Modeling the location choice: evidences from an evolutionary game based on regional input-output analysis*

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This article proposes a new methodology to analyze the strategic decision about firms' location choice. In this way, we combine the Evolutionary Game Theory (EGT) approach with input-output analysis. As the location pattern of firms that compete in the automotive sector of Mercosur countries has not been widely debated yet, that specific region was chosen to empirically describe and evaluate our model. By doing so, Mercosur was separated into two strategic regions: Brazil and Rest of Mercosur. To decide where to locate, firms consider the following exogenous factors: (i) potential market; (ii) local productive interdependence; (iii) government tax incentive and (iv) macroeconomic stability. To generate the results, we create hypothetical scenarios, in which firms can assign specific weights to each of these factors in the decision-making process. The outcomes suggest that, when companies give homogeneous weights to these factors, the balance occurs with the two competitors in the market where there was the governmental tax incentive. On the other hand, if factors are assigned with different weights, the long-term equilibrium of the game changes, which provides evidence that competing in the market where there is a tax exemption is not always an ideal location decision. That is, the other factors are relevant in the decision making of the firms. This may contradict common sense, which presupposes a direct relationship between government incentive and attraction of firms to a region.

Keywords: location decision, strategic interaction, input-output analysis

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1 Introduction and literature review

The discussion about firms' strategic location decision is not a new topic in many fields of Economic Literature. The Industrial Organization (IO) approach for example, is mostly concerned with the theoretical understanding of the competition nature in markets when firms strategically decide where to locate[1]. Another important field of research, International Economics (IE), contributes to the theoretical discussion related to the Location Theory[2] (in general) and to the location decision of multinational firms (in particular). In turn, the Regional Economy considers that geographic space is an inherent dimension in the study of economic phenomena and its treatment in the economy involves a significant degree of variability, complexity and heterogeneity. In this way, even though it is not a recent discussion, the issue of firms' locational decision is quite dense, and it extends by several strands of the economic theory.

Firms and other economic agents choose, based on a set of factors, their locations, thus provoking imbalances in the spatial distribution of resources and economic activities. This spatial differentiation generates concentration in certain areas and empties in others. Its consequences for the economic development are also issues widely debated in IO, IE and Regional Economy. Enhanced by the latter, the various economic agglomerations, which reproduce the unequal nature of space, influence the way the economic system works and regional performance itself (Capello, 2009; Capello & Nijkamp, 2009; Combes et al., 2009).

Nevertheless, as Fujita & Thisse (2013, p.14) stress, 'the very nature of the process of spatial competition is (...) oligopolistic and should be studied within a framework of interactive decision making. This was one of the central messages conveyed by Hotelling (1929) but was ignored until economists became fully aware of the power of game theory for studying competition in modern market economies'. Since the seminal paper by Hotelling, a large and rich literature on spatial competition[3]

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[1] To illustrate the interface of these fields, we can mention D'Aspremont et al. (1979), who considered a slightly modified version of Hotelling's model, in which exists a tendency for both sellers to maximize their differentiation. This constitutes a counterexample to the conclusions originally presented by Hotelling (1929). By its turn, Gabszewicz & Thisse (1992) provided the framework for a spatial competition model and the location of firms.

[2] See Chen & Moore (2010), Stam (2007), Fujita et al. (1999), Krugman & Venables (1995).

[3] See Salop (1979), Economides (1984), Hinloopen & Van Marrewijk (1999), Lijesen (2013) for models inspired by Hotteling's seminal model.

emerged, encompassing either Bertrand or Cournot competition, linear or non-linear markets and complete or incomplete information models (Biscaia & Mota, 2013).

Despite the vast literature that has been established about location decision in these three fields of study, to the best of our knowledge, there are no studies about spatial competition lying on the interface of evolutionary game theory (EGT) and regional science[4]. Although it may still be in its infancy, this theme should attract more interest from regional analysis, because the competitive locational problem emerges as a prototype of many economic situations involving dynamically interacting decisions in which firms can learn with their own choices over time[5].

