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Analyzing complexities in the Brazilian soybean supply chain: a systems thinking and modeling approach

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Abstract

Purpose – This study aims to analyze the complexities of the Brazilian soybean supply chain (SSC) and develop strategic interventions to improve the origin system's performance.

Design/methodology/approach – This study used stakeholder interviews to identify the SSC bottlenecks and determine and assess drivers of competitiveness. A methodological framework based on the systems thinking approach for developing long-term structural changes was used. The problem was structured using behavior over time graph and causal loop modeling to propose three investment strategies to solve the logistics problem in SSC.

Findings – This study highlights the gaps in coordination between stakeholders and the public sector regarding the public policy for infrastructure investment. Three strategic interventions were developed to address the agro-industrial logistical problem, namely, investment in storage, multimodal transport systems and improvements in existing transport infrastructure. To overcome transport and storage logistics limitations, the authors suggest different forms of partnerships, including public-private partnerships.

Research limitations/implications – This research is limited to evaluating an agricultural commodity (soybean) and does not include its by-products. The sample of stakeholders was limited and the boundary of

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analysis was Brazil. Nevertheless, the study showed how strategic interventions could be developed following a holistic analysis.

Practical implications – The proposed integrated approach illustrates the development of three strategic initiatives. It can be implemented by stakeholders, including the public sector, which is the basis for providing assertive long-term investments in Brazilian logistics.

Social implications – The SSC analysis could promote the implementation of systemically determined interventions and strategies. It could significantly improve the performance of agricultural systems and help the formulation of public policies aimed at rural development.

Originality/value – The use of system dynamics to identify intervention points is an essential contribution to mitigating the SSC's hindrances. Moreover, the combining methodologies resulted in comprehensive intervention strategies.

Keywords Brazil, Systems thinking, Causal loop model

Paper type Research paper

1. Introduction

Global soybean production has doubled in the past 20 years, going from 174 million tons in 2000/2001 harvest to 363 million tons in the 2020/2021 harvest. The largest producers are Brazil and the USA, which produce around 70% of all the world's soy (United States Department of Agriculture – USDA, 2021). Currently, one out of four agribusiness products in circulation worldwide is Brazilian (EMBRAPA, 2020). In addition, soybean has become a protagonist in developing Brazilian agribusiness (Caetano *et al.*, 2018; Kamali *et al.*, 2017). In 2019/2020, Brazil produced 128.5 million tons of soybeans, of which almost 72% were exported (United States Department of Agriculture – USDA, 2021). The Brazilian Midwest region produced 48% of this crop, with the state of Mato Grosso accounting for 36.0 million tons of soybeans (Companhia Nacional de Abastecimento – CONAB, 2021).

Despite its prominent position in the international commodities market, the country has a series of obstacles to soybean exports. Brazilian production is concentrated above Parallel 16 while the main ports are below it. Therefore, long distances between production areas and ports, poor road conditions, low railway efficiency and lack of capacity generate long lines of trucks at the main ports of export, especially during the harvest season. These factors result in long waiting times for ship mooring and failure to meet the grain delivery schedules of international buyers (Lopes, 2021).

In the Brazilian soybean supply chain (SSC), trading companies are the most important players, as they can intermediate the process of acquiring agricultural inputs (Barter) and provide benefits and loans to local producers, which, in turn, can sell soybeans to traders, cooperatives, spot markets and grain elevators (Reis, Sanches Amorim, Sarsfield Pereira Cabral, & Toloi, 2020). However, when the producer sells to cooperatives, they become responsible for transporting and storing the production while transport is outsourced for other types of sales.

The Brazilian situation differs from that of the USA, where a significant portion of the grain produced by farmers in the Midwest is drained by the Mississippi River system (Wetzstein, Florax, Foster, & Binkley, 2021). In 2020, the Mississippi waterway system moved nearly half of the USA grains and oilseeds destined for exports (United States Department of Agriculture – USDA, 2021).

The high logistical costs are evident regardless of the use of multimodal transport routes (Goneli, 2021). Agricultural companies have managed to overcome the inefficiencies associated with logistics, but it is unknown how long this model will be sustained (Oliveira, 2014; Fliehr, Zimmer, & Smith, 2019). In addition, trading companies in production pay a lower price than the Chicago Trade Board for the soybean produced in the state of Mato

Grosso. This scenario reduces the profitability of the Brazilian producer (Oliveira & Silveira, 2013; Melo, Péra, Júnior, do Nascimento Rebelatto, & Caixeta-Filho, 2020).

