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THE SUPPLY CHAIN OF BRAZILIAN MAIZE: APPLICATION OF A PARTIAL EQUILIBRIUM MODEL

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Abstract

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The main consumers of Brazilian corn are in Asia and the main Brazilian production regions are far from ports, causing this product to travel long distances to arrive at its destination. This study begins with the hypothesis that reductions in transport costs can promote the competitiveness of corn on the international market, using intermodality. The methodology used is a partial equilibrium model based on quadratic programming to optimise the logistic flows of corn. Three scenarios are proposed. Scenario 1 depicts the reality currently practised in the sector and being the base scenario. Scenario 2 simulates a 15% reduction in costs in waterway and railway transportation to verify the potential of intermodal routes. Finally, Scenario 3 considers two new routes from new public infrastructure works. Results indicate that there were significant gains resulting from increased transportation options for corn,as well as the consequent revenue gains, especially in Scenario 2, in which 60% of the active routes were intermodal. Scenario 3 is also worth mentioning as it showed increased production in the region of Mato Grosso. This indicates that investments in logistics infrastructure will increase the competitiveness of Brazilian corn in the international market.

Key words: Brazilian maize; intermodality; equilibrium model; logistics; infrastructure

Introduction

The Brazilian agribusiness expansion has been characterised by increasingly integrated production chains and the intensive use of capital in various segments. According to Oliveira (2011), agriculture is still characterised by a substantial share in the GDP, increased trade surplus as well as a significant contribution in controlling inflation. Brazilian agro-industrial systems are highly developed.

Brazil's market share in global corn exports is approximately 22% (33 million tonnes), representing 35% of the national produce, and supports Brazilian trade (USDA, 2017). Besides the economic importance, corn is an essential component of animal feed for livestock such as poultry, pork and cattle.

Corn is grown in practically all Brazilian territories, with the south, southeast and Midwest regions comprising approximately 90% of the produced volume. The main consumer markets are located outside Latin America, and the main Brazilian production regions are far from the ports, causing this cereal to travel long distances to arrive at its destination. Thus, transport and storage costs are major factors limiting the competitive potential of Brazilian corn.

Logistics has a fundamental role in terms of competitiveness. Therefore, the efficient use of multimodal transport is crucial for the minimisation of costs and the expansion of production chains. However, when the modes of transport cannot be fully used, managing the cost becomes a problem (Fernandes et al., 2010).

According to Morabito et al. (2012), the main function of transport in logistics is adding place value to the product as the products are not always consumed on the same site where they are produced. The transport system can have

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agreat impact on the logistics costs as well as impact other logistics activities. It is estimated that transport costs can represent up to two-thirds of logistics costs.

Morabito et al. (2012) also mentioned that one of the ways to contrast the economies of developed and developing countries is to compare their transportation matrixes and the role that it plays in the activity. That is, a developed country will rarely have an inefficient transportation system and/or a developing country will rarely have an efficient transport system. An efficient transportation system contributes to greater competitiveness, economies of scale and price reductions.

According to Caixeta-Filho and Gameiro (2001), there was great movement in the spatial arrangement in the Brazilian agricultural economy, where agribusiness occupied borders such as north and Midwest and moved to the northeast to the region called MATOPIBA.[1] In general, this was done through activities that incorporate modern production technologies. As a consequence, it was essential to attract a support chain for the main business, including suppliers of inputs, warehousing and processing industries' cluster around the production areas, to minimise transportation costs as per the principles of economic rationality. They also state that in Brazil, the average distance travelled by agricultural loads is more than 1600 km. Moreover, considering the total loads transported by railroads, the average distance travelled is less than 500 km.

According to Batalha (2010), an efficient transportation system contributes to generating more competitiveness as products coming from long distances become competitive in the same market, increase the economies of scale, reduce losses and damages and reduce costs.

In this context, the change in the direction of the flow of agricultural production stems from a reduction in transport costs caused by multimodality and the reduction of the distance to the port.

However, the Brazilian situation illustrates an inefficient transport system. Unfortunately, the trajectory of rapid growth in demand for transport activities was not accompanied by the investments and maintenance necessary for Brazilian infrastructure. According to Oliveira (2011), if the large expanse of the Brazilian territory is compared to that of other countries of similar size that use railways and/or waterways more often, the load transport matrix in Brazil is highly concentrated on highways and does not use the other modes to their full capacity. According to data from CNT (2014), the highway modality accounted for approximately 61% of what was transported in the year.

Caixeta-Filho (1996) stated that this predominance is explained by the difficulties that other modalities have in responding to increases in demand, which may be considered inappropriate for long distances, especially in relation to the agricultural loads. One of the factors of predominance of this mode is the great availability of highways in Brazil and also the difficulties of transportation others modes face in meeting demand in more distant areas of the country, which are not served by railways and waterways.

Therefore, the aim of this paper was to evaluate the logistics distribution of corn and identify obstacles for it to gain competitiveness in the world market. To optimise the transportation of Brazilian corn, we applied a spatial equilibrium model of quadratic programming. The largest part of the total costs with the commodity is represented by transportation costs; therefore, analysing the transportation of this cereal in the supply chain is a key to the design of strategies for the sector.

Methodology

In economic theory, the aspects related to distribution and spatialisation of productive activities is topics subjected to constant analysis. In various theoretical approaches, the cost of transportation is the main factor for the decision to undertake a certain productive activity and also determines the relation between activities and regions (Oliveira, 2011).