While the traditional theory of games requires that players have a very high level of rationality, the EGT[6] model has been used to successfully explain a number of aspects of agents' behavior. More specifically, EGT may accomplish better success in describing and predicting the choices of locational decisions, since it is better equipped to handle the weaker rationality assumptions. Furthermore, in an evolutionary game, departing from an initial condition, a unique stable steady state will be reached, making it possible to know how players choose between multiple solutions.

Considering the existing literature and the lack of contributions of EGT to spatial theories as mentioned before, in this work we develop a new model that considers the projection made from the Regional Economic analysis for dynamically guiding firms to the Evolutionary Stable Strategy (ESS), i.e. to the optimal strategy location decision in the long term. The idea behind an ESS is to ensure that a so-called mutant strategy will not be able to dominate a competitive environment that embraces the incumbent strategy.

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[4] Silva et al. (2015) presents a quantitative retrospective about the use of Game Theory in Regional Economics. Recently, the models of limited rationality, the basis of EGT, have been applied in research linked to Industrial Organization (Ellison, 2006). Hehenkamp & Wambach (2010) model a Hotelling market with multidimensional product differentiation in an evolutionary framework. In addition, unlike the aforementioned approach, our article is concerned with evaluating how exogenous variables can interfere in the location decision-making of economic actors (firms, in our context). In this sense, our paper may be a pioneer in the application of this methodology in Regional Economics.

[5] In Chan (2001) and Fischer & Nijkamp (2014) there is a useful compendium of spatial analysis techniques which points out the commonalities among models used to locate facilities one at a time and to forecast the economic development pattern in an entire region. In this regard, it unifies the models applied in spatial science, which is defined by the author as the analytical techniques that explicitly recognize the spatial elements and examine the determinants of location decision.

[6] A small sampling of topics that have been analyzed from the evolutionary perspective includes altruism (Boyd et al., 2003) and behavior in public goods game (Clemens & Riechmann, 2006; Huberman & Glance, 1995).

The concept and intuition of an ESS will be better explained in the methodology section, but it is convenient to inform the reader that although it has been widely used in contexts where there is a large population of players, the dynamics of EGT, and particularly ESS, can indeed apply to finite population systems (Ficici & Pollack, 2000; Nowak et al., 2004). Furthermore, as explained in Friedman (1991), the EGT provides a refinement of the dynamic approach applied in the traditional game theory, allowing an inference about which Nash Equilibrium (NE) corresponds to an ESS.

According to Samuelson (2002), the EGT model is a convenient tool especially in anti-coordination games, which is a model of conflict that fits well in our case of study. To illustrate and offer more intuition about the reason why the anti-coordination game could be applied in strategic locational decision, let us consider a scenario in which there are two representative competing multinational firms. Each of those intends to build a new plant and choose simultaneously between two different countries with similar potential markets. If they choose the same country, they will split the market share. If they choose different countries, they will avoid the competition for the market share and their payoffs will probably be higher. Therefore, in this scenario, the best response is to adopt the opposing strategy of your opponent - characterizing a game in literature known as an anti-coordination game. On this point, the model proposed here allows us to infer which country should be selected by each representative firm to build their new production plant.

According to what has been exposed so far, some points justify the use of EGT in the locational decision modeling of firms. First, locational decisions, prior to investment, are dynamic and taken in an environment of economic uncertainty. And second, as has been illustrated, these decisions are interdependent, that is, the strategic action of a particular firm will impact the decision-making of the other rivals.

Therefore, we present a study of case about automotive plant location patterns in Mercosur countries[7]. There is a vast literature[8] that provides a description of the location decision patterns of the North American and European auto industry over the last

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[7] Currently, Mercosur (Common Market of the South) promotes the integration between Argentina, Brazil, Paraguay, Uruguay and Venezuela, considered as States Parties, through the free movement of goods, services and factors, the establishment of a Common External Tariff (CET), the adoption of a common commercial policy, the coordination of macroeconomic and sectorial policies and the harmonization of legislation.

[8] See Lagendijk (1997), Klier & McMillen (2015, 2008), Domanski & Lung (2009) and Bentley et al. (2013).

several decades. On the other hand, we can say that this matter has not been widely debated yet in South America, where the market we analyzed in this paper is located.