The Brazilian SSC system is composed of segments ranging from upstream, which depends on inputs, such as land, fertilizer, fuel and machinery (da Silva, van der Werf, Spies, & Soares, 2010; Garrett, Lambin, & Naylor, 2013; Jia, Peng, Green, Koh, & Chen, 2020), to downstream, which requires transportation to meet the global demand (He, Zhu, Chen, Cao, Chen, & Wang, 2019) and activities of these segments are performed by different stakeholders (Elias, 2017). This system is in an organizational and institutional environment where all stakeholders, whether economic or social agents, must efficiently work together to sustain competitiveness (Batalha & Silva, 2014). When there is a problem in the activities of one of the segments, the entire system's efficiency is compromised (Elias, 2017). Collaboration among stakeholders raises questions about the SSC's effective mechanisms and the drivers and potential barriers behind them (Jia *et al.*, 2020; Lima, Fioriolli, Padula, & Pumi, 2018).

There has been an increasing interest in SSC research. Many researchers showed great dedication to proposing solutions to problems in this field. Logistical bottlenecks, especially the shortage in warehousing (Filippi & Guarnieri, 2019), the inefficient cargo transportation (Silva & D'Agosto, 2013; Reis & Leal, 2015; Oliveira & Alvim, 2017) and transaction cost of ports of export (Esteves *et al.*, 2020) have been analyzed. Optimization models have been dedicated to solving problems of more efficient transport routes for agricultural commodities (Branco, Bartholomeu, Junior, & Caixeta Filho, 2020; Oliveira, Filassi, Lopes, & Marsola, 2021), minimizing the transportation cost for grains (Mogale, Kumar, & Tiwari, 2018), evaluating agricultural exports through simulation models dedicated to transportation (Lopes, Lima, Leal, & Nelson, 2017; Lopes, Lima, & Leal, 2020), and reducing losses of agricultural products in transportation (Nourbakhsh, Bai, Maia, Ouyang, & Rodriguez, 2016; CONAB, 2018).

A critical analysis of the literature pointed out the need for a more holistic analysis of the different factors related to the transportation issues in the SSC. It also showed the need for strategic models to contribute to the usual operational and mathematical models available. Systems thinking as an approach is holistic in nature and considers the complex interactions between different parts of a system (Elias & Davis, 2018). This approach has already been used by Banson, Nguyen & Bosch (2018) to model problems in agriculture, assessing the structure, conduct and performance of the agricultural sector in Ghana; the study was also used in the Indonesian chili pepper value chain as a case study to understand price volatility (Muflikh, Smith, Brown, & Aziz, 2021).

In this context, this research intends to systemically analyze the complex behavior of interrelated factors affecting the SSC in Brazil to suggest strategic interventions to improve the system. The novelty of this study is to present an analysis based on the quantitative and qualitative characterization of the factors that make up the SSC drivers of competitiveness. In Section 2, article is divided into two methodological frameworks: Part I – Characterization of drives, Part II – System dynamics; followed by results, divided into Section 3.1 – Drives and factors, Section 3.2 behavior over time (BOT) and causal loop model (CLM), followed by Section 4 – Conclusions.

2. Methodological framework

The methodological framework consists of two main parts. The first is based on the methodology described in Batalha & Silva (2014) to determine and evaluate drivers of competitiveness that impact the Brazilian SSC and find out the main problem. The second part addresses the systems thinking and modeling methodology developed by Maani & Cavana (2000) to propose strategic solutions to the problem identified in the first part. For this purpose, the BOT graph and a CLM were used (Sterman, 2010).

2.1 Drivers and factors

In the first part of the study, SSC drivers were characterized. Only grains directed for exportation were considered. In the last two crops (2017–2018 and 2018–2019), Brazil was responsible for 50% of all soybeans exported in the world (United States Department of Agriculture – USDA, 2020). Soybean meal and oil products were neither included in the research nor was the domestic consumption of the grain. In characterizing the drivers, this study considered the Institutional environment, the Technology and Market structure drivers developed by Batalha & Souza Filho (2009), and the Logistics infrastructure and Market relations drivers developed by the authors (Table 1).

After identifying the drivers and factors that compose these segments, we elaborated questions about each of these factors, and a questionnaire was applied via e-mails, phone and video calls, with 14 experts belonging to large companies in the SSC (Table 2).