The location theory was composed of models developed by Von Thünen in 1826, Alfred Werber in 1909, August Lösh in 1940 and Walter Isard in 1956, which focused on the issue of productive activities associated with transport costs (Azzoni, 2011).

For this study, a spatial equilibrium model formulated as a mixed complementarity problem(MCP) was used based on the works of Samuelson (1952) and Rutheford (1994). The MCP was proposed by Thore (1992), Rutheford (1995) and Bishop et al. (2001), and models based on these authors have already been used by Alvim (2003), Alvim and Waquil (2005), Oliveira (2011) and Caetani (2014).

Partial EquilibriumModel

The partial equilibrium models, also known as spatialequilibrium models, usually consider an industry or product and investigate the effects of a variation (exogenous) of the relative price on equilibrium of the sector, assuming that the allocation in the rest of the economy remains unchanged. Thus, the method aims to solve trade problems between different regions, which have supply, demand and different trade flows spatially separated (Alvim, 2003).

[1] Term created with the initials of the involved states: Maranhão, Tocantins, Piauí and Bahia

Samuelson (1952) formulated the problem, considering an area of maximisation under all excess demand curves minus the area of all the excess supply curves minus the total transportation costs. The maximisation of all these areas results in a competitive solution of spatial equilibrium, i.e. one that is based on the areas resulting from the intersection of the curves of these variables (Martins and Lemos, 2006).

According to Alvim (2003), Samuelson's (1952) formulations consist of presenting a spatialequilibrium model that is represented from a problem of optimisation by a net social payoff (NSP) objective function, obtained by the sum of producers and consumers' surpluses represented by the corresponding integrals to each surplus in the equation minus the transportation costs. Maximising the function means that producers and consumers reach well-being at the Pareto optimality.[2] Therefore, considering a non-conditioned optimisation to any product, in a given region, the NSP concept can be presented as a function of the quantity, which is shown as:

$$NSP = \int_0^{q_0} p^d(q)dq - \int_0^{q_0} p^s(q)dq, \tag{1}$$

where:

p^d – price of the product payed by the consumer
p^S – price of the product received by the producer
q – consumed or produced quality.

The first integral is interpreted as the sum of the total benefits of agents who consume a product. The second integral is interpreted as the sum of the cost of production for a given product.

Takayama and Judge (1971) extended Samuelson's (1952) formulation by developing an algorithm to solve the spatial equilibrium conditions involving various commodities traded between many supply and demand areas and also the price level. Therefore, they used a linear dependent price and functions of demand and supplyextended from Samuelson's (1952)formulation to obtain spatial and intertemporal dimensions of price, production, use factor and consumption determined by aquadratic programming chart.

According to Oliveira (2004), the theoretical structure of this model can be expanded, including multi-exporting and importing regions as well as multimodal and multi-commodity transport. They can be used to simulate the impact on the markets resulting from the application of trade policies, such as quotas, tariffsand others.

Mixed Complementarity Problem (MCP)

The MCP is a partiale quilibrium model developed by Rutherford (1995), which consists of a system of simultaneous equations (linear and/or non-linear) described as inequalities based on the functions of supply and demand of the concerned product. It has the advantage of allowing the incorporation of tariffs, tariff quotas and changes in the cost of transportation with greater ease. This model is based on interior point algorithms, i.e. equivalent to the Karush–Kuhn–Tucker[3] (KKT) conditions, which are necessary and sufficient to achieve the maximum NSP, which, in turn, implies the achievement of a balance in all markets and regions (Rutherford, 1995).

Figure 1 represents the spatial equilibrium conditions for agricultural commodities in export and import regions, tak-

[2] Pareto optimality: A situation in which resources are allocated in such a way that no different reordering can improve the situation of any individual or economic agent without worsening the situation of any other (Sandroni, 2008)

[3] Karush–Kuhn–Tucker conditions, also known as Kuhn–Tucker or KKT conditions are the necessary conditions for a solution to problems of non-linear mathematical programming being optimal, satisfying certain regularity conditions. In general, they are a generalization of the Lagrange multipliers method (Chiang, 1982)

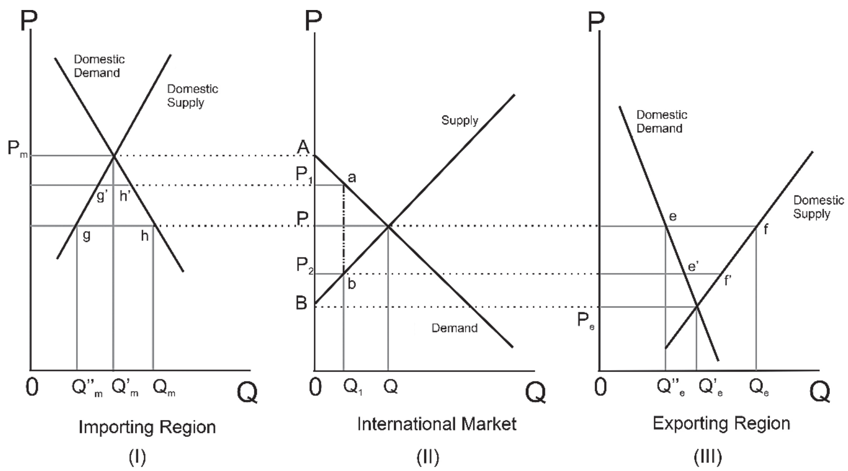

Fig. 1. International balance of trade between two regions
Source: Oliveira (2011)

ing transport costs into consideration, with P corresponding to price and Q to quantity.