We suppose two representative firms, called F_A and F_B, which are the players of the game and produce homogeneous goods. They are competing for larger market shares in the automotive sector. Both firms are evaluating a region where they will install their new production plant. We will limit firms' strategies between two possible regions: Brazil (BRA) and rest of Mercosur (RMSUR).

To make that decision, the following factors are considered: (i) potential market; (ii) local productive interdependence; (iii) government tax incentive and (iv) macroeconomic stability. In the evolutionary game presented, we construct the payoff matrices based on weighted factors, whose weight varies according to each scenario proposed. Since there are multiple possible outcomes, we show that each scenario and its inherent uncertainty may affect the strategic decisions when the outputs cannot be predicted.

The objective of this paper is to offer a reasonable explanation about location decision patterns of firms. For this, we will carry out an empirical exercise, evaluating the automotive sector under a new methodology. As this market is composed of a substantial number of players and the location decision is a key strategic variable (Holweg, 2008), we believe that through the ESS concept it is possible to capture the effects of exogenous variables that can affect the strategic location decisions.

In order to reach our purpose and develop the discussion presented in this introduction, the remainder of this paper is organized as follows. Section 2 describes the algorithm used to design the evolutionary game and the structure of the payoff matrix. Section 3 introduces the regional input-output analysis framework and the empirical model applied to the automotive sector in Mercosur countries. Section 4 brings the results of the empirical analysis and Section 5 presents our conclusions.

2 Methodology

Based on the motivation proposed by Nicoleta et al. (2013), which states that the evolutionary perspective suggests a long-term analysis of the firm’s behavior on adapting to the competitive environment of the market and that this adjustment being made based on random processes as well as on the identification of new routines, we

begin this section presenting some basic background on Evolutionary Game Theory (EGT) and on the understanding of the Evolutionary Stable Strategy (ESS), that will be used to reach the objective specified before. In sequence, we will provide the necessary analytical tools to understand the evolutionary algorithm structure and, from then on, the reader will be able to replicate the extensive derivations that configure the stable equilibrium conditions of the games presented in the results section.

The mathematical idea behind the dynamic replicator, which is a model of evolution and prestige-biased learning[9] in games is analyzed. It is composed by a system of ordinary differential equations (ODE). The analytical solution of the nonlinear ODE system will govern the dynamic of the evolutionary game and will make it possible to do inference about the ESS. In addition, the Malthusian dynamics of the replicator is discussed. The open source software Dynamo[10] is used for plotting the phase diagrams[11], responsible for mapping the dynamic equilibria of the proposed games.

2.1 Evolutionary Game Theory Model

As written by Friedman (1991), the evolutionary game is effectively dynamic since it is based on a mechanism that allows one to understand how the strategies followed by the players can change as the game evolves. In this case, an important element is added to those considered by the classical game theory. In addition to players, strategies and payoffs, it is now also considered a dynamic rule, based on the replicator dynamics presented in equation (1), that can change payoffs and, therefore, the way players interact with each other over time.

In evolutionary games, according to Maynard Smith and Price (1975), a convergence to the dominant long-run equilibrium is expected. This equilibrium is achieved after a period of dynamic interaction, in which players must have adopted an evolutionary stable strategy (ESS), that is a strategy where players have no incentive to abandon, unless some external force disturbs the underlying conditions of the game.

Then, if classical game theory can be defined as the science that studies strategic behavior, with the theory of evolutionary games it takes a step forward, since we now

[9] A preference for imitating prestigious players. See Taylor & Jonker (1978) for detailed discussion.
[10] See Sandholm et al. (2012).
[11] The phase diagrams of the scenarios presented in this paper are in session 4.

have the science that studies the robustness of strategic behavior. In an evolutionary game it is assumed bounded rationality, a large population, n, of players ($n \to \infty$) and an implicit recognition that agents learn. Every period, a player is randomly matched with another player and they play a two-player game. Each agent is assigned a strategy and they cannot choose their strategies. In other words, they are "programmed" to play a strategy in the initial period ($t = 0$) and it may not maximize their utility function. However, the systematic interaction with other agents will lead them to modify or update their behavior over time by choosing a given strategy. Thus, we can say that players imitate others' strategies.