Besides having vision and access to information on the SSC, the experts interviewed have a prominent position within companies (Table 2). These companies were chosen because of their national representativeness, considering that sizeable agro-industrial trading companies have a high integration level. Due to the high degree of competitiveness of the agricultural commodities market, the vertical integration model is used to ensure greater control of the chain, seeking to create value in its various domains (Oliveira & Schneider, 2016). Some trading companies even operate from the supply of agricultural inputs to the distribution of products directly to their customers. Archer Daniels Midland (ADM), Bunge, Cargill, Louis Dreyfus and Amaggi stand out among the trading companies with a high degree of vertical integration. The first four companies are foreign multinationals that lead both the world agricultural commodities market and the Brazilian market. They form the group known worldwide as ABCD, an acronym for their names (Oliveira & Alvim, 2017; Oliveira & Schneider, 2016). These companies have vessels, ports, railways, refineries, silos, mills and factories, and, together, represent 70% of the world market for agricultural commodities (Santos & Glass, 2018) and include the different stakeholders (business association, producers association, consultancy services, trading, research institutions, fertilizers) in the SSC (Table 2).

The methodology used in this study is known as *rapid assessment* or *quick appraisal* (Chambers, 1981; Ellman, 1981). This methodological approach is used to support decision-making, as it gathers and combines diverse sources of information (quantitative and qualitative) that can be validated with key actors (Kumar, 1993). The technique is widely used in several areas of agricultural research, such as the assessment and proposition of bioenergy policies (Maltsoglou, Kojakovic, Rincón, Felix, Branca, Valle, S., & Thofern, 2015), appraisal of problems and innovation capacity of the agricultural system (Schut, Klerkx, Rodenburg, Kayeke, Hinnou, Raboanarielina, & Bastiaans, 2015), support in the prioritization of climate-smart agriculture technologies (Mwongera, Shikuku, Twyman, Läderach, Ampaire, Van Asten, & Winowiecki, 2017) and evaluation of the sustainability of agricultural landscapes (Eichler, Kline, Ortiz-Monasterio, Lopez-Ridaura, & Dale, 2020).

In this study, the integrated analysis was performed using a data set from secondary sources (semi-structured interviews with key players) to understand the dynamics of the sector. The questionnaire ensured uniformity of answers within a Likert scale, ranging from *very favorable* to *very unfavorable*. Intermediate values used were *favorable*, *neutral* and *unfavorable*. Subsequently, this qualitative scale was transformed into quantitative by assigning values from "−2" for *very unfavorable* to "+2" for *very favorable*, allowing the representation of the results graphically. Delphi methodology was used to assign the weights (p) for each factor, argument and individual opinions of each interviewee (Batalha & Silva, 2014).

Drivers	Factors	Reference articles	Contribution
Institutional environment	Credit	Araujo & Souza Filho (2018)	Indicate that credit availability is important for supply chain development
	Taxation	Batalha & Souza Filho (2009)	Point out that the growth of soybean exports was higher than derivative products due to tax exemption (ICMS)
	Trade agreements	Batalha & Souza Filho (2009)	Cite the importance of Amazon rainforest preservation deals
Technology	Biotechnology	Batalha & Souza Filho (2009)	Analyze of the relationship between government and research, and technology spending with generating soybean variations
	Traceability	Lourenzani & Silva (2004)	Conclude that traceability can be used as a marketing and sales strategy
Market structure	Concentration level	Lourenzani & Silva (2004)	Demonstrate how an increased level of consolidation can negatively impact other actors in the supply chain
	Synergy	Batalha & Souza Filho (2009)	Discuss how partnerships between stakeholders contribute to supply chain development
Logistics infrastructure	Storage	Mardaneh *et al.* (2021)	Decision support system to evaluate different grain harvesting and distribution strategies, such as store on farm or use of bulk storage facilities away from the farm
	Cargo transportation	Oliveira & Alvim (2017)	Analyze how cargo transportation impacts agricultural supply chains
	Ports	Danao *et al.* (2015)	Cite long distances between production areas and ports of export
Market relations	Contracts	Lourenzani & Silva (2004)	Conclude that formal or informal contracts that specify transaction characteristics guarantee market relations
	Foreign market	Batalha & Souza Filho (2009)	Point to the necessity of non-GMO soybean investment to ensure access to EU markets

Note: EU = European–Union

Table 1.
Review of previously published literature

The parameters are $n = \{1, \ldots, 12\}$ – set of factors of evaluated drivers and x_i – the value assigned to the factors i. Z is the sum of the factors weighted by specific weight p, determined by:

$$Z = \sum_{i=1}^{n} x_i \cdot p_i \tag{1}$$

in which

Z = final value of the driver;
x_i = assigned value to the factor i;
p_i = assigned weight to the factor i; and
n = number of factors contained in the driver.`