Equating the transportation cost to zero for trading between the two regions, the flow of the commodities traded is equal to the excess of supply (*ef*) in the export region (III); however, the imported volume is equal to the excess demand (*gh*) at the equilibrium price (I). Assuming the existence of tariffs and transport costs between (a) and (b) in the graph (II), it is assumed that the price difference between imports and exports is equal to rates and transportation costs and that costs and rates are the same as those adopted by the export and import regions, following the behaviour of the respective elasticities.

Using Takayama and Judge (1971) as reference, it is possible to replace the two trade regions as i regions, causing supply functions (3) and demand (2) to be described as:

$$p_i = d_i(y_i)\forall i \quad (2)$$

$$f_i = s_i(z_i)\forall i \quad (3)$$

where,
p_i – demand price in the region i
y_i – demanded quantity with price p_i on region i
f_i – supply price on region i
z_i – supplied quantity with price p_i on region i

The partial equilibrium model that limits the level of production and consumption, the marketing price and quantity sold between the regions is represented by:

$$MaxNW = \sum_{i=1}^{n} W_i(y_i, z_i) - \sum_{i=1}^{n}\sum_{i=1}^{n} t_{ij}x_{ij} \quad (4)$$

s.a

$$y_i = \sum_{i=1}^{n} x_{ji} \quad \forall i$$

$$z_i = \sum_{i=1}^{n} x_{ij} \quad \forall i$$

$$y_i, z_i, x_{ij} \geq 0 \quad \forall i, j$$

MCP Applied to the CornCase

The solution suggested by this model can help determine the trade flows between the regions, detailing the best options for transporting the corn and considering transport costs, the location of production and consumption. In addition, it is possible to quantify the reduction of Brazilian competitiveness in the international market given the unbalanced transport matrix.

Market equilibrium is achieved by maximising the NSP function by the sum of surpluses of producers and consumers and subtracting transportation costs between producer and consumer regions (Samuelson, 1952). When the analysis is restricted to a region, the NSP is equal to the total surplus (ET), but when different regions are considered, the NSP is equal to ET minus the sum of the transportation costs between regions (Alvim, 2003).

The model was developed by taking into consideration the approach of Samuelson, Takayama and Judge (1971), which showed that by using a quadratic programming framework, it is possible to determine the spatial and intertemporal dimensions of price, production, factor of use and consumption.

To ensure that the supply regions extrapolate the quantity exported by considering quantity produced and that the demand regions do not import more than the demanded capacity, restrictions (5) and (6) were included in the model. As for restriction (7), it ensures that the produced quantities consumed and marketed do not have negative values (Waquil, 2000;Alvim, 2003).

Therefore, the proposed approach is represented by

$$NSP = \sum_{j=1}^{J}\int_{0}^{q_j} p_j dy_i - \sum_{i=1}^{I}\int_{0}^{q_i} p_i dz_i - \sum_{i=1}\sum_{i=1} t_{ij}x_{ij}$$

and is subject to:

$$\sum_{j}^{J} x_{ij} - z_i \leq 0 \quad (5)$$

$$y_i - \sum_{j}^{I} x_{ij} \leq 0 \quad (6)$$

$$y_i \geq 0,\ zj \geq 0 \text{ and } x_{ij} \geq 0, \quad (7)$$

being:
q_j – consumption on region j
q_i – consumption on region i
p_j – demand price on the region j
p_i – supply price on the region i
y_j – demanded quantity on region j
z_i – supplied quantity on region i
x_{ij} – product flow between regions i and j
t_{ij} – transportation costs between regions i and j
J – Lagrange multiplier: shadow price for corn on producer region i
I – Lagrange multiplier: shadow price for corn on producer region j

To obtain the Lagrangian function[4] and the Karush–Kuhn–Tucker conditions associated with the optimisation problem, the objective function must be differentiable, concave and with linear restrictions. It might be presented by:

[4] In cases involving restrictions of the 'equality' type, but with more restrictions, the Lagrange multiplier method is recommended (Caixeta-Filho, 2001)

$$L = \sum_{j=1}^{J}\int_{0}^{q_j} p_i dy_i - \sum_{i=1}^{I}\int_{0}^{q_i} p_i dz_i - \sum_{i=1}\sum_{i=1} t_{ij} x_{ij}$$

$$- \sum_{i}^{I} \varphi_i\left[\sum_{j}^{J} x_{ij} - z_i\right] - \sum_{j}^{J} \lambda_i\left[y_i - \sum_{i}^{I} x_{ij}\right] \quad (8)$$

Thus, the MCP model that is proposed to analyse the Brazilian corn market is presented by:

i = supply regions (i = 1,…,8)

j = domestic demand regions (j = 1, 2)

k = international demand regions (k = 1,…,4)

r = transport routes (r = 1, …, 13)

p_i = supply price

p_j = domestic demand price

p_k = international demand price

z_i = supply quantity

y_j = quantity consumed by domestic demand

y_j = quantity consumed by international demand

x_{ij} = quantity transported from i to j

t_{ij} = transport cost from i to j

φ_i = shadow price associated with the supply region i

λ_j= shadow price associated with the domestic demand region j

μ_k = shadow price associated with the international demand region k

Model Data

To create and implement the Scenario 1 model, we identified the regions of supply and demand and the existing routes to transport the agricultural production from these localities. After this step, we selected the representative producer and consumer Brazilian states as well as representative demand from thecountries trading with Brazil. The selected states were the following: Paraná, Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais and São Paulo as regions with corn supply. Santa Catarina and Rio Grande do Sul were regarded as areas of demand. The corn-importing countries considered were the following: Iran, Taiwan (China), Japan and South Korea.