In this way, Friedman (1991) presents the replicator dynamics as an efficient analytical tool, capable of inferring the pattern of evolutionary behavior of a population of players. Considering a utility function given by $u(s_i, \sigma)$ as the fitness, i.e., the number of descendants of an individual of type i adopting strategy s_i, against the average population fitness, σ, and let t be time instant:

$N(t)$: Population size;

$N_i(t)$: Number of individuals playing the strategy s_i;

$p_i(t)$: Proportion of the individuals playing s_i, i.e., $p_i(t) = \frac{N_i(t)}{N(t)}$;

d: Population mortality rate (constant);

$u(s_i, \sigma)$: The expected number of descendants (fitness) of an individual adopting s_i when it competes in a population whose average fitness is $\sigma(t)$.

The reduced form of the replicator dynamics is given by:

$$\dot{p}_i(t) = \frac{d}{dt}\frac{\dot{N}_i(t)}{N(t)} = \frac{N_i(t)N(t) - N_i(t)\dot{N}(t)}{[N(t)]^2} = p_i(t)[u(s_i, \sigma) - u(\sigma, \sigma)] \qquad (1)$$

According to Binmore (1992), the results obtained by equation (1) say that the more successful a strategy that competes in a population in a state $\sigma(t)$, the greater its payoff[12] and consequently the greater its relative growth. Thus, the replicator dynamics provides the rate of growth of the proportion of players that adopt a certain strategy available in the game over time. To find the asymptotically stable points, that is, points of equilibrium, starting from a system of nonlinear differential equations, we must (i) find the stationary points by doing $\dot{p}_i = 0$ and (ii) verify its stability. In the next subsection, we will begin a more detailed discussion about the stability of the system

[12] As a synonym of fitness or aptitude, we interpret payoff as rate of reproduction.

when we have two populations of players competing against each other, which is the situation that depicts the competitive context we are modelling in this paper.

2.2 Two-dimensional games

In this class of games, we have two populations of players competing against each other, i.e., players from one population do not compete against their peers[13]. They will only compete with players from the rival population. In this sense, imagine a situation where each population has the same two available strategies. What we present in equation (2) is a system of nonlinear ODEs where each population has its replicator dynamic. So that:

$$\begin{aligned} \dot{p} &= p[u(s_i, \sigma) - u(\sigma, \sigma)] \\ \dot{q} &= q[u(s_i, \sigma) - u(\sigma, \sigma)] \end{aligned} \tag{2}$$

To check the stability of the points that are candidates for an ESS, i.e. an asymptotically stable steady state, we must use the Jacobian matrix (Ω) to linearize the system presented in (2) and to study the local behavior of the stationary points by calculating the eigenvalues:

$$\Omega(p,q) = \begin{bmatrix} \frac{\partial \dot{p}}{\partial p} & \frac{\partial \dot{p}}{\partial q} \\ \frac{\partial \dot{q}}{\partial p} & \frac{\partial \dot{q}}{\partial q} \end{bmatrix}; \text{doing the determinant } det(\Omega - \lambda i) = \begin{vmatrix} \frac{\partial \dot{p}}{\partial p} - \lambda & \frac{\partial \dot{p}}{\partial q} \\ \frac{\partial \dot{q}}{\partial p} & \frac{\partial \dot{q}}{\partial q} - \lambda \end{vmatrix} = 0$$

We finally have that $\lambda_{1,2} = \frac{tr\Omega \pm \sqrt{tr\Omega^2 - 4det\Omega}}{2}$. In order for the stationary point to be asymptotically stable, the eigenvalues $\lambda_{1,2}$ of the matrix (Ω) evaluated at points that hold the condition $\dot{p}_i = 0$ and $\dot{q}_i = 0$ must have negative real parts.

As written in Friedman (1991), in a two-dimensional game where each population has the same two pure strategies (e^1, e^2) available, S^1 corresponds to the state (average payoff) of the first population and is given by $S^1 = \{p, 1-p\} \therefore p \in [0,1]$. In words, S^1 can be understood as if a representative agent is playing a mixed

[13] We do not consider the intra-population competition in order to capture some degree of cooperation that may exist among players from the same population. In the context of the empirical exercise in section 3, this would be a way of taking into account the fact that some brands share the same productive structure to produce their vehicles. As an example, we can cite the Renault-Nissan-Mitsubishi Alliance and the Group PSA alliance.

strategy, i.e., making a random choice between the two available pure strategies of the game (e^1, e^2) with probabilities p and $1-p$. The state of the second population is given by $S^2 = \{q, 1-q\} \therefore q \in [0,1]$ and its intuition is analogous to S^1. The matrices A and B, shown below, represent the payoffs of $Population$ 1 (row player) and $Population$ 2 (column player), respectively (3) and (4):

$$A = \begin{bmatrix} 0 & a_1 \\ a_2 & 0 \end{bmatrix} \tag{3}$$

$$B = \begin{bmatrix} 0 & b_1 \\ b_2 & 0 \end{bmatrix} \tag{4}$$

According to the values of a_1, a_2, b_1 and b_2 there are, in total, nine possible cases[14]. Here, only two of them will be analyzed, as shown in Table 1, which are appropriate under the circumstances presented in session 3 of this article.

[Table 1 near here]

Case I matches with the anti-coordination game and case II matches with the Prisioner's Dilemma. Both of them represent a social dilemma that have attracted significant interest in social and behavioral science, and the evolutionary game theory approaches provide useful complementary insights into decision-making in social dilemmas.

[Figure 1 near here]

Figure 1 shows the matrix representation of a two-dimensional game. Note that both populations have the same strategies e^1 and e^2. To find the replicator dynamics for each population, we must rewrite equation (2) as $\dot{p} = p(u(e^1, S^2) - u(S^1, S^2))$. In words, the proportion (p) of players in $Population$ 1 that will adopt strategy e^1 depends on how good their performances are against the state of $Population$ 2, S^2. The term $u(e^1, S^2)$ is the payoff obtained by the representative agent from $Population$ 1 when he is playing his first pure strategy, e^1, against a representative player from $Population$ 2 that plays a mixed strategy, i.e., plays the state of the $Population$ 2. If e^1 is a better response to S^2 than e^2, then the proportion of players in $Population$ 1

[14] For the complete analysis and discussion of all nine cases, see Friedman (1991).

adopting e^1 will raise in the long term. Rewriting $u(e^1, S^2)$ and $u(S^1, S^2)$ as follows, and after some trivial algebra we find the replicator equation.

$$u(e^1, S^2) = e^1 * \mathrm{A} * S^2 = [1 \quad 0] \begin{bmatrix} 0 & a_1 \\ a_2 & 0 \end{bmatrix} \begin{bmatrix} q \\ 1-q \end{bmatrix} = a_1(1-q)$$

$$u(S^1, S^2) = S^1 * \mathrm{A} * S^2 = [p \quad 1-p] \begin{bmatrix} 0 & a_1 \\ a_2 & 0 \end{bmatrix} \begin{bmatrix} q \\ 1-q \end{bmatrix} = a_2(1-p)q + a_1 p(1-q)$$

For $Population$ 1, the replicator is given by $\dot{p} = p(1-p)[a_1(1-q) - a_2 q]$ and by symmetry, for $Population$ 2, the replicator is $\dot{q} = q(1-q)[b_1(1-p) - b_2 p]$. The system formed by $\dot{p}$ and $\dot{q}$ is linearized by the Jacobian matrix (Ω) and then, as explained above, the neighborhood of the candidate points to asymptotic equilibrium is studied through the trace and the determinant of Ω.

[Figure 2 near here]

Figure 2 presents the phase diagram for cases I and II. We can see that case I matches with the anti-coordination game, which is in Figure 2a. Typically, it has two asymptotically stable points (attractor points): (0,1), (1,0), meaning that the best action for a player is to adopt the opposite strategy of your opponent. The points (0,0) and (1,1) are unstable and there is a possibility for a solution to start arbitrarily close to that stationary point and eventually leave its neighborhood over time. The critical point (p^*, q^*) is a saddle point and is unstable. On Figure 2b, we can see that for case II the only asymptotically stable point is (1,1). The points (1,0), (0,1) are saddle points and (0,0) is unstable.