Company	Expert position	Type of company	Location
ABIOVE	Manager	Business Association	São Paulo-SP
ADM	Analyst	Trading	São Paulo-SP
Agria Network	CEO	Technology Consulting	São Paulo-SP
Aprosoja	Analyst	Producers Association	Cuiabá-MT
Bunge	Manager	Trading	São Paulo-SP
Caramuru	CEO	Trading	Goiás-GO
Ceagro	Manager	Exporter and Importer	Campinas-SP
Céleres	CEO	Consultancy Services	Campinas-SP
Datagro	Consultant	Consultancy Services	São Paulo-SP
Embrapa Soja	Researcher	Research	Londrina-PR
Embrapa Território	Researcher	Research	Campinas-SP
Magenta Agro	Coordinator	Consultancy Services	Nova Mutum-MT
Mosaic	Coordinator	Fertilizers	Rondonópolis-MT
PwC	Manager	Consultancy Services	Campinas-SP

Note: CEO = Chief Executive Officer

Table 2. Research participants

In equation (1), considering the value assigned to each factor i weighted by p_i, the value of the competitiveness driver, which is the sum of the factors, was determined. Finally, the factors were classified according to their degree of controllability as follows: Controllable by the Company (CC) – factors controlled by the actions of non-governmental agents, usually companies or industries; Controllable by the Government (CG) – factors controlled by the actions of government agents, often under the influence of companies or industries; Nearly Controllable (NC) – factors that cannot be controlled directly by a company or by the government, but are influenced by chain coordination as a result of more significant strategic planning – and Uncontrollable (U) – uncontrollable factors, related to natural or climatic events (van Duren, Martin, & Westgren, 1991).

2.2 Behavior over time and causal loop model

In the second part, first, a BOT graph was created with the main variables in the system to capture the current problem. A BOT graph or a "reference model" is a tool used in systems thinking to show the trends and patterns of the main variables over an extended period, typically several months to several years. The most important elements captured by a BOT chart are the overall trends, directions and variations, not the numerical value of the variable. Therefore, BOT graphs are usually drawn in a rough sense without exact numerical values attached (Maani & Cavana, 2000).

As the next step, a CLM was developed using cause-effect relationships between different system variables. The behavior in a BOT graph can be explained using the CLM. The variables were extracted from the information collected during the first part, and additional causal links were applied as supplementary data, like the experiences of authors and interviewees, observations and archival data (Sterman, 2010).

Therefore, each variable presented is linked by arrows to other variables to demonstrate the cause-effect relationship of the feedback loops (Maani and Cavana, 2000). For example, an arrow with a positive link (+) indicates that if the cause of one variable increases, the effect on the next variable will also increase, and if the cause of one variable decreases, the effect on the next variable will also decrease. Conversely, a negative link (−) means the opposite as follows: if the cause of one variable increases, the effect on the next variable will decrease, and if the cause of one variable decreases, the effect on the next variable will increase (Sterman, 2010).

To understand the CLM, we had to analyze each of the feedback loops formed, which were divided into *reinforcing* ("R") or *balancing* ("B"). Although reinforcing loops reflect positive feedback systems, they can represent increasing or declining actions. On the other hand, balancing loops reflect negative feedback systems and seek stability or return to control (Sterman, 2010).

Finally, an attempt was made to develop a few strategic interventions that could improve this complex system. This methodology allows long-term structural behavior changes (Senge, 2006).

3. Results

3.1 Drivers and factors

Table 3 and Figure 1 show the controllability degree, value and weight assigned to the factors and, consequently, the results of the drivers.

The quantitative assessment of the factors gave rise to the graph (Figure 1). None of the final values of the driver (Z) reached 2 or −2, thus Very favorable (VF) and very unfavorable (VU) results were not obtained.

3.1.1 Logistics infrastructure. Logistics infrastructure was indicated as the driver that contributes to the unfavorable export scenario the most. Problems in road, rail and waterway modes are related to the poor quality of the roads, the high long-term cost of rail, and the lack of public interest in enabling the use of waterways. Moreover, the storage network does not keep up with the dynamism of the sector. Storage, transportation and port

Drivers/factors	Controllability degree[a] CC	CG	NC	Value[b] (x)	Weight[c] (p)
Logistics infrastructure					
Storage (static capacity, regions)	X	X		U	0.3
Cargo transportation (modes, quality)	X	X		U	0.4
Ports (system)	X	X		U	0.3
Institutional environment					
Credit (rural loan, rural insurance)	X	X		F	0.4
Taxation (tax war, tax exemption mechanisms)		X		N	0.4
Trade agreement (environmentally sound cultivation)	X			F	0.2
Market structure					
Concentration level (trading companies)			X	N	0.4
Synergy (associations, institutions, companies)	X			F	0.6
Technology					
Biotechnology (transgenic soybean)	X	X		F	0.6
Traceability (biosafety standards)	X	X		F	0.4
Market relations					
Contracts (Chinese market)	X	X		F	0.5
Foreign market (trade disputes)			X	F	0.5

Notes: [a]Controllability degree: CC: Controllable by the Company; CG: Controllable by the Government; NC: Nearly Controllable; U: Uncontrollable. [b]Value assigned to factor (x): VU: Very Unfavorable = −2; U: Unfavorable = −1; N: Neutral = 0; F: Favorable = +1; VF: Very Favorable = +2. [c]Weight assigned to factor (p): Weight of factor over the driver

Table 3. Evaluation of the competitiveness drivers of soybean exports

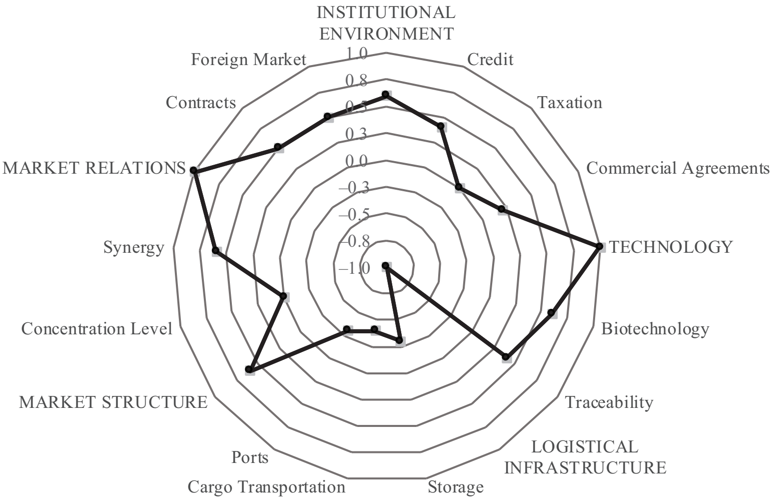

Figure 1.
Competitiveness drivers of soybean exports

infrastructure represent relevant factors in the transfer of production to the processing and exporting centers, as Brazil's major soybean production areas are very far from ports of export (Lima, Fiorioli, Padula, & Pumi, 2018).

3.1.2 Institutional environment. The institutional environment and the market structure were not shown as unfavorable drivers of competitiveness, but they must be carefully considered. The rural loans offered by the government through the National Support Program for the Medium Rural Producer increased 37%, equivalent to 4 million Brazilian reais from the 2018–2019 crop to the 2019–2020 crop (MAPA, 2019). Rural producers' access to agricultural credit occurs through the so-called *tie-in sales* of rural insurance, a common practice performed by financial institutions. The coalition between lenders and insurers often upsets producers due to the lack of alternatives. To curb this practice, Law No. 13,195/2015 introduced a measure whereby the government cannot establish rules that oblige the producer to contract rural insurance to access credit, and the financial institutions will be required to offer, at least, the option of two policies from different insurers (Brasil, 2015).

Also, a tense dispute called *tax war* is fueled by the difference in tax collection between states. Tax exemption mechanisms such as Kandir Law No. 87/1996 exempt the collection of the Tax on Movement of Goods and Provision of Services (ICMS – *Imposto sobre Circulação de Mercadorias e Prestação de Serviços*) on exports of semi-elaborated primary and industrialized products (Brasil, 1996) and benefit soybean exports, thus worsening this dispute.

3.1.3 Market structure. Different companies have entered the soybean market, but bargain power is still concentrated in the hands of large and traditional trading companies. ABCD companies and national companies, such as Amaggi, I. Riedi and Sperafico were responsible for 70% of all soybean commerce (Dall'agnol, Roessing, Lazzarotto, Hirakuri, & De Oliveira, 2007). Nevertheless, this scenario is changing. Asian traders, such as China National Cereals, Oils and Foodstuffs Corporation, which is the largest producer and crusher of soybeans, oil refiner and producer of processed foods, shipped 45% of the grains exported by Brazil in 2015 while ABCD shipped 37% (Bonato, 2016). However, the synergy between associations, institutions and companies that make up the segments mitigates conflicts of interest. Brazilian Association of Vegetable Oil Industries (ABIOVE) plays an essential role as an instrument to support compliance with public sector norms and private sector agreements. For example, ABIOVE promotes trade agreements such as the Soy Moratorium (ABIOVE, 2020), which guarantees national and international commercial arrangements with private companies that value environmentally sound cultivation and favor the preservation of the Amazon Biome.

3.1.4 Technology. Drivers of technology and market relations are favorable to the competitiveness of exported soybeans. The relationship between biotechnology factors and the foreign market contributes to this result. Besides, joint public-private investments in biotechnology have brought improvements to the soybean production process. Incorporation of mechanical, biological and chemical technologies in commodity production allows the intensification of land use and productivity increase (Ferreira Filho *et al.*, 2016). In recent years, crops of transgenic soybeans were predominant, comprising 96.5% of the cultivated area (Conselho de Informações sobre Biotecnologia – CIB, 2016), being influenced by the increase in demand of the foreign market. In 2018, the participation of the Chinese market was 82% in the exports of Brazilian soybean (Ministério da Indústria, Comércio Exterior e Serviços – MDIC, 2019).

Recently, trade disputes between China and the USA brought about the expectation of an increase in Brazilian exports to China. However, the COVID-19 pandemic and disagreements between the Chinese and Brazilian Governments can harm this prospect. Furthermore, Brazil is susceptible to policies imposed by importers, as it has no clear policies of its own. Therefore, contracts with other markets are essential, requiring traceability that ensures integrity and transparency along the food value chain, faced with the demand for non-transgenic soybeans by the European continent. Moreover, law No. 11,105/2005 establishes biosafety standards through mechanisms for monitoring activities from handling to disposal of the Genetically Modified Organisms (GMO) and its derivatives (Brasil, 2005).

3.2 Behavior over time and causal loop model

Results of the second part of this study begin with structuring the problem using a BOT graph. In agreement with the problems in the logistics infrastructure driver, four variables were identified. The behavior of both production and export value variables has been growing over the past 10 years, but transport investments are declining counterintuitively while the storage capacity deficit is growing (Figure 2).

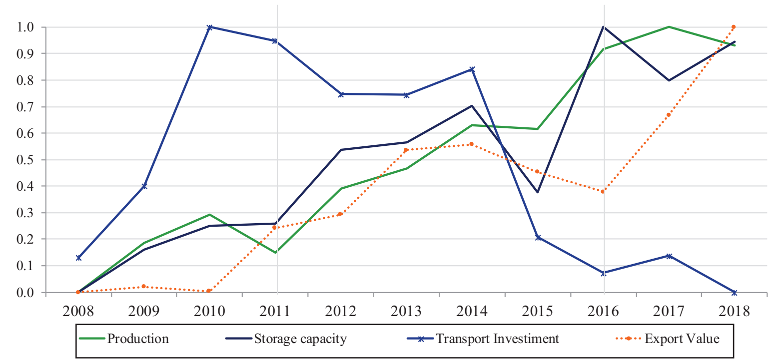

Figure 2.
Behavior of soybean production and exports compared to investments in transportation and storage capacity deficit

Data collected for developing the BOT graph show that soybean production (tons) increased 201% from 2008 to 2018 (Companhia Nacional de Abastecimento – CONAB, 2019a), and exports (billion dollars) increased 33.2% in the same period (MDIC, 2019). However, the storage capacity deficit occurs at both public and private levels, going from 6.6 million tons in the 2008–2009 crop to 76.0 million tons in the 2018–2019 crop (Companhia Nacional de Abastecimento – CONAB, 2019b).

The CLM developed in this research includes two *reinforcing* (production and exports) and three *balancing* (political, transportation modes and supply chain) feedback loops, named R1 and R^2 and B1, B2 and B3, respectively. Data triangulation with a holistic view of the SSC resulted in three key strategies (Figure 3). These interventions are expected to change the system behavior captured in the BOT graph (Figure 2).

R1 (production loop): The variable named *soybean farmers* is a good starting point for loop analysis. The more soybean is produced, the greater the need for loans from the government. Due to difficulties in accessing credit lines, some grain producers adopt Barter operations as a mechanism for accessing credit, where inputs from suppliers and trading companies are exchanged for grain (Silva & Lapo, 2012). Part of the loans for soybean cultivation is invested in technology. In Brazil, the use of technology in the field reflects increased productivity and, consequently, more significant soybean production. As production has been growing, more rural

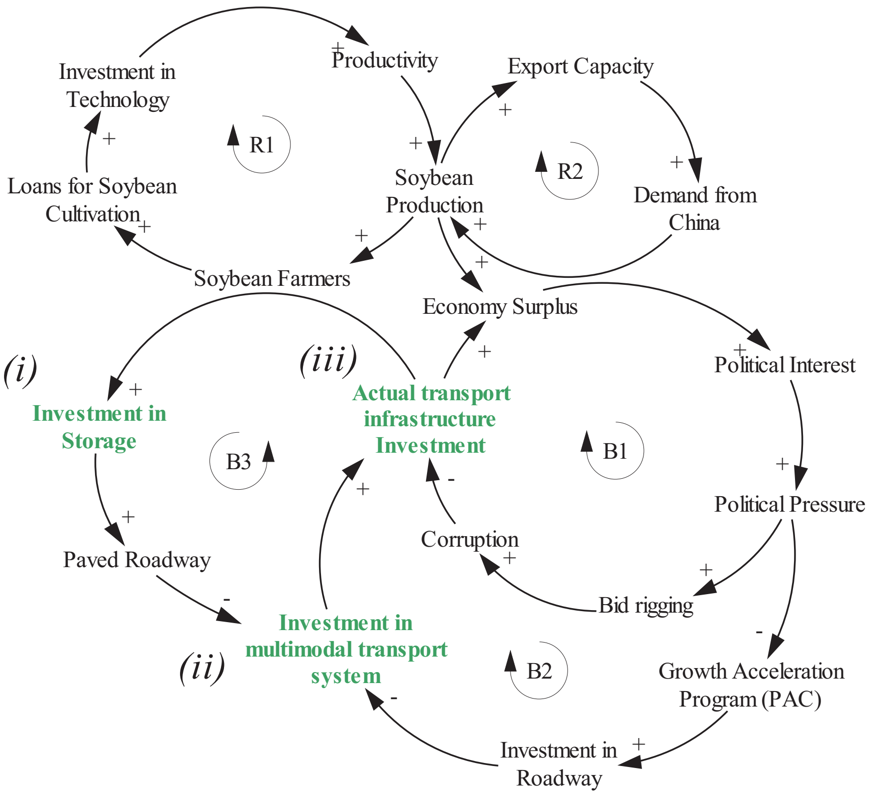

Figure 3.
CLM and strategic interventions

producers are interested in producing this grain, completing the first loop. This is a reinforcing feedback loop.

R^2 (export loop): In Brazil, most soybean production is destined for the foreign market. Thus, when there is an increase in soybean production, exportation capacity increases, and consequently, Brazil can meet the growing demand from China. In fact, this resulted recently in soybean breaking crop records. Therefore, this is also a reinforcing feedback loop.

B1 (political loop): This loop shows how Brazilian politics interferes with the logistics system. Soybean production is responsible for generating jobs and foreign exchange for the country. The increase in production means a more significant economic surplus, which attracts more political interest in this sector. In Brazil, there is a high-level economic dependence on the agricultural sector, and therefore, higher political pressure is involved in economic activities related to this system. When such political pressure increases, the government interferes in bidding public works to the private sector for concession agreements. This tactic generates corruption scandals, which negatively impact transport infrastructure investment. A result of ineffective transport investment is a reduction in economic surplus in the Brazilian soybean system. Technically, this is a balancing feedback loop.

B2 (transportation modes loop): This loop shows a different dynamic of political pressure and the need for the holistic development of the transport system. Political pressure in Brazil results in logistical planning projects, such as the Growth Acceleration Program (PAC), and short-term decisions leading to more investment in roadways, resulting in limited investments in multimodal transport systems. This is a balancing feedback loop.

B3 (supply chain loop): With the lack of actual investment in transport infrastructure, investment in storage is lower. Recently, in Brazil, the deficit in static storage capacity has been growing, causing the hurried sale of soybean production to the foreign market. If investment in storage is not enough, paved roadways must be improved for soybean flow, as it is the most used mode for this purpose. However, when transport investments are concentrated on paved roadways, investment in multimodal transport systems is lower, and the effectiveness of transport investment decreases. Thus, this is also a balancing feedback loop.

3.3 Strategic interventions

3.3.1 Investment in storage. The first strategic intervention aims at improving the investment in storage and, thereby, the effectiveness of the SSC in Brazil. This strategy addresses one loop in the CLM, namely, the supply chain loop (B3). Only 1.35% of the country's total static capacity belongs to the Public Supply Company – CONAB (Companhia Nacional de Abastecimento – CONAB, 2019b), which shifts the storage problem to the following agent in the chain: the producers. The strategy adopted by producers is the Rural Warehouse Condominiums, a type of entrepreneurial organization that enables a complete storage structure among partner producers. In addition to helping overcome the storage deficit, condominiums provide cost savings (Filippi & Guarnieri, 2019). It is an alternative for producers not to sell their crops quickly without considering price fluctuations over time.

Despite the concentration on private companies, in 2020, the static capacity was 171.5 million tons, implying a deficit of about 85.5 million tons (Companhia Nacional de Abastecimento – CONAB, 2021; Goneli, 2021). Deficit considerations are necessary for the issue is not always capacity but location and it is also important to assess the dynamic capacity that considers the number of spins the storage unit has. Currently, the Rural Condominium Warehouse is the primary strategy for producers to combat the deficit in storage capacity. Government support through credit lines is vital to maintain and expand this initiative.

Agricultural trading companies have a significant market share in intermediate storage. The deployment of storage assets in new production regions is also a strategic factor at the source. Trading companies seek to deploy their assets to control flows between origin and shipment to factories and ports.

3.3.2 Investment in multimodal systems. The second strategic intervention aims at increasing the investment in multimodal transport systems. This strategy addresses two loops in the CLM, namely, transportation modes loop (B2) and supply chain loop (B3).

In the case of soybean and corn exports, 50% are transported by road, 40% by rail and 10% by waterway (Branco, Bartholomeu, Junior, P. N. A., & Caixeta Filho, 2020; Brasil, 2019). In the past decade, investments in highways represented about 50% of all investments (Confederação Nacional do Transporte – CNT, 2021). In 2010, highways concentrated 62% of investments, and, in 2020, following the significant drop in investments, the concentration in highways was 52% (Confederação Nacional do Transporte – CNT, 2021). Although agricultural trading companies move significant volumes through railways and waterways, these modes have limited capacity, and their real potential remains unused, either due to lack of assets or investment. In the case of railroads, a large part of their capacity is dedicated to handling ore and steel products, whereas grains correspond to only 11% of rail capacity (Agência Nacional de Transportes Terrestres – ANTT, 2021). For waterways, besides the lack of investments, there is the issue of competing use of water for energy generation (hydropower dams) (Pompermayer, Campos Neto, & de Paula, 2014; Oliveira, 2014).

Due to economic crises throughout the 1980s and 1990s, the State had limited financing capacity to develop and expand logistics infrastructure. As a result, in the early 2000s, railways were decapitalized and could not obtain resources to increase the capacity of the transport system. Private companies that operated Brazilian railways proposed long-term transportation contracts with trading companies in the sugar-energy sector in which they guaranteed transportation and investment for the system recovery. In contrast, the trading companies purchased locomotives and other materials (Oliveira, 2015). Like sugar, soybeans offer large volumes regularly, and this multimodal transport can be replicated to the grain sector.

To balance Brazilian soybean production and export dynamics, Brazil needs investments to improve the existing infrastructure and enable new multimodal routes, especially regarding the North and Northeast ports above Parallel 16 (Lopes, 2021). This lack of railroads and waterways allowed the 2018 truck drivers' strike to cause a severe shortage crisis in the country, the agricultural sector being one of the most affected (Kreter, Souza Junior, Staduto, & Oliveira, 2018).

3.3.3 Actual transport infrastructure investment. This strategy addresses three loops in the CLM, namely, political loop (B1), transportation modes loop (B2), and supply chain loop (B3). Due to the lack of resources, instead of expanding the existing road infrastructure, the Growth Acceleration Program (PAC) has been investing mainly in the maintenance of road stretches. The budget actions for road construction represented, at most, 26.0% of the resources from 2006 to 2017 (CNT, 2017). The main problem is that the country's logistical planning projects lack continuity as they are long-term so hampered by changes in government, which often abandon old projects in the name of a renewed agenda. The difficulties in maintaining public investments in this sector can be explained mainly by the economic and political crises that the country has been going through in recent governments.

The articulation of public policies as public-private partnerships can be one of the leverages here (Elias & Davis, 2018). Provided for in Law No. 11.079/04 (Brasil, 2004), this type of contract between the parties supplies the insufficiency of the government's resources for investments in infrastructure. Therefore, transparency of procedures and decisions, financial sustainability, and socio-economic advantages of partnership projects are guidelines of this law. In addition, these partnerships can contribute to the country's transportation multimodality, thus improving the effectiveness of transport investment.

7. Conclusions

This study provided a systemic analysis of some complexities associated with the SSC system in Brazil. The main challenge mentioned by the experts was the lack of coordination between stakeholders and government in articulating public policies aimed at infrastructure investments. Therefore, three strategic interventions were designed to address these issues. The first strategic intervention aims at improving the investment in storage, whereas the second intervention aims at increasing the investment in multimodal transport systems. Finally, the third strategic intervention aims at improving transportation infrastructure investment.

In Brazil, the advances in agribusiness are in synchronicity with some sectors of the economy, such as science and technology, but not logistics, causing some weaknesses, either due to the lack of transport infrastructure or to the discontinuation of logistical planning projects. In addition, the storage network does not keep up with the dynamism of production.

This study is limited to the evaluation of an agricultural commodity (soybean) and does not include its by-products. Furthermore, the sample of stakeholders was limited, and the boundary of analysis was Brazil. Finally, this study can encourage further empirical research, which will help explain complex problems in agribusiness systems. For future studies, the evaluation of the cradle to grave SSC and the internal market could be performed, as well as the comparison of Brazilian SSCs with other countries with similar territorial extension and strong agricultural competitiveness, such as the USA.

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