For the implementation of the model, 13 routes were selected. Some of these exclusively use the highway mode. The sources of production data were the following: the Brazilian Institute of Geography and Statistics (IBGE), the National Supply Company (CONAB), the United States Department of Agriculture (USDA) and the Food and Agriculture Organization of the United Nations (FAO).Consumption data was from the following sources: the IBGE, the Brazilian Association of the Producer and Exporter Industry of Swine (ABIPECS) and the Brazilian Association of Poultry Producers and Exporters (ABEF).The price of corn for the different states was based on the CONAB while for the international market, we used data from the USDA. Table 1 shows the data set.

Table 1
Model parameters, regions of supply and demand of corn (2013/2014)

Supply	Production (t)	Consumption (t)	Oversupply (t)	Price (US$/t)	Elasticity-price of supply
Mato Grosso	19 883.8	6 157.8	13 726.0	-	0.30
North - MT	13 521.0	4 514.6	9 006.4	111.97	0.3
Southeast - MT	6 362.8	2 003.2	4 359.6	117.86	0.3
Mato Grosso do Sul	7 669.8	2 684.1	4 985.7	144.94	0.45
Paraná	16 110.6	11 520.8	4 589.8	161.07	0.38
Goiás	6 410.5	3 468.1	2 942.4	166.55	0.41
Minas Gerais	7 220.2	4 557.6	2 662.6	190.10	0.29
São Paulo	4 687.2	3 924.7	762.5	187.46	0.29
Total	**81 865.9**	**38 830.9**	**43 035.0**		
Domestic Demand	Production (t)	Consumption (t)	Excess of Demand (t)	Price (US$/t)	Elasticity-price of demand
Santa Catarina	3 242.0	7 055.7	3 813.7	180.71	-0.11
Rio Grande do Sul	5 345.8	6 779.7	1 433.9	191.48	-0.11
Total	**8 587.8**	**13 835.4**	**5 247.6**		
International Demand	Production (thousand t)	Consumption (thousand t)	Excess of Demand (thousand t)	Price (US$/t)	Elasticity-price of demand
Japan	1.0	15 200.0	15 199.0	231.03	-0.21
South Korea	80.0	9 900.0	9 820.0	231.03	-0.38
Iran	1 250.0	6 250.0	5 000.0	231.03	-0.19
Taiwan	100.0	4 325.0	4 225.0	231.03	-0.48
Total	**1 431.0**	**35 675.0**	**34 244.0**		

For transportation by highway, railway, waterway and the ocean,we used the System for Transportation Information (SIFRECA). As for the data on price elasticities of supply and demand, we used the studies developed by Fuller et al. (2001 and 2003) and the Food and Agricultural Policy Research Institute (FAPRI, 2011).

The highway transportation costs were estimated by linear regression based on distances and on prices charged for corn using a database of highway transportation prices charged in 2013 and 2014.

The MCP model proposed was implemented in the modelling system for mathematical programming and optimisation called the General Algebraic Modelling System (GAMS).

Scenario 2 included a reduction of 15% in the waterway and railway transportation opportunities. The data on supply and demand have not changed but the transportation costshave. This scenario was created by the assumption that the construction works proposed in PAC II were completed and would thus result in a reduction in these costs, impacting the entire distribution logistics chain. With this, it is expected