3 The basis of the case study: modeling firms' locational choice in the automotive sector

We start this session by bringing the model designed to deal with the situations described in the introduction and in session 2. Let us suppose two representative firms, called F_A and F_B, which are the players of the game and produce homogeneous goods. They are competing for larger market shares in the automotive sector. Both firms are

evaluating a region where they will install their new production plant[15]. We will limit firms' strategies between two possible regions: Brazil (BRA) and rest of Mercosur (RMSUR). The final decision will be based on a set of factors and their respective weights. In the next sub session, we present four categories of locational factors considered in our model[16].

3.1 Factors considered for strategic locational decision

As the main objective is to provide a reasonable explanation of the competing business location decision patterns in the EGT model presented here, we construct the returns based on information mostly received from the input-output framework and computable general equilibrium (CGE) framework. It incorporates weighted factors, whose weights vary according to each scenario we construct to capture the uncertainty inherent in a dynamically competitive environment. To make this decision, the following factors are considered.

i. Market potential

The firms consider the influence of market conditions, since resources must be allocated to regions with better economic returns (Christaller, 1966; Fujita, Krugman, & Venables, 1999; Lösch, 1954). Thus, a measure of the absorption capacity of a particular good or service in a region is necessary. We observe the demand present in R_1 and R_2 in order to design a potential market to be serviced post-installation. The metric used follows the gravitational model of Isard et al. (2017) in which each of the regions s, located around city r, contribute to the composition of their market potential (ρ_r). It is assumed that the attribute Z of the k regions is weighted by the inverse distance ($1/d_{rs}$) to r in order to obtain $\rho_r = \sum_{s=1}^{k} Z_s/d_{sr}$.

[15] This study is concerned with the strategic decision process in which firms make their investment ex ante. This process differs from an ex post locational analysis, in which the locational choice becomes irreversible, given the cost of re-localization.

[16] Naturally, the factors considered will depend on the activity under consideration and the time horizon of the investment. In this way, adjustments in the presented model are recommended. It should be noted that the model developed in this section is hypothetical and aims to demonstrate the ability of the methodology linked to EGT in explaining the locational decision of firms. From this general experiment, readers will be able to apply a similar approach in their empirical studies.

The market potential calculated on the basis of the gravitational model considers, for each analyzed region, i.e. Brazil and Rest of Mercosur, first, per capita GDP in the PPP-US$[17] concept, representing the Z attribute and second, the minimum distance between the economic capitals[18], used in the calculation of the inverse distance. The values obtained of potential market, for the year of 2011.

ii. Local productive interdependence

The firm will be located in an environment of greater productive integration, characterized by the ease in the acquisition of inputs - backward effects (Hirschman, 1958; Weber, 1909). This information can be easily captured through the Input-Output matrix (IO). The Production Multiplier[19] will be considered as a proxy for productive interdependence since it is defined as the total value production of the good j, taking into account all sectors of the economy that are necessary to satisfy the increase of final demand of the productive sector in question. The equation $\pi_{j,r} = \sum_{i=1}^{N} \alpha_{ij}$ represents the Production Multiplier of good j in the region $r(\pi_{j,r})$ given by the sum of the rows of the Leontief matrix (direct and indirect production requirement), which is represented by the term a_{ij}. The greater the level of interdependence of this sector in relation to the others, the greater the systemic impact in the economy.

The acquisition of the labor factor is also observed by the company (Weber, 1909). We will assume that it is non-mobile and its contracting will take place in the destination region of the firm. It is also necessary to differentiate these workers into skilled and unskilled workers, given their productivity difference. The chosen region will be the one with the lowest labor cost per unit of production, either qualified ($\psi 1$) or not ($\psi 2$), calculated from the respective expressions $\psi 1_{j,r} = L1_{j,r}/Y_{j,r}$ and $\psi 2_{j,r} = L2_{j,r}/Y_{j,r}$ where $L1_{j,r}$, $L2_{j,r}$ and $Y_{j,r}$ are, respectively, the total remuneration received by the skilled and unskilled workers in addition to the total produced from the asset j in

[17] The GDP per capita data were obtained from World Bank Data. For more details see https://data.worldbank.org/. For the rest of Mercosur, the average of Argentina, Paraguay, Uruguay, and Venezuela was calculated.

[18] Cities adopted as centroids: São Paulo (Brazil), Buenos Aires (Argentina), Asunción (Paraguay), