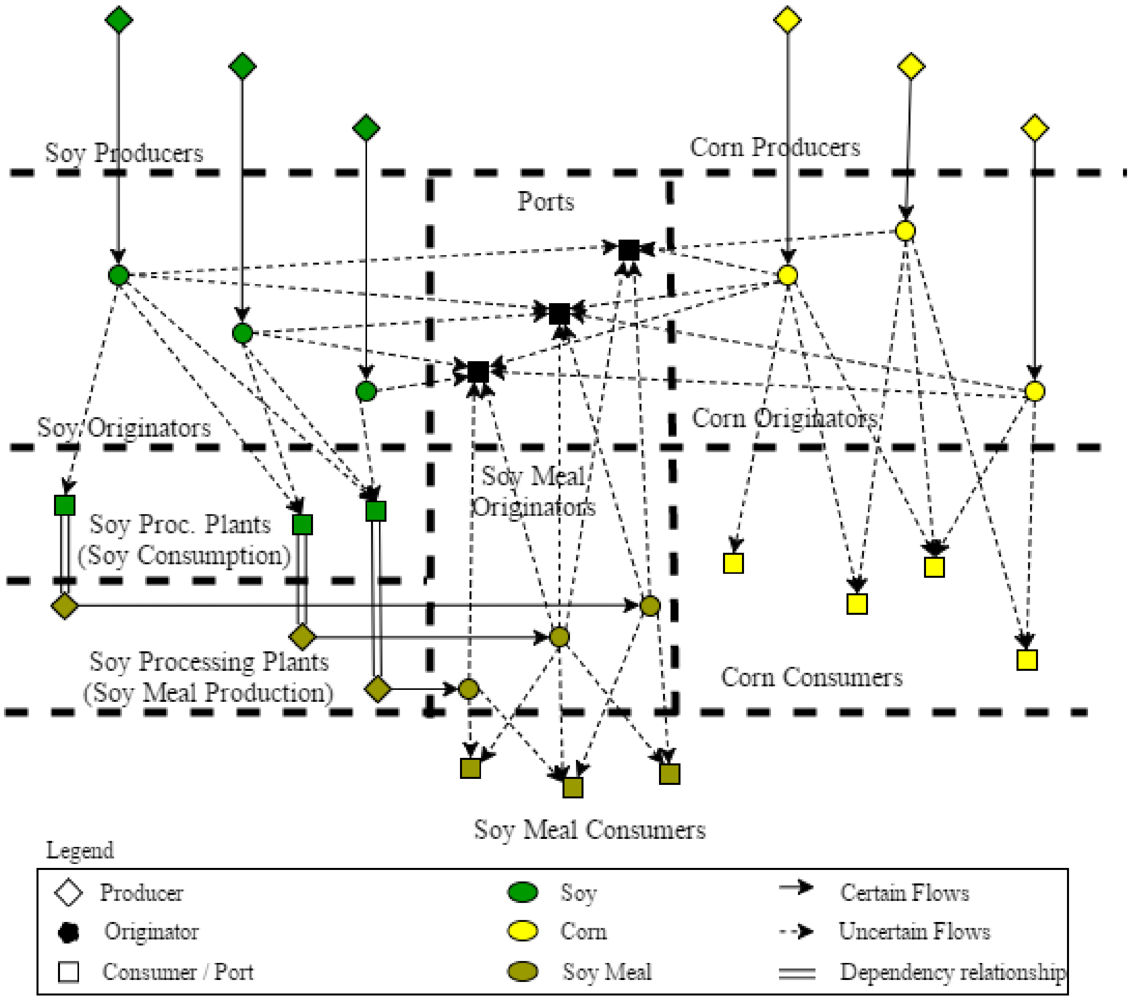

Figure 26 - Commodity flows in the consolidated model

The flows presented in Figure 26 show the relationships already explicated in the introductory chapter, pointing that soy processing and soy meal production are directly linked, moreover, there is a mutual interference relationship at the ports, because this is the main shared bottleneck for the mentioned commodities. In addition, the flows in the represent the information flows in Figure 27, detailing the price feedbacks that exist in between ports, processing industries, corn and soy consumers and the originators.

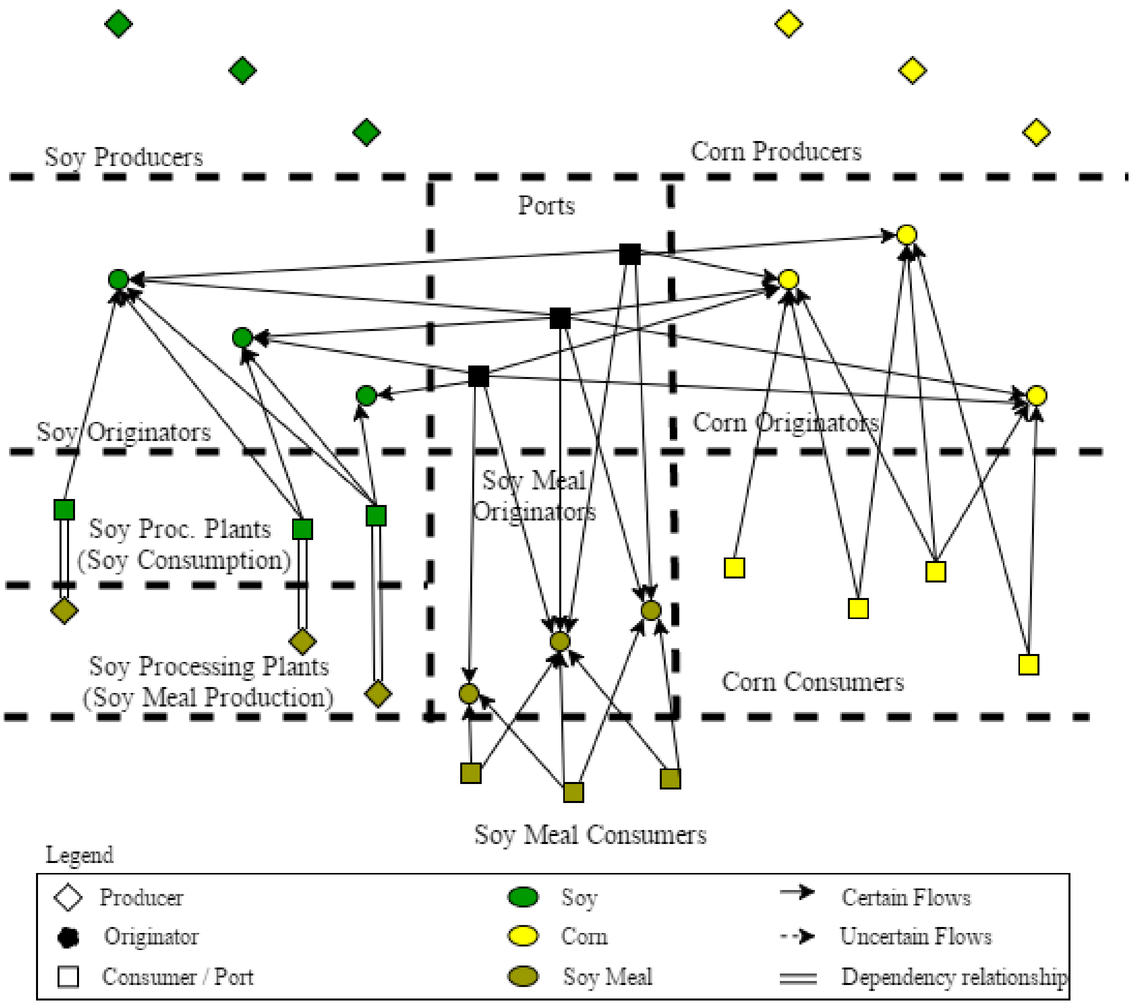

Figure 27 - Information flow in the consolidated model

Finally, the algorithm used to model all agents' actions and decisions is shown in the flowchart in the Figure 28, in the next page. This algorithm translates the conceptual model into programmable steps, therefore, enabling the reproduction of it in a computational model. In this case, the model was implemented with spreadsheets, using Excel 2013. The model time frame is the entire year of 2015 and each computed time step represents a day. Even though local commodity prices are very dynamic, the chosen time step is appropriate because it is not long enough to significantly distort agents' decisions, while maintaining the computational complexity at an acceptable level.

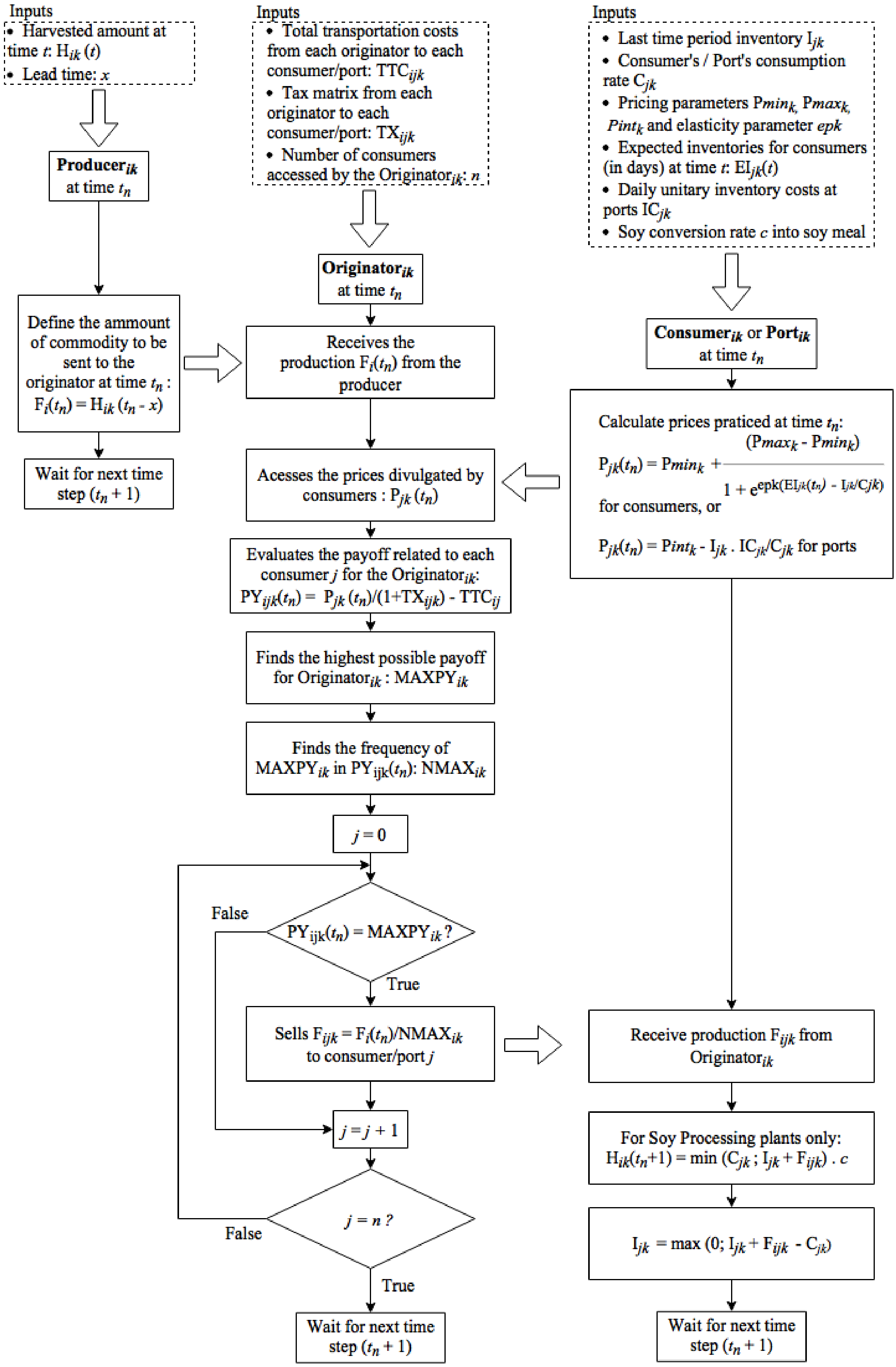

Figure 28 - Algorithm proposed for the Agent Based Model

6.1 Model Validation

The model was validated through the opinion of specialists of the grain sector; this process took place by presenting the work to Guilherme Bastos and Celso Roseghini Lopes, Market Intelligence Manager and Market Intelligence Coordinator at Multigrain S.A. These experts gave their opinions about the model, validating assumptions and indicating possible improvements. They have also validated and commented the model mechanism at the micro level, which is the main objective of this chapter.

Considering the behavior of the producers, the model assumes that they behave as if the production was previously sold through future contracts before the models start. In this case, producers automatically transfer their harvests to originators instead of storing it. Therefore, the stocks in the model are concentrated at ports and end users. This was the main assumption criticized by Roseghini and Bastos, because, even though this represents about half of the grain market, producers do store part of their production depending on future market's prices. Therefore, this assumption may have some impacts over the model's lead times and minor impacts over grain allocation. As such, in order to consider this mechanism, the model would have to take into account future market prices and transportation prices elasticity as those two variables are main drivers for producers to decide whether to store grains or not. This mechanism was not incorporated in the model because the additional complexity would imply in major software and hardware modifications.

In terms of origination, ports and consumers, both Roseghini and Bastos agreed with the agent's behaviors. Originators do make their decisions based on the price and freight cost trade off, deciding to sell their grain where it would have the largest margin. Ports act passively, but the value of a certain grain at a port tends to decrease as congestions increase. Finally, consumers tend to increase their inventory positions during the harvest season in order to do not run out of grain during the rest of the year, but there is a price threshold at which consumer's operations become unprofitable and they run out of grain, stopping their processing plants or using alternatives to feed their animals.

Roseghini and Bastos also have given important inputs in terms of the emerging behavior of the model. Even though a path dependent tax system contributes for the deindustrialization of the soy sector, other factors have to be taken into account in order to evaluate the potential of growth of this industry. As such, it is not clear if there is space for additional soy meal in the

Brazilian market because it depends on how other countries will choose to supply their meat market in the future.

6.2 Preliminary results and Model Calibration

The model's emerging behavior was validated by comparing it with data concerning real grain flows, as such; SECEX (2015) provides a good documentation of the grain destined to exports. This process used two scenarios; a preliminary scenario, which uses the results given by the model with no adjustments and a base scenario, built by a calibration process in which routes would receive bonuses or penalties in order to approximate its output to the real data. The justification for this process is the presence factors not captured by the model, such as infrastructure quality, return cargo, local tributary particularities, among others. The model validation and calibration were made by comparing the export's over time, as seen in the Chart 16, and port's influence areas in Figure 29, Figure 30 and Figure 31 and exports in Table 6, Table 7 and Table 8 below.

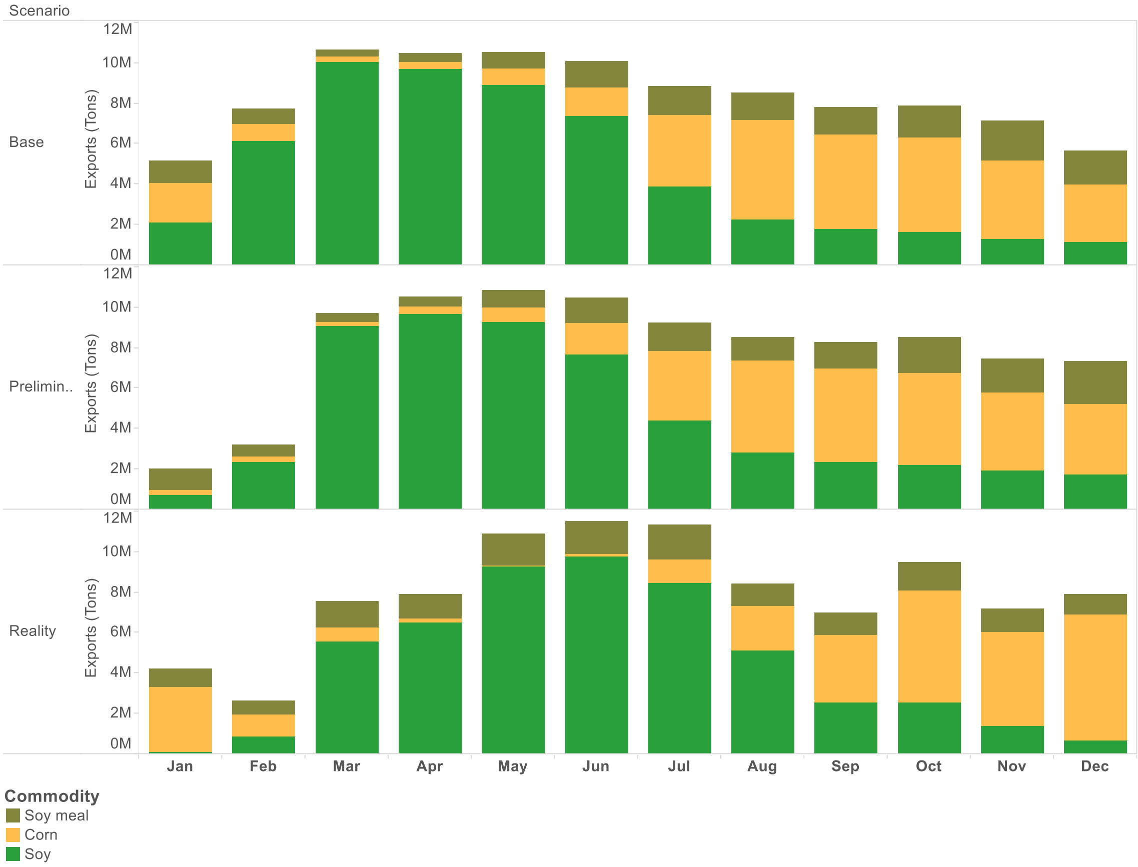

Chart 16 - Brazilian aggregated exports of soy corn and soy meal provided by SECEX and the model

The chart above presents the profile of Brazilian exports according to both modeled scenarios and the actual exports (SECEX, 2015). Observing that the model is not accurate at considering delays and transportation lead times, a time gap in between the model and the reality is expected. As such, there is one month of difference in between the scenarios and the reality. The modeled and displaced profiles are quite similar as they reach a plateau, from March to June or May until July, when ports operate at close to their maximum capacities, what is followed by a gradual decrease in exports until December. The curve presented by SECEX also shows a steeper and more variable decline in exports than the modeled ones. This is due to the fact that the model does not consider climatic conditions that affect Southern ports' performance (Northern ports are covered against rain), especially during the rainy season from September to March.

Moreover, in order to make a more comprehensive analysis of the models outputs, it is adequate to compare the geographic profile of Brazilian exports, as observed in the tables and figures below. The figures were built by considering the port with the highest share on grain exports in a 200 km radius for each Brazilian city. This analysis was also used to calibrate the Base scenario incorporating factors not considered previously, giving it a similar hinterland configuration to the presented on the reality.

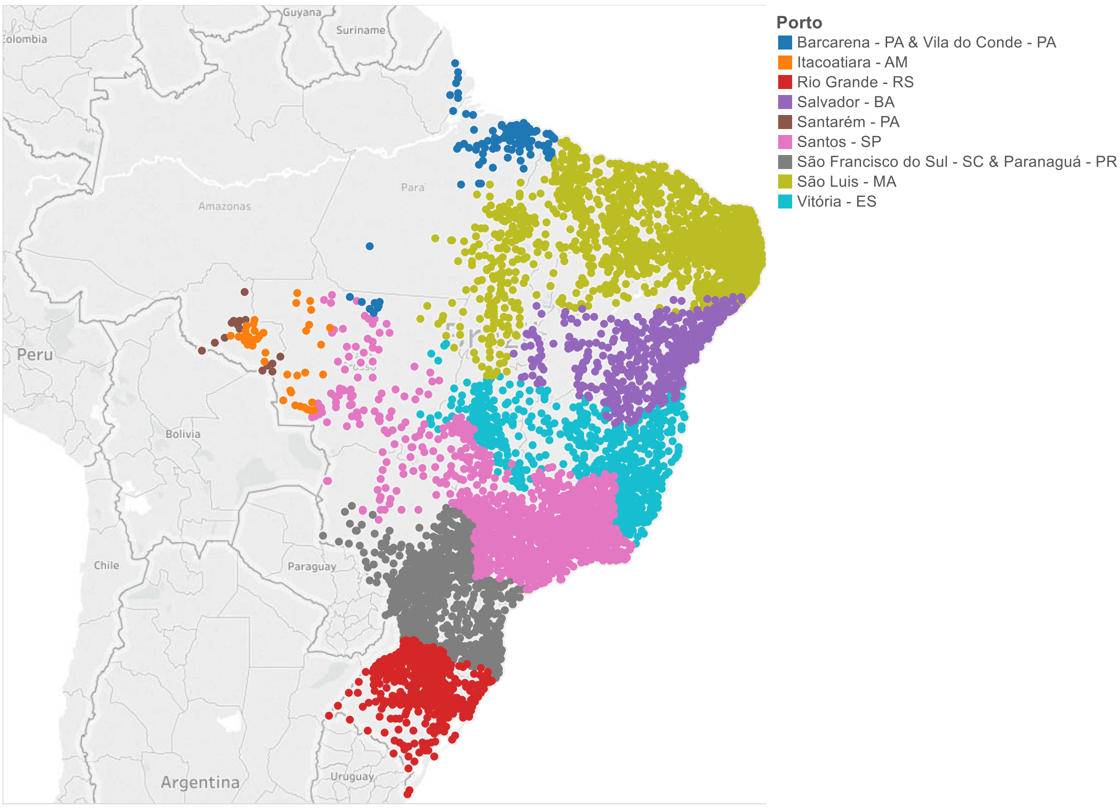

Figure 29 - Port's Influence areas elaborated with data from SECEX (2015)

The Figure 29 above shows an approximation of each port's hinterland, these areas are a reflex of the current port's access infrastructure. For instance, São Luis's port and Vitória's port receive great influence form FNS and EFVM railroads. In addition, it is possible to the reach of Santos's port given by ALLMN railroad and Tietê-Paraná waterways. As such, the calibration process shall try to reproduce the same patterns in the base scenario.

Table 6 - Exports by crop and port according to SECEX (2015) (k tons)

Port	Soy	Corn	Soy Meal	Total
Itacoatiara, AM	1.654	1.228	464	3.345
Barcarena, PA	2.198	578	0	2.775
Santarem, PA	1.027	1.648	0	2.676
Sao Luis, MA	4.745	2.045	139	6.929
Salvador, BA	2.605	74	1.001	3.681
Vitoria, ES	3.624	2.357	852	6.833
Santos, SP	13.081	13.240	4.296	30.617
Paranaguá, PR & S. Francisco do Sul, SC	12.737	6.851	5.376	24.965
Rio Grande, RS	11.029	379	2.695	14.103
Total	52.700	28.401	14.824	95.925

The table above reproduces the exports at each port, providing a quantitative input to the map representing the hinterlands in the last page. It is noticeable that exports are concentrated on southern ports, as Rio Grande, Paranaguá, São Francisco do Sul, Santos and Vitoria represent 80% of all exports. Moreover, exports are concentrated on soy exports representing 55% of the total.

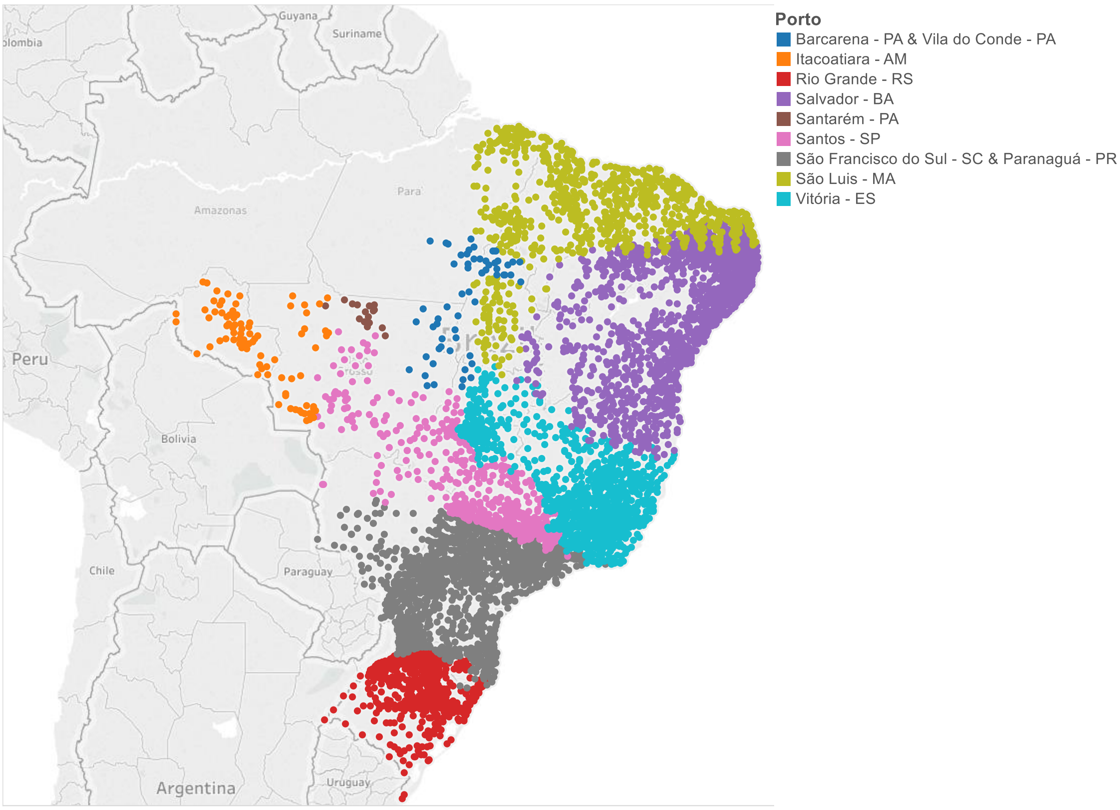

Figure 30 - Ports' influence areas according to the preliminary scenario

Comparing Figure 29 and Figure 30, we can observe similar patterns in terms of ports influence areas, nevertheless, Santos loses some influence to Paranaguá port, and northern ports became more representative, as we can see by comparing Table 6 to Table 7 below. This difference is explained mainly due the fact that the model does not considers infrastructure quality, as such, according to the Confederação Nacional do Transporte (CNT, 2015), the North region (ports of Itacoatiara, Santarém and Barcarena) presents 24% of its roads in good or excellent condition, which is close to half of the National average of 43%. On the other hand, the Southeastern region (Santos and Vitoria ports) and Paraná state (Paranaguá port and access to São Francisco do Sul port) have 56% and 48% of their roads in good or excellent condition, respectively.

Table 7 - Exports by crop and port according to the Preliminary scenario (k tons)

Port	Soy	Corn	Soy Meal	Total
Itacoatiara, AM	2.753	1.980	502	5.235
Barcarena, PA	2.562	884	12	3.459
Santarem, PA	2.051	1.115	218	3.383
Sao Luis, MA	4.167	1.090	154	5.411
Salvador, BA	3.534	1.006	838	5.378
Vitoria, ES	3.304	2.220	896	6.420
Santos, SP	13.515	10.823	5.230	29.568
Paranaguá, PR & S. Francisco do Sul, SC	13.314	8.090	4.422	25.826
Rio Grande, RS	8.920	649	1.649	11.217
Total	54.119	27.858	13.921	95.898

The situation explained above justifies the calibration process, which penalizes routes conducing to northern ports and gives bonuses in terms of freight costs. To be more specific, routes going to the Nothern Ports (Itacoatiara, Santarém and Barcarena) have received penalties ranging from R$ 70,00 until R$ 110,00 per ton depending on the crop and port, while Southern ports (Santos, Rio Grande, Paranaguá, São Francisco do Sul and Vitoria) have received freight costs reductions up to R$ 30,00. This calibration process also balances the effect of the presence of return cargo in such ports as Paranaguá, Santos, Vitoria and Rio Grande have terminals dedicated to imports of fertilizers and their inputs (ANTAQ, 2015) with considerable volumes. These materials are, then, transported to fertilizers processing plants or farms in the Midwest region using the same kind of containers used to transport soy, corn and soy meal, increasing those routes efficiencies and decreasing their costs, therefore, increasing the mentioned ports output.

Finally, we have the final scenario below, which derived from the adjustments given to the preliminary scenario, presenting a hinterland configuration closer to the one shown on Figure 29 as the influence of ports such as Itacoatiara, Barcarena and Santarém decrease, while southern ports gain importance.

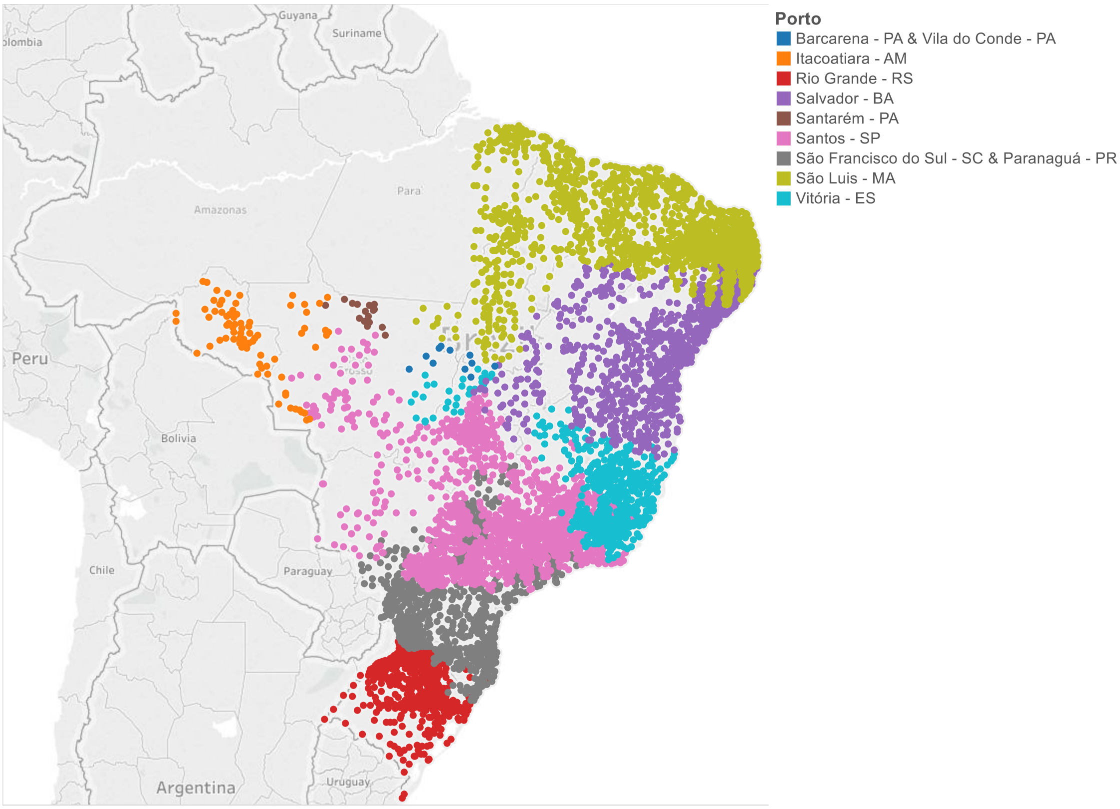

Figure 31 - Ports' hinterlands according to the Base Scenario

Furthermore, even though exports presented in Table 8 are slightly larger and the numbers previously indicated, its proportions are closer to the one presented on the Reality in Table 6 than the one given by Table 7 in the preliminary scenario. Therefore, this will be the scenario used to evaluate the effects of the ICMS the soy supply chain.

Table 8 - Exports by crop and port according to the Base scenario (k tons)

Port	Soy	Corn	Soy Meal	Total
Itacoatiara, AM	1.699	1.234	0	2.934
Barcarena, PA	2.291	832	714	3.836
Santarem, PA	1.595	1.713	86	3.395
Sao Luis, MA	4.327	1.568	225	6.120
Salvador, BA	3.767	761	927	5.456
Vitoria, ES	4.377	2.713	338	7.427
Santos, SP	13.836	14.368	4.646	32.850
Paranaguá, PR & S. Francisco do Sul, SC	12.868	6.871	6.395	26.134
Rio Grande, RS	11.268	226	800	12.294
Total	56.028	30.287	14.130	100.446

7 RESULTS AND DISCUSSION

In order to evaluate the effects of ICMS tax's path dependency in the soy supply chain, we are going to consider an additional scenario: a NOTAX Soy scenario, which considers a system where there is no path dependency in the tax system for the soy grains, consequently, taking out the tradeoff between taxes and logistic costs. This additional scenario will be compared to the Base scenario in terms of: quantity of soy processed (Chart 17), and congestions at ports, represented by the aggregated quantity of grain waiting to be exported (Chart 18 and Chart 19). Additionally, this chapter will analyze the aggregated transportation demand, which is the product of each route's distance by its amount transported on each simulated day (Chart 20 and Chart 21). It those cases, it is expected an increase in the soy processing activity, representing a growth in soy processing plants utilization and flatter curves in terms of transportation demand and inventory positions at ports, representing a decrease in the seasonal character of the system.

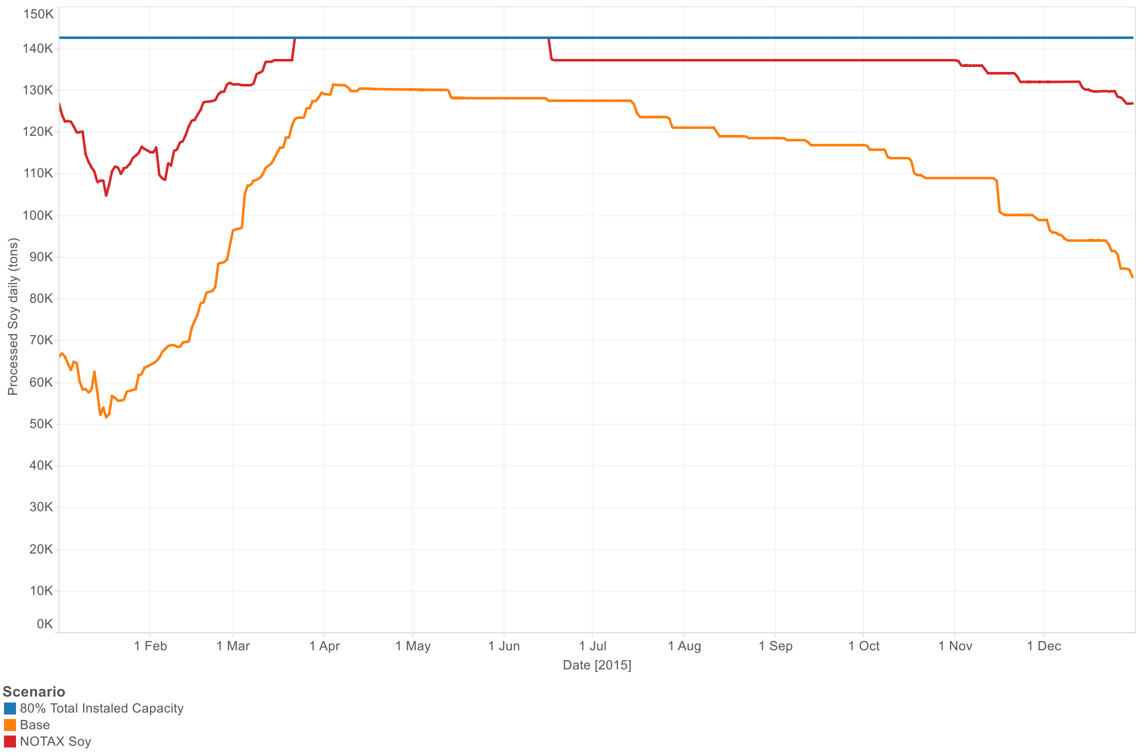

Chart 17 - Comparison of the Base scenario with a non-path dependent tax scenario in terms of soy processing

In the Chart 17 above, there is an increase of 23% in the soy processing activity, rising soy plants utilization from 61% up to 75% in the NOTAX Soy scenario. Furthermore, soy meal production becomes more stable as more soy plants work at their maximum capacities for longer periods. In addition, the increase in processed soy should have positive reflexes in terms of ports congestions and transportation demand because the intensification of soy meal production should improve infrastructure utilization during the off season, while peaks resulting from the soy harvest season should be smoothed by the additional amounts of soy being absorbed by the processing plants.

Analyzing the ports inventories by product in the chart below, it is observable that the aggregated amount of grains waiting to be exported is dependent on those grains seasonality, having their peaks shortly after the harvests peaks. Nevertheless, there are slight changes in between scenarios in terms of inventory volumes because soy meal has a more consistent presence over time. This situation was already expected due to the increase in soy meal production seen in the last chart. Moreover, the additional processed volumes of soy should decrease the soy peaks in terms of inventories and the increase of soy meal volume should increase ports' inventory positions during the off-season, therefore decreasing the seasonal character of exports.

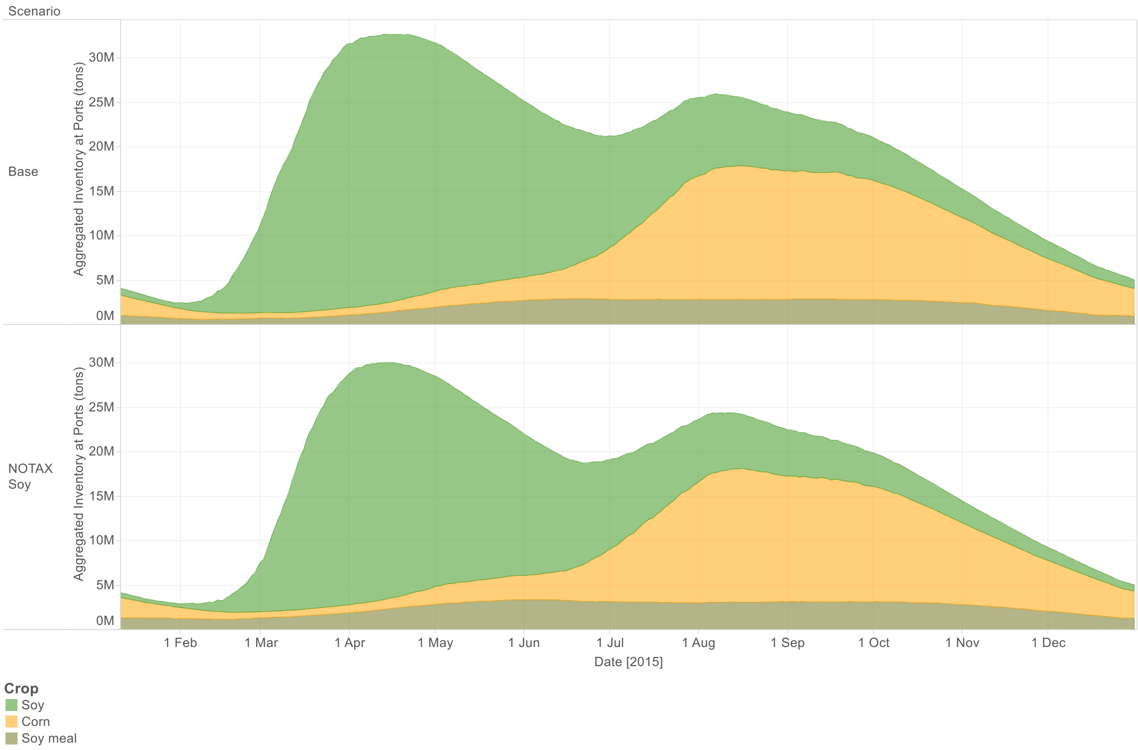

Chart 18 - Aggregated inventory positions at ports by day and crop (tons)

The mentioned situation is better observed and confirmed by the Chart 19 in the next page. This chart directly compares aggregated ports inventories across scenarios, showing that the export's valley, in February, is more active while the peak period, from April until October, is smoother in the NOTAX Soy scenario. This condition should lower the waiting time for ships to board load their grain, but this is not quantified by the model.

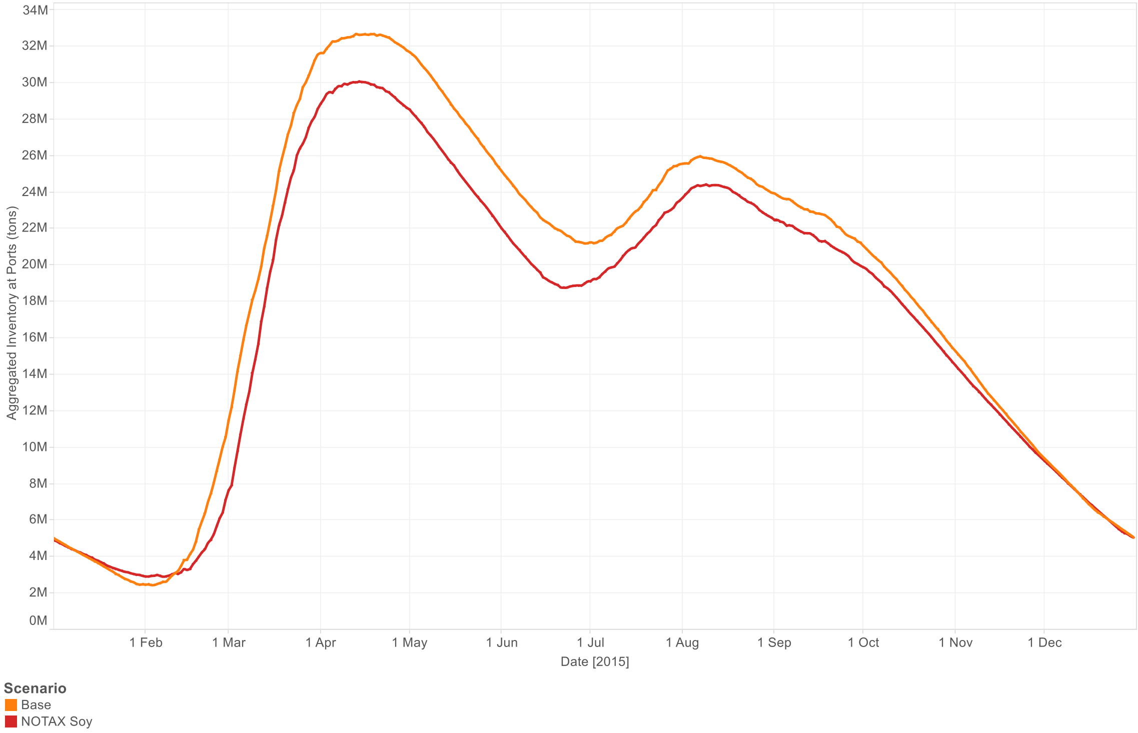

Chart 19 - Comparison of the aggregated inventory positions at ports in the evaluated scenarios (tons)

Proceeding to transportation demand, we have the multiplication of distances by daily transported quantities on Chart 20 and Chart 21. It is possible, again, to observe a very subtle increase in the soy meal participation, but the stochastic nature of the analyzed variable. No other changes are very perceptible in Chart 20.

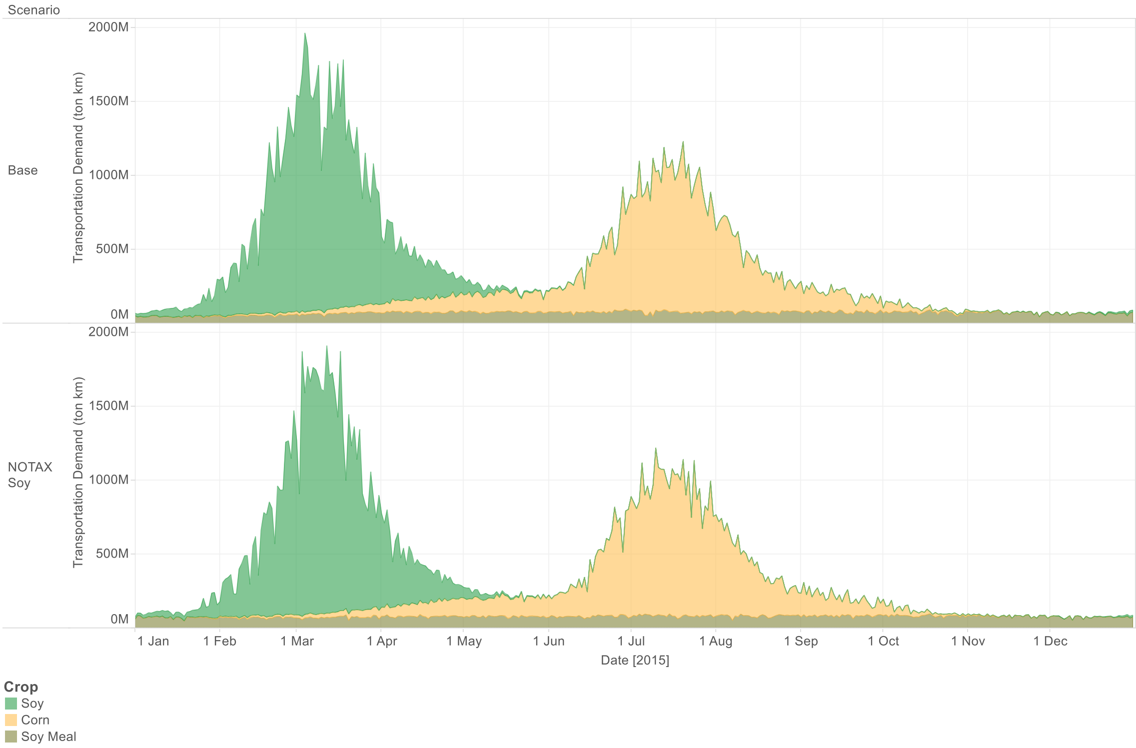

Chart 20 - Daily transportation demand in each scenario by crop (ton km)

In Chart 21, the transportation demand in both scenarios is very similar, presenting the same pattern, but still, the Base scenario presents its peak slightly larger (1,96 billion ton km) than the one in the NOTAX Soy scenario (1,91 billion ton km). For valleys, the same analogy is true because the Base scenario also presents the lowest minimum (42,5 million ton km) if compared to the NOTAX Soy scenario (53,0 million ton km), however, the overall difference is not big enough to be measured considering the stochastic behavior of the observed variables.

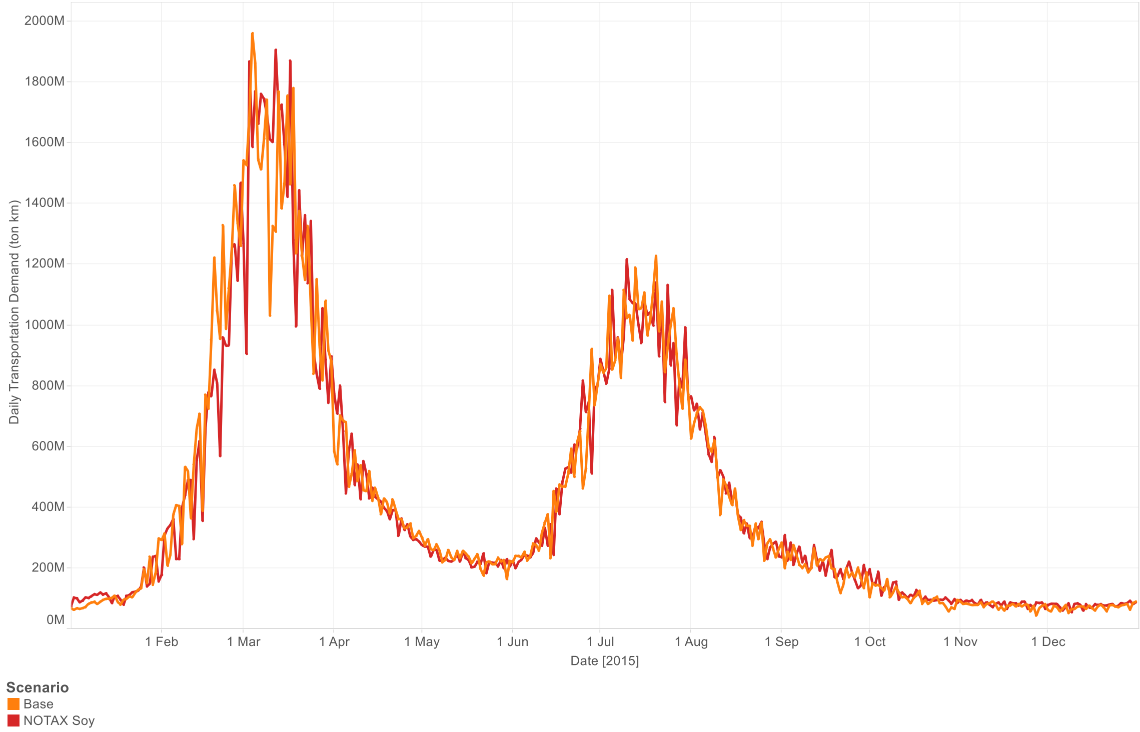

Chart 21 - Comparison in between transportation demands in the evaluated scenarios (ton km)

Summarizing the results presented in this chapter, it is possible to indicate that if taxes ceased to be path dependent for soy grains, the entire supply chain would benefit from this in terms of efficiency in large or small scale. First, the soy processing plants would have a great increase in terms of utilization, second, ports would have less congestions due to the reduced inventories during the peak season and would be less idle during the off seasons. Finally, the overall transportation infrastructure may observe the same effect in a smaller scale because the increased amounts of soy meal would slightly decrease infrastructure sub utilization during the off season, while smoothing demand peaks during the harvests seasons because soy needs to travel smaller distances to reach processing plants in the countryside rather than to reach ports on the seaside.

8 CONCLUSION

This chapter retakes the objectives described in the first chapter and compares them with the developed project, identifying how each topic has been achieved. Therefore, this chapter qualitatively observes if the chosen solution, agent based simulation, fits the studied problem. In addition, this chapter evaluates if the model has fulfilled all proposed requirements in terms of aiding governmental organs in their decision making process. Finally, this chapter ends by identifying possible improvements and next steps.

8.1 Agent Based Model Suitability

Referring to the first objective listed in the first chapter of this work, we can conclude that it has been achieved, because the developed agent based model has proven itself as an example of a tool able to evaluate scenarios in order to support a decision making process. Furthermore, this work presents a didactic and step by step development process of a complex model, following the guidelines proposed by some authors in the literature. Therefore, the steps used in this work can be replicated in order to aid the development of similar model applied to other problems.

Moreover, the developed model is accurate and robust, providing a detailed picture of the grain supply chains in Brazil under different conditions in a scenario analysis. The multiple outputs of the model in terms of exports, internal consumption, grains flows and routes, show internal consistency and are qualitatively endorsed by other works in the literature, thus, the chosen solutions fits the study of Brazilian soy supply chain efficiency subject to the current tributary policy.

Nevertheless, an agent based model development requires a large amount of resources in terms of data, time and computational power if compared to other simulation paradigms due to its bottoms up nature. As such, this kind of model requires a deep knowledge of all major components' behaviors of complex systems in order to be developed. In addition, this kind of model presents challenges in terms of software because there is no consolidated standard tool able to deal with a large number of agents and such models may exceed hardware constraints. Still, such models have the best performance when dealing with systems, which present many components with decentralized decisions and behavior contribution for an emerging pattern, which is the case for grain supply chains. Therefore, even though the model uses a great amount of resources, this effort is paid off by the model's great accuracy and consistency.

8.2 Considerations about the model and next steps

We can state that the second objective of this work has been fulfilled as the model presented in the last chapters is able to mimic grain flows in Brazil with enough accuracy in order to aid the decision making process on the public sector. As such, the presented model has estimated the impact of the current tax system path dependency in the soy supply chain through a scenario analysis, indicating that it has negative consequences in terms of processing plants utilization, congestions at ports and transportation infrastructure in a smaller scale.

The created model is not limited to the public sector, it can be useful in other contexts as well. This statement is true because, even though the model was used to estimate the impact of taxes, additional modification in the assumptions of this model could simulate scenarios of infrastructure improvement, forecasting the flows through new waterways, railroads and roads or even estimating the utilization of a new soy processing plant.

Finally, this work can still be improved, in terms of next steps, achieving a more precise representation of the reality. This improvement would require some changes in the software, what would possibly allow the model to incorporate additional complexity, for example, the mechanism concerning the producers' willingness to store their production rather than selling it, as recommended by Bastos and Roseghini. Also, some assumptions could be refined in terms of freight costs, as the model may consider freight cost elasticity in order to calculate freight prices. Additionally, grain demand could be refined and better characterized at a local level, by, for instance, the differentiation between extensive animal creation from intensive animal creation.

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ATTACHMENT I – Production and Harvest Dates in Each one of the 66 regions

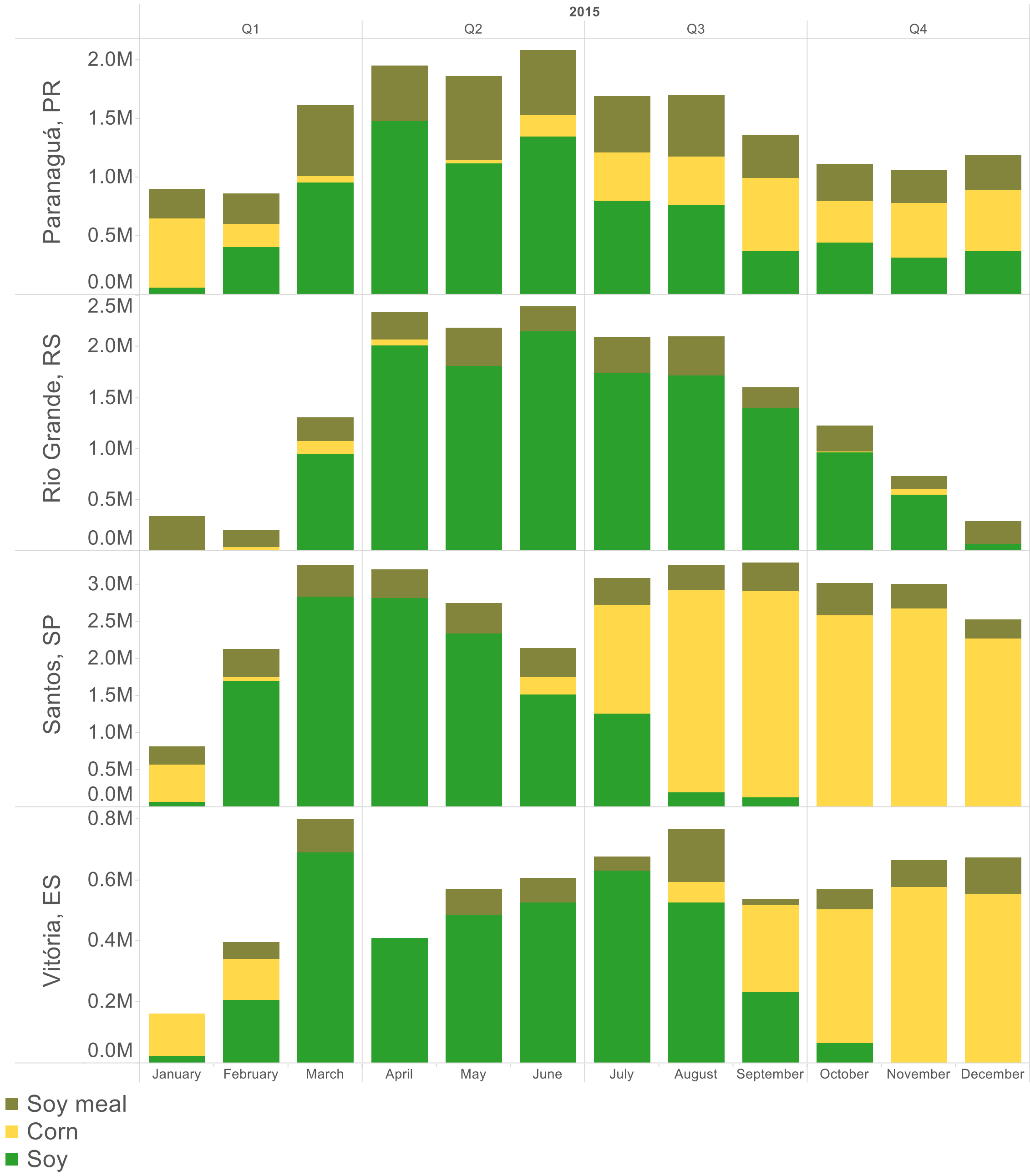
Centroid	soy Production			Winter corn			Winter corn		
	Production (tons)	Peak Date	Harvest (days)	Production (tons)	Peak Date	Harvest (days)	Production (tons)	Peak Date	Harvest (days)
Bage, RS	1291493	15/3/15	120				226931	1/4/15	180
Alegrete, RS	898820	15/3/15	120				196863	1/4/15	180
Cruz Alta, RS	6575904	15/3/15	120				1869369	1/4/15	180
Santa Cruz do Sul, RS	1477961	15/3/15	120				997284	1/4/15	180
Passo Fundo, RS	3685470	15/3/15	120				2034755	1/4/15	180
Vacaria, RS	951852	15/3/15	120				847798	1/4/15	180
Lages, SC	519673	1/4/15	120				810790	1/4/15	180
Xanxere, SC	914492	1/4/15	120				1900965	1/4/15	180
Mafra, SC	486135	1/4/15	120				477345	1/4/15	180
Cascavel, PR	6783734	1/3/15	105	5726050	1/9/15	150	1158091	1/4/15	165
Guarapuava, PR	2785618	1/3/15	105	50510	1/9/15	150	1349212	1/4/15	165
Ponta Grossa, PR	2485720	1/3/15	105	83682	1/9/15	150	1437411	1/4/15	165
Jaboti, PR	1344543	1/3/15	105	1241675	1/9/15	150	413407	1/4/15	165
Maringa, PR	3810885	1/3/15	105	4077582	1/9/15	150	325280	1/4/15	165
Dourados, MS	4187477	15/3/15	90	6126016	15/7/15	135	15887	15/3/15	135
Bonito, MS	299005	15/3/15	90	322621	15/7/15	135	4753	15/3/15	135
Navirai, MS	831235	15/3/15	90	1129056	15/7/15	135	7404	15/3/15	135
Agua Clara, MS	131999	15/3/15	90	148241	15/7/15	135	2190	15/3/15	135
Chapadao do Sul, MS	707500	15/3/15	90	528649	15/7/15	135	100882	15/3/15	135
Coxim, MS	1020383	15/3/15	90	854018	15/7/15	135	43184	15/3/15	135
Rondonopolis, MT	2133541	1/3/15	120	1777887	1/7/15	135	116953	1/4/15	150
Pontes e Lacerda, MT	965112	1/3/15	120	813932	1/7/15	135	35161	1/4/15	150
Jangada, MT	1356574	1/3/15	120	769641	1/7/15	135	35465	1/4/15	150
Tangara da Serra, MT	2990553	1/3/15	120	2045076	1/7/15	135	111516	1/4/15	150
Primavera do Leste, MT	3199816	1/3/15	120	2387058	1/7/15	135	84617	1/4/15	150
Nova Xavantina, MT	1242031	1/3/15	120	628871	1/7/15	135	29781	1/4/15	150
Ribeirao Cascalheira, MT	2804403	1/3/15	120	1224939	1/7/15	135	10910	1/4/15	150
Confresa, MT	1210177	1/3/15	120	920582	1/7/15	135	759	1/4/15	150
Colider, MT	1492683	1/3/15	120	896316	1/7/15	135	12402	1/4/15	150
Sorriso, MT	9531500	1/3/15	120	8382185	1/7/15	135			
Castanheira, MT	1092210	1/3/15	120	458712	1/7/15	135	20637	1/4/15	150
Ariquemes, RO	732900	15/3/15	75	551300	1/8/15	150	100000	15/2/15	120
Presidente Prudente, SP	200256	15/3/15	120	358320	23/7/15	150	61916	1/4/15	180
Marilia, SP	469015	15/3/15	120	695395	23/7/15	150	188640	1/4/15	180
Aracatuba, SP	117812	15/3/15	120	56224	23/7/15	150	138312	1/4/15	180
Sao Jose do Rio Preto, SP	59217	15/3/15	120	41471	23/7/15	150	227525	1/4/15	180
Itapeva, SP	1022126	15/3/15	120	484783	23/7/15	150	898399	1/4/15	180
Ribeirao Preto, SP	461511	15/3/15	120	170725	23/7/15	150	437876	1/4/15	180
Campinas, SP	36563	15/3/15	120	47283	23/7/15	150	359332	1/4/15	180
Uberlandia, MG	1568335	15/4/15	90	598407	15/7/15	120	1325526	1/5/15	135
Araxa, MG	561696	15/4/15	90	151000	15/7/15	120	1396743	1/5/15	135
Betim, MG	12858	15/4/15	90	5416	15/7/15	120	374751	1/5/15	135
Varginha, MG	103127	15/4/15	90	26802	15/7/15	120	1084485	1/5/15	135
Barbacena, MG	25324	15/4/15	90	7592	15/7/15	120	460055	1/5/15	135
Pirapora, MG	885490	15/4/15	90	473100	15/7/15	120	572452	1/5/15	135
Januaria, MG	350171	15/4/15	90	142584	15/7/15	120	245588	1/5/15	135
Rio Verde, GO	3689393	15/3/15	90	5448246	1/7/15	135	179257	15/4/15	120
Jussara, GO	444091	15/3/15	90	97219	1/7/15	135	89747	15/4/15	120
Goiania, GO	2576750	15/3/15	90	469175	1/7/15	135	603498	15/4/15	120
Brasilia, DF	1914866	15/3/15	90	1302060	1/7/15	135	804699	15/4/15	120
Gurupi, TO	722498	1/4/15	120	6583	15/7/15	150	56900	1/5/15	135
Porto Nacional, TO	986547	1/4/15	120	84870	15/7/15	150	144111	1/5/15	135
Colinas do Tocantins, TO	381470	1/4/15	120	83694	15/7/15	150	28267	1/5/15	135
Araguaina, TO	385186	1/4/15	120	559152	15/7/15	150	86723	1/5/15	135
Barra do Corda, MA	1574515	1/4/15	105	480404	1/7/15	120	580704	15/4/15	135
Acailandia, MA	145352	1/4/15	105	34432	1/7/15	120	193378	15/4/15	135
Buriti Bravo, MA	349734	1/4/15	105	4163	1/7/15	120	176219	15/4/15	135
Bom Jesus, PI	1405770	15/4/15	120				494814	1/5/15	135
Canto do Buriti, PI	428030	15/4/15	120	114900	1/7/15	120	454487	1/5/15	135
Iguatu, CE							151400	15/5/15	120
Acu, RN							7500	15/5/15	120
Campina Grande, PB							20300	15/5/15	120
Caruaru, PE							58200	15/5/15	90
Aracaju, SE				668500	15/10/15	105			
Barreiras, BA	4180700	1/4/15	105	101902,3	15/10/15	105	2285138	8/5/15	27
Senhor do Bonfim, BA				355597,7	15/10/15	105	30762	8/5/15	27

ATTACHMENT II – Source Code of the API ran in VBA to retrieve distances

```
Sub getDistances()
Dim xhrRequest As XMLHTTP60
Dim domDoc As DOMDocument60
Dim ixnlDistanceNodes As IXMLDOMNodeList
Dim ixnNode As IXMLDOMNode
Dim lOutputRow, loLink, loOrigem, loDestino As Variant
Dim Lines As Integer
Dim Columns As Integer
Dim i As Integer
Dim j As Integer
Dim step As Integer
Dim Total_distance As Single
Dim Summary As String
Dim Distances(300) As Long
Dim Pointer As Integer
Dim MDistances() As Single
Dim MSummary() As String
Dim MValidate() As String
Dim SValidate As String
Dim Time As Variant
i = 3
' Find the number of Lines and Columns
Do While Worksheets("Distances").Cells(i, 2).Value <> ""
i = i + 1
Loop
Lines = i - 3
ReDim MDistances(Lines) As Single
ReDim MSummary(Lines) As String
ReDim MValidate(Lines) As String
For i = 0 To Lines - 1
    Time = (Now + 0.000001
    loOrigem = Worksheets("Distances").Cells(i + 3, 2).Value
    loDestino = Worksheets("Distances").Cells(i + 3, 3).Value
    loLink = "https://maps.googleapis.com/maps/api/directions/xml?origin=" & loOrigem & "&destination=" & loDestino
    ' Read the data from the website
    Set xhrRequest = New XMLHTTP60
    xhrRequest.Open "GET", loLink, False
    xhrRequest.send
    ' Copy the results into a format we can manipulate with XPath
    Set domDoc = New DOMDocument60
    domDoc.LoadXML xhrRequest.responseText
    ' The important bit: select every node called "value" which is the child of a node called "distance" which is
```

```
    ' in turn the child of a node called "step"
    Set ixnlDistanceNodes = domDoc.SelectNodes("//step/distance/value")
    ' Store the distance value of each step in the vector Distances
    Pointer = 0
    For Each ixnNode In ixnlDistanceNodes
      Distances(Pointer) = ixnNode.Text
      Pointer = Pointer + 1
    Next ixnNode
    If Pointer > 300 Then
    Dialog = MsgBox("Increase the vector sizes on the source code (Default 100)!", vbOKOnly + vbInformation,
"Warning")
    End If
    ' Store the summary value (name of the road) in the vector Summary
    Set ixnlDistanceNodes = domDoc.SelectNodes("//summary")
    For Each ixnNode In ixnlDistanceNodes
      Summary = ixnNode.Text
    Next ixnNode
    ' Sums up all steps' distances
    Total_distance = 0
    For step = 0 To Pointer
      Total_distance = Total_distance + Distances(step)
    Next step
      Total_distance = Round(Total_distance / 1000, 1)
    Set ixnNode = Nothing
    Set ixnlDistanceNodes = Nothing
    Set domDoc = Nothing
    Set xhrRequest = Nothing
    MDistances(i) = Round(Total_distance, 1)
    MSummary(i) = Summary
    MValidate(i) = SValidate
    Worksheets("Distances").Cells(i + 3, 4).Value = MDistances(i)
    Worksheets("Distances").Cells(i + 3, 5).Value = MSummary(i)
    If Time < Now Then
      Application.Wait (Now + TimeValue("00:00:12"))
    End If
Next i
End Sub
```

ATTACHMENT III – Port's Capacity Estimation



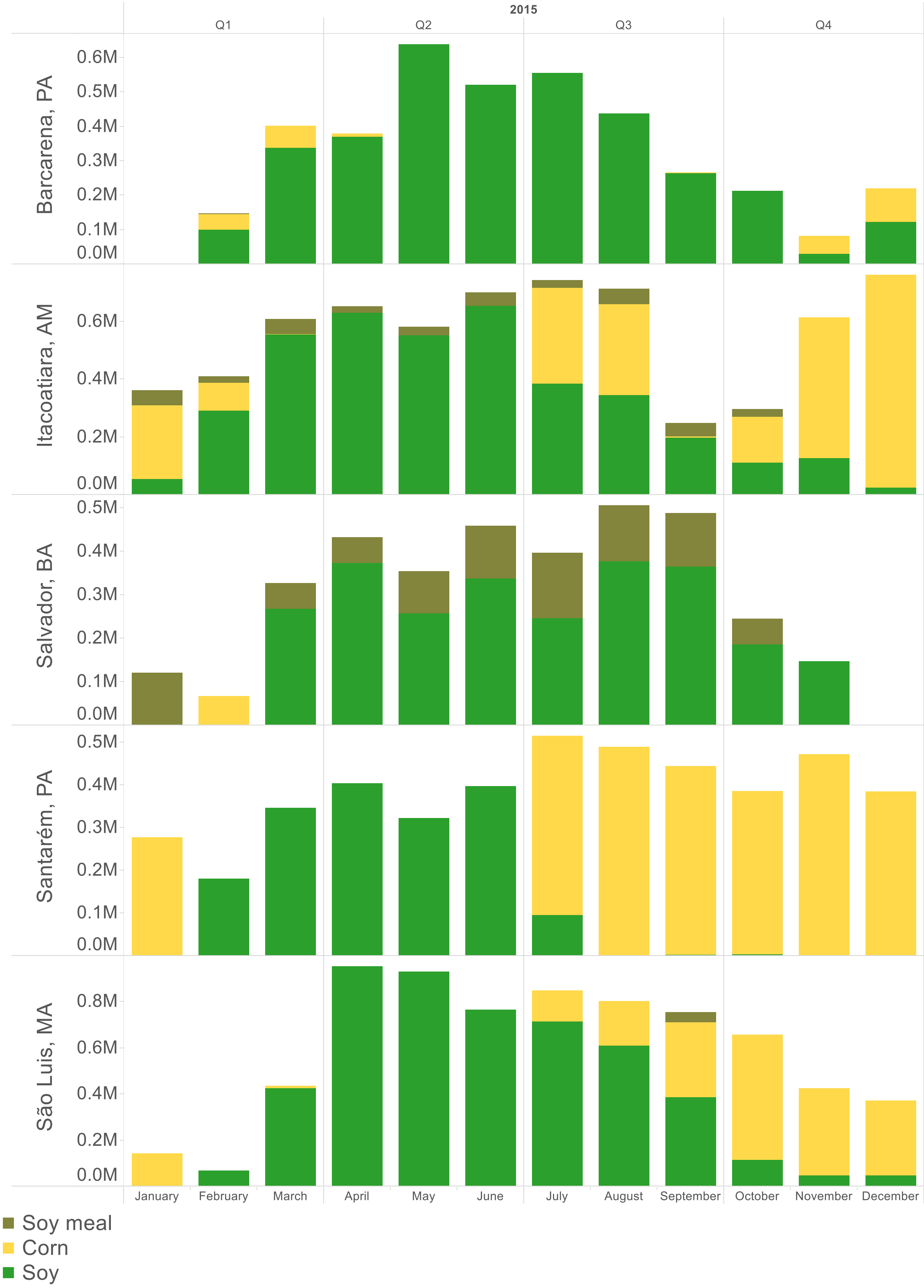
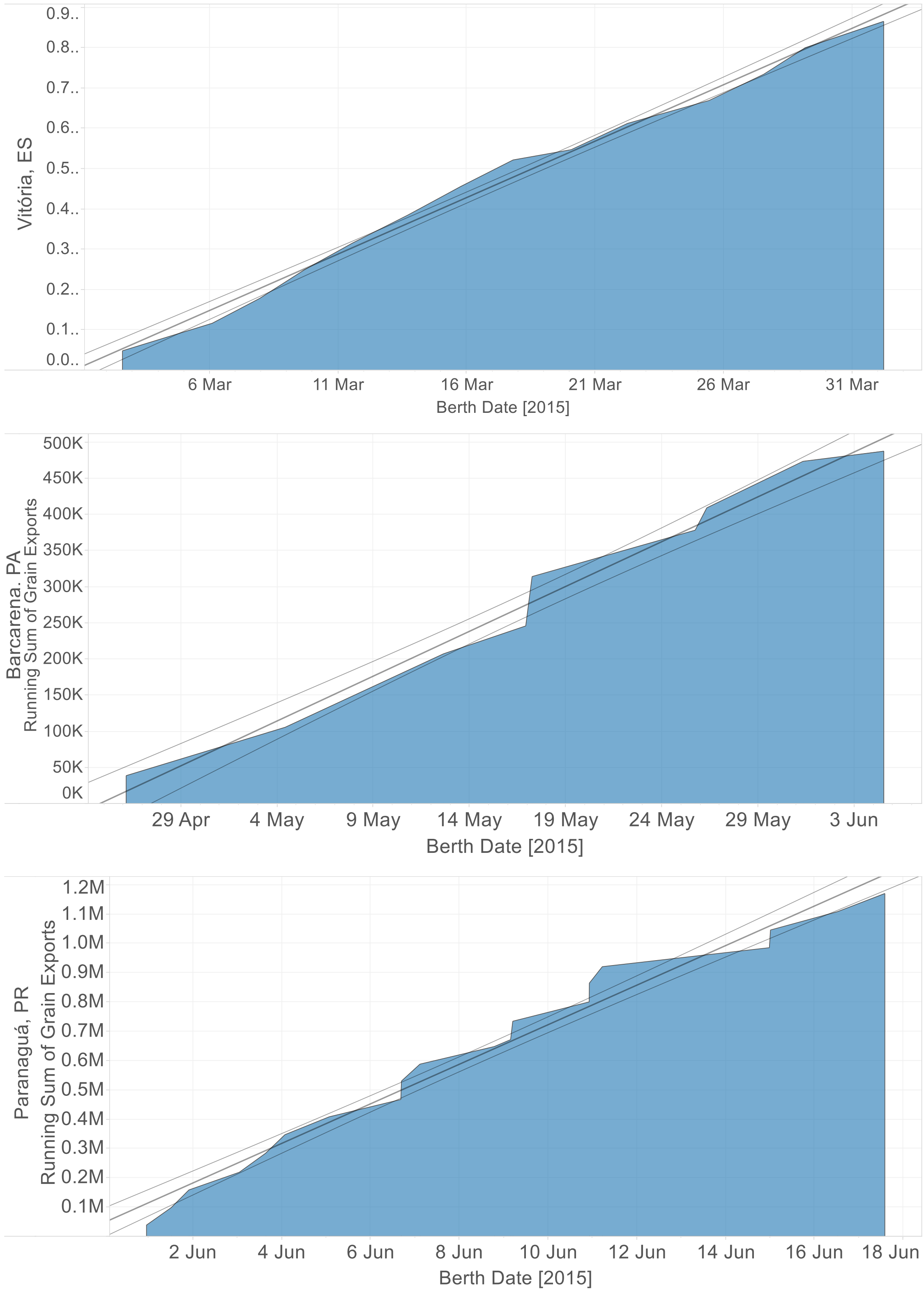
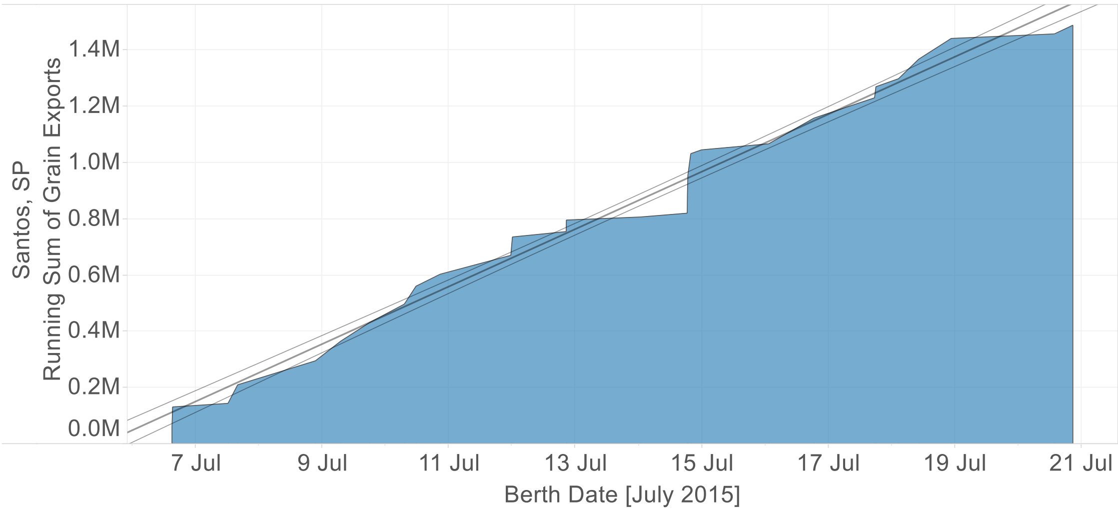
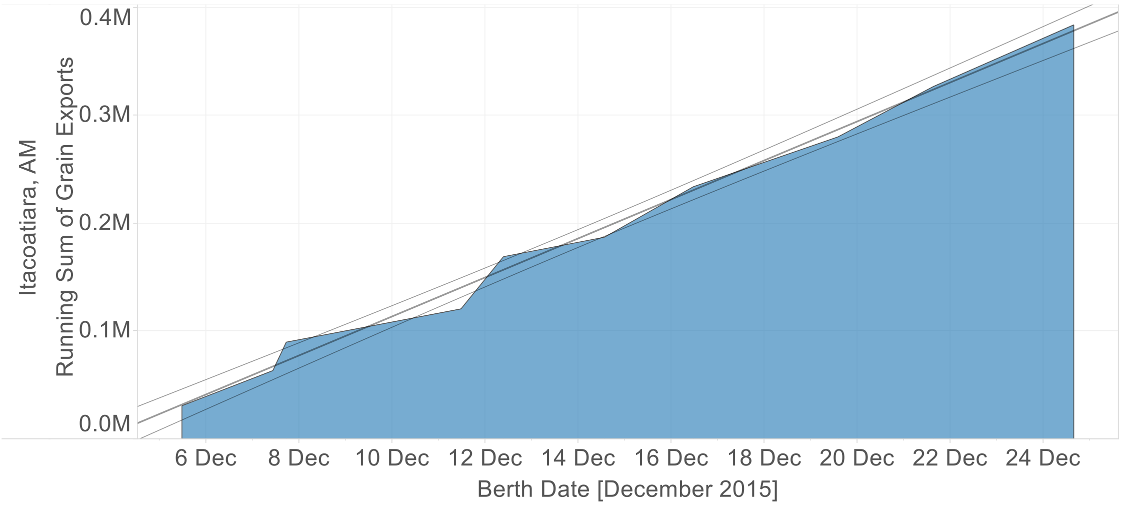
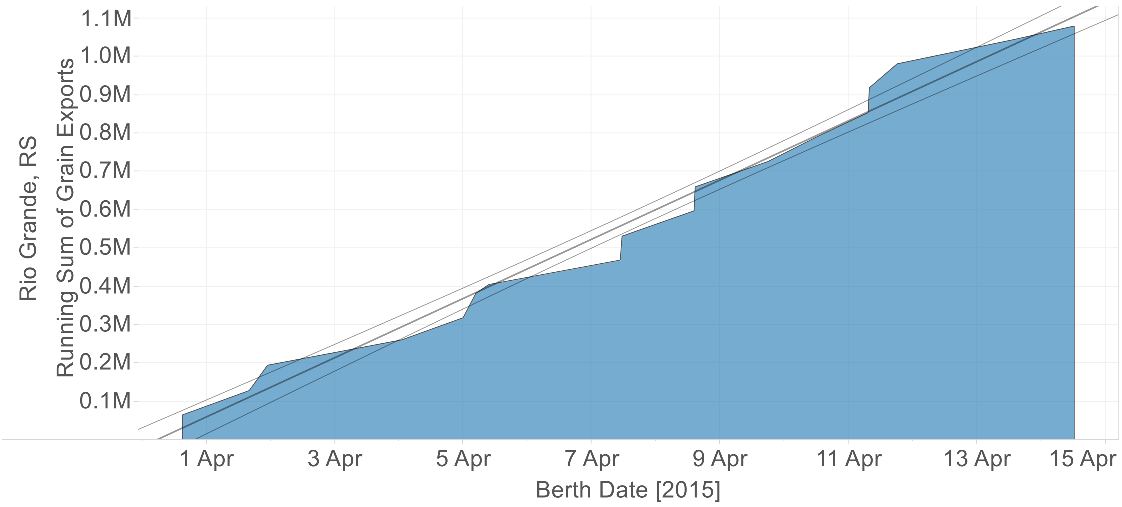


Chart 22 - Ports' total grain exports by month


Vitória, ES
0.9..
0.8..
0.7..
0.6..
0.5..
0.4..
0.3..
0.2..
0.1..
0.0..
6 Mar
11 Mar
16 Mar
21 Mar
26 Mar
31 Mar
Berth Date [2015]
Barcarena. PA
Running Sum of Grain Exports
500K
450K
400K
350K
300K
250K
200K
150K
100K
50K
0K
29 Apr
4 May
9 May
14 May
19 May
24 May
29 May
3 Jun
Berth Date [2015]
Paranaguá, PR
Running Sum of Grain Exports
1.2M
1.1M
1.0M
0.9M
0.8M
0.7M
0.6M
0.5M
0.4M
0.3M
0.2M
0.1M
2 Jun
4 Jun
6 Jun
8 Jun
10 Jun
12 Jun
14 Jun
16 Jun
18 Jun
Berth Date [2015]


Santos, SP
Running Sum of Grain Exports
1.4M
1.2M
1.0M
0.8M
0.6M
0.4M
0.2M
0.0M
7 Jul
9 Jul
11 Jul
13 Jul
15 Jul
17 Jul
19 Jul
21 Jul
Berth Date [July 2015]


Itacoatiara, AM
Running Sum of Grain Exports
0.4M
0.3M
0.2M
0.1M
0.0M
6 Dec
8 Dec
10 Dec
12 Dec
14 Dec
16 Dec
18 Dec
20 Dec
22 Dec
24 Dec
Berth Date [December 2015]


Rio Grande, RS
Running Sum of Grain Exports
1.1M
1.0M
0.9M
0.8M
0.7M
0.6M
0.5M
0.4M
0.3M
0.2M
0.1M
1 Apr
3 Apr
5 Apr
7 Apr
9 Apr
11 Apr
13 Apr
15 Apr
Berth Date [2015]

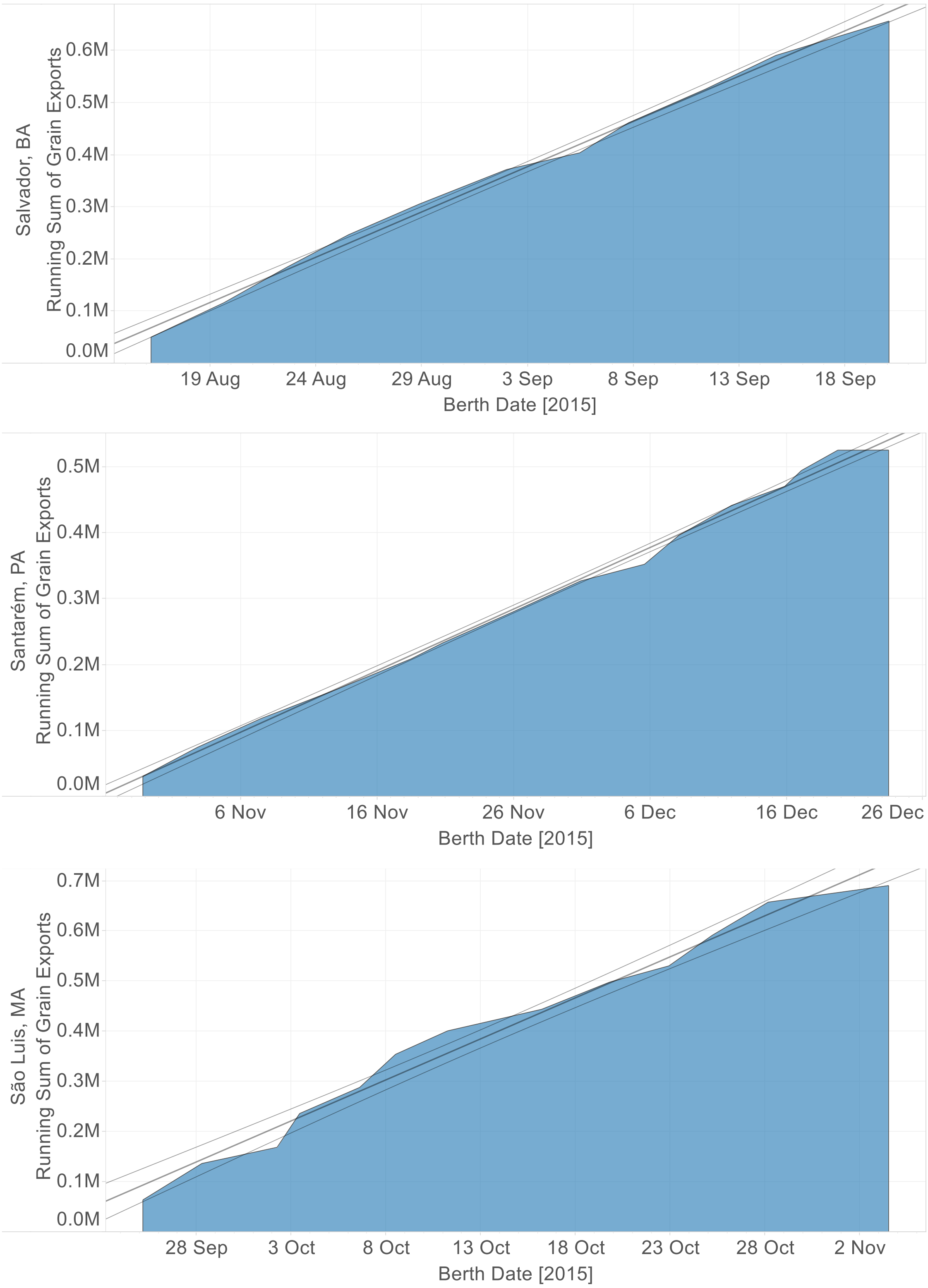


Chart 23 - Ports capacity estimation