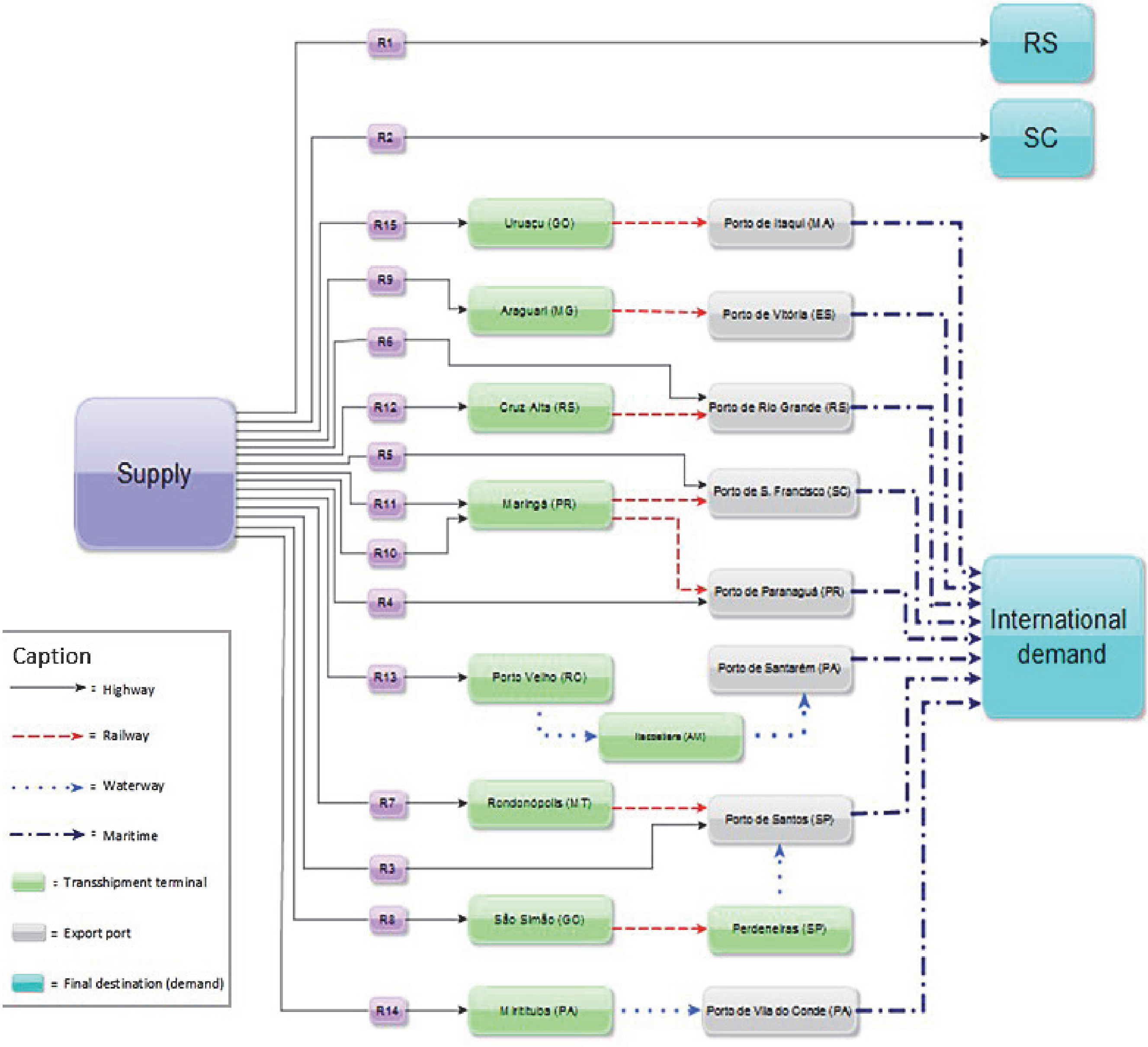

Fig. 2. Flow of routes between supply and demand regions

that the intermodal routes would become more competitive.

In Scenario 3, the same database of Scenario 1 was used, adding routes from the Growth Acceleration Program (PAC), new public works of infrastructure, with improvement works carried out in the midwest and north regions. Therefore, in this scenario, we considered the extension and the paving of highway BR-163 and the potential waterway private terminal in the district of Miritituba, west of Pará, to thus move through the waterway of the Tapajós, having the port of Santarém as a destination in addition to using the Norte-Sul Railway, from the transshipment terminals in Goiás. In this scenario, we expected that with the inclusion of the new routes, they are activated by the model. The routes added are the following: rota R14, which is the highway to the port of Miritituba, following the Tapajós waterway to the port of Vila do Conde. Route R15, which is the highway to the transshipment terminal in Uruaçu (state of Goiás), following through the Norte-Sul Railway towards Açailândia. After this point, it will follow the Carajás railway to the port of Itaqui (state of Maranhão).Figure 2 illustrates the logistical flow of the routes considered for the development of this model in three scenarios, indicating the points of origin, their transshipment terminals, export ports or destination and the transportation modes used.

Results

The spatial equilibrium model obtained in this study went through a process of verification and validation of data to determine its reliability and utility and thus to generate future scenarios. First, we verified the resulting data, analysing the flows generated between supply and demand for corn in the respective regions.

According to Alvim (2003), mathematical programming models are validated by checking the consistency of the problem's results. For Waquil and Cox (1995), validation required an adaptation of the coefficients and of the structure of the model. The model can be validated by verifying how well the solution suggested by the model approaches the real situation. Therefore, differences occurred between the results estimated by the model and the data observed but without invalidation (Table 2).

It is important to note that the model applied in this study is restricted by demand. Despite counting a supply of 29308.98 thousand tonnes, the general demand is of 16889.02 thousand tonnes. Thus, the model satisfies the demand and even results in a bigger supply. In other words, in this case, we can enlarge international trade relations, including other demanding countries.

Table 2
Volumes of supply, domestic demand and international demand. Model estimates (Scenarios 1, 2 and 3) and Observed Data

Selected regions	Scenario 1 (A)	Scenario 2 (B)	Scenario 3 (C)	Observed Data	Variation (B/A)	Variation (C/A)	Variation (C/B)
SUPPLY		(thousand tonnes)				(%)	
Mato Grosso	7 908.36	8 065.96	9 116.03	13 366.03	1.99	15.27	13.02
North	4 844.29	4 871.96	6 365.55	9 006.40	0.57	31.40	30.66
Southeast	3 064.07	3 194.00	2 750.48	4 359.63	4.24	-10.23	-13.89
Mato Grosso do Sul	3 016.20	2 950.13	2 678.72	4 985.75	-2.19	-11.19	-9.20
Paraná	3 450.14	3 410.47	3 251.22	4 589.80	-1.15	-5.77	-4.67
Goiás	1 802.01	1 849.11	1 628.94	2 942.39	2.61	-9.60	-11.91
Minas Gerais	1 993.58	1 974.57	1 897.33	2 662.56	-0.95	-4.83	-3.91
São Paulo	598.23	593.32	573.52	762.45	-0.82	-4.13	-3.34
TOTAL SUPPLY	18 768.53	18 843.55	19 145.75	29 308.98	0.40	2.01	1.60
DOMESTIC DEMAND							
Santa Catarina	4 035.71	4 045.19	4 083.65	3 813.66	0.23	1.19	0.95
Rio Grande do Sul	1 524.31	1 527.83	1 542.10	1 433.92	0.23	1.17	0.93
SUB-TOTAL	5 560.03	5 573.02	5 625.75	5 247.58	0.23	1.18	0.95
INTERNATIONAL DEMAND							
Japan	4 061.69	4 074.31	4 124.77	3 737.26	0.31	1.55	1.24
South Korea	4 055.21	4 078.09	4 170.17	3 484.88	0.56	2.83	2.26
Iran	2 362.48	2 369.50	2 397.59	2 168.57	0.30	1.49	1.19
Taiwan	2 729.11	2 748.63	2 827.47	2 250.72	0.72	3.60	2.87
SUB-TOTAL	13 208.50	13 270.53	13 520.00	11 641.44	0.47	2.36	1.88
TOTAL DEMAND	18 768.53	18 843.55	19 145.75	16 889.02	0.40	2.01	1.60

Scenario 1 represents trade transactions without imposing cost reductions or changes to routes, representing the transactions with the data already used in the market. Mato Grosso, a supply region, shows an increase of 1.99% in Scenario 2 and of 15.27% in Scenario 3, considering Scenario 1. This demonstrates the prioritisation of this supply region to the model,while other regions of supply showed a decrease. Regarding demand, the demanding regions, both domestic and international, showed an increase in volume.

Scenario 2, which considered a 15% reduction in transportation costs, obtained an increase in the commercialisation in regions that used intermodal routes, such as Mato Grosso. As for regions such as São Paulo and Minas Gerais, which used highways directly, they suffered a reduction in trade volume. In Scenario 3, which considered two new routes, we obtained an improvement in trading volume on the intermodal route for the north of Mato Grosso, which shows that the project of using this route (R14) and getting one more option for transporting corn by the ports in the north of the country is feasible.

Tables 3, 4 and 5 present the trade flows and the logistical routes used for the transporting corn in Scenarios 1, 2 and 3, respectively.

Scenario 1 demonstrates that for the domestic market, the state of Santa Catarina, considered a consumer state, receives the total corn production of the state of Paraná and a portion of the production of the state of Mato Grosso do Sul (approximately 19.4%), While the other portion produced by the state of Mato Grosso do Sul (approximately 50.5%) is sent to the state of Rio Grande do Sul. In both cases, the production is transported through highways (routes R1 and R2) (Table 3).

Table 3
Trade flows by transportation route in Scenario 1 (thousand tones)

Supply	Demand	Routes *					
		R1	***R2***	***R3***	***R7***	***R10***	***R13***
PR	SC		3 450.14				
MS	SC		585.57				
MS	RS	1 524.31					
MT-N	Japan						4 061.69
MT-N	Korea						782.60
MT-SE	Taiwan				2 691.35		
MT-SE	Korea				372.72		
MS	Korea					906.32	
GO	Iran			1 764.25			
GO	Taiwan			37.76			
MG	Korea			1 993.58			
SP	Iran			598.23			

Scenario 1: Highway route (unimodal): R1; R2; R3. Intermodal route: R7, R10; R13
* Description of the routes and supply and demand regions, see APPENDIX A

Table 4
Trade flows by transportation route in Scenario 2 (thousand tonnes)

Supply	Demand	Routes						
		R1	***R2***	***R3***	***R7***	***R8***	***R10***	***R13***
PR	SC		3,410.47					
MS	SC		634.72					
MS	RS	1,527.83						
MT-N	Japan							4,074.31
MT-N	Korea							797.65
MT-SE	Taiwan				2,748.63			
MT-SE	Korea				445.37			
MS	Korea						787.58	
GO	Korea					1,849.11		
MG	Iran			1,974.57				
SP	Iran			394.93				
SP	Korea			198.39				

Scenario 2: Highway route (unimodal): R1; R2; R3. Intermodal route: R7, R8; R10; R13

Table 5
Trade flows by transportation route in Scenario 3 (thousand tonnes)

Supply	Demand	Routes *					
		R1	***R2***	***R3***	***R7***	R10	R14
PR	SC		3 251.22				
MS	SC		832.43				
MS	RS	1 542.10					
MT-N	Japan						4 124.77
MT-N	Korea						2 240.78
MT-SE	Taiwan				2 750.48		
MS	Iran					227.19	
MS	Taiwan					76.99	
GO	Korea			1 628.94			
MG	Iran			1 897.33			
SP	Iran			273.07			
SP	Korea			300.45			

Scenario 3: Highway route (unimodal): R1; R2; R3. Intermodal route: R7, R10; R14
*Description of the routes and supply and demand regions, see Appendix A

Analysing the international market, Scenario 1 demonstrates that 83.8% of production in the north of the state of Mato Grosso is sent to Japan and 16.2% to South Korea, both by the intermodal route (highway and waterway) to the port of Santarém, through the Madeira River waterway (route 13). In contrast, from the production of southeast of Mato Grosso, approximately 88% is sent to Taiwan and 12% to South Korea but both through the intermodal transportation (highway and railway), via the Transhipment Terminal of Rondonópolis to the port of Santos (route R7). The remaining production of the state of Mato Grosso do Sul (approximately 30%) is destined to South Korea and is sent through an intermodal route (highway and railway) to the port of Paranaguá (route R10). The largest part of the production of the state of Goiás, approximately 98%, is sent to Iran and the rest to Taiwan, via highway, to the port of Santos (route R3). The production of the states of Minas Gerais and São Paulo are sent to South Korea and Iran through the port of Santos, also via highway (route R3) (Table 3).Figure 3 illustrates the trade flows between the supply and demand regions, considered the active routes in Scenario 1.

With a 15% reduction in the waterway and rail transportation prices, no major changes happened in the producing regions of Mato Grosso, Mato Grosso do Sul and Parana for corn in Scenario 2. However, the state of São Paulo began supplying the cereal to two countries, Iran (66.6%) and South Korea (33.4%); Minas Gerais began to supply all its cereal production to Iran, both via the port of Santos by highway mode (route R3). The state of Goiás, which previously supplied Iran and Taiwan, went on to provide corn only for South Korea, via the port of Santos by an intermodal route (highway and railway), through the transshipment Terminal of São Simão (route R8), which began to be competitive (Table 4).Figure 4 illustrates the trade flows between the regions of supply and domestic and international demand, demonstrating the active routes in Scenario 2. Compared with Figure 3, it is possible to see the movement of flows and the increased use of intermodal routes.

With the implementation of new routes in the model, Scenario 3 presented an increase in production in the north of Mato Grosso compared with Scenario 1, at approximately 24%. In this producer region, the portion of the production sent to Japan

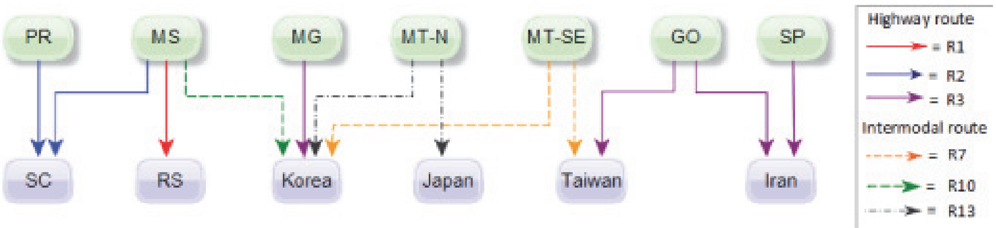

Fig. 3. Trade flow by transportation route between supply and demand regions, Scenario 1

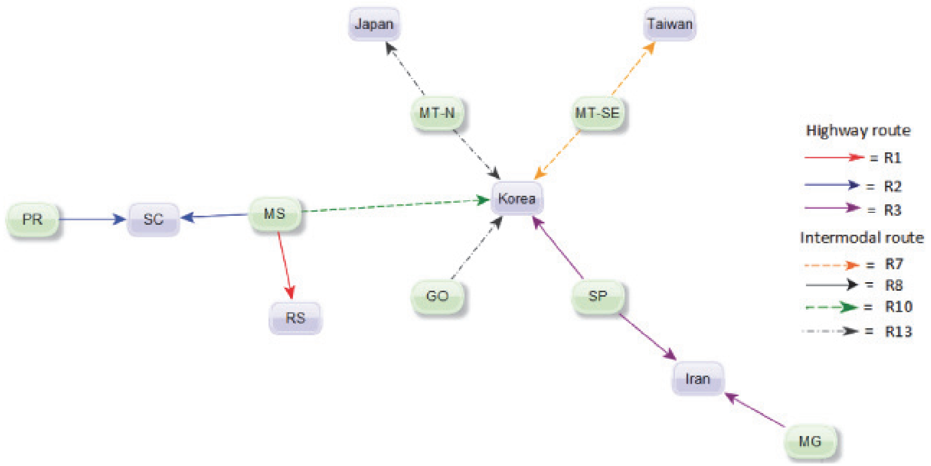

Fig. 4. Trade flow by transportation route between supply and demand regions, Scenario 2

(65%) and to South Korea (35%) followed the changed route. Earlier, the products were sent to the destination countries via the port of Santarém. This scenario shows that the competitive route is the intermodal route that uses highway and waterway, with the production moving by truck until the port of Miritubа and then by the Tapajós waterway to the port of Vila do Conde (route R14). Another change is in the production of the southeast of Mato Grosso, which is sent in its entirety to Taiwan through the intermodal route, moved by truck to the rail terminal of Rondonópolis and then to the port of Santos via railway (route R7). The production of the state of Mato Grosso do Sul is destined for the international market, which was earlier approximtely 30% (Scenario 1) and 26% (Scenario 2). In this scenario, it is sent to two countries, Iran (9.6%) and Taiwan (3.2%), and saw a reduction of the production exported by approximately 500000 tonnes. However, it still uses the intermodal route (highway and railway), moving by truck to the rail terminal of Maringá and via railway to the port of Paranaguá (route R10) (Table 5). Figure 5 illustrates the trade flows between the regions of supply and domestic and international demand, demonstrating the active routes in Scenario 3.

Analysing logistics transportation considering the modes used, it is possible to observe that in Scenarios 1 and 3 – 50% of the routes for transporting the production of corn between supply and demand regions was done through unimodal routes (highway), while in the other intermodal routes used, one-third of the production was transported by highway and waterway. In contrast, in Scenario 2 – 60% of the routes were intermodal. Thus, Scenario 1 and 3 transported approximately 53% and 51%, respectively, of the production via highways. While in Scenario 2 – 56.8% of the corn production was transported through intermodal routes. It is worth highlighting that the north region of Mato Grosso, in Scenario 3, which increased its capacity and production according to the results of the model, also saw an improvement in transport costs because, through the lower transportation costs, the model gives priority to this

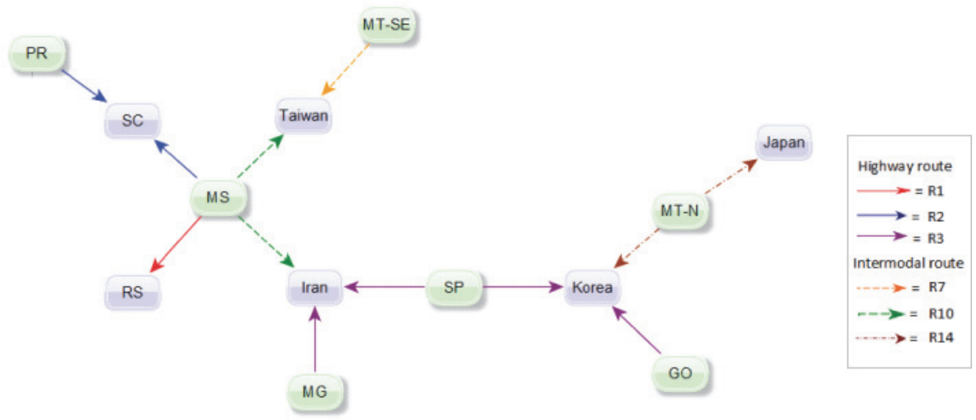

Fig. 5. Trade flow by transportation route between supply and demand regions, Scenario 2

Appendix A
Description of the routes considered in the model

Route	Description		
	Destination	Transport modes	Transshipment point
R1	RS demand	Highway	
R2	SC demand	Highway	
R3	Port of Santos	Highway	
R4	Port of Paranaguá	Highway	
R5	Port of São Francisco	Highway	
R6	Port of Rio Grande	Highway	
R7	Port of Santos	Highway and railway	Rail terminal of Rondonópolis
R8	Port of Santos	Highway and railway	Railway terminal of São Simão
R9	Port of Vitória	Highway and railway	Railway terminal of Araguari
R10	Port of Paranaguá	Highway and railway	Railway terminal of Maringá
R11	Port of São Francisco	Highway and railway	Railway terminal of Maringá
R12	Port of Rio Grande	Highway and railway	Railway terminal of Cruz Alta
R13	Port of Santarém	Highway and waterway	Waterway port of Porto Velho
R14	Port of Vila do Conde	Highway and waterway	Waterway port of Miritituba
R15	Porto de Itaqui	Highway and railway	Railway terminal of Uruaçu

Source: Developed by the authors from research data, 2014

region instead of others that do not have competitive transportation costs. Therefore, it is possible to notice the importance of creating a new route,which is implemented in this scenario, thus validating the suggest route R14.

Final Remarks

In recent years, Brazil's agricultural sector has seen great expansion. Regions such asthenorth, northeast and midwest begin to stand out more in terms of grain production. This study aimed to evaluate the logistics distribution of the Brazilian corn and to identify some barriers to the improvement of the product's competitiveness on the international market.

We found that the country's exports of corn grew, but it was clear that the long distances that the product needs to travel to get to its destination are significant and mostly done on highways. Thus, the flow of the agricultural production is important to increase economic competitiveness.

With the application of the methodology, it was possible to observe the effects of transportation of corn flows between different regions from the perspective of supply and demand, with the implementation of two possible scenarios. These scenarios considered the reduction of railway and waterway transportation costs and added two routes. The scenarios assumed that improvement works in the Brazilian logistics infrastructure were completed. Thus, we confirmed the hypothesis that intermodality contributes to increases in trade flows and transported quantity.

However, the current logistics infrastructure has direct implications in transportation costs, especially for the highway mode in which the transportation prices charged can vary in different regions on the basis of the conditions of the roads, the average age of the fleet and large vehicle traffic in urban centres. Because of this, there may bean excessive charge to handle goods in the country.

Intermodality is a solution for the efficiency of the transport system as well as being a way to reduce costs. The combination of the modes is feasible if it respects the ability and the specific characteristics of each transportation mode to be used. In Brazil, as a result of the precarious and inadequate infrastructure, it is not possible to utilise the maximum capacity of certain modes. This is true for waterways for example, which are not fully navigable, and it is also true for the small number of railroads in use.

With the proposed model, which demonstrates a great distribution of the transported volume and the use of intermodality, particularly in the northern region of Mato Grosso, investments in the national logistics infrastructure must be considered by the government. We can conclude that only through intermodality and logistics infrastructure investments, particularly in the north of the country, will Brazil be more competitive in international markets.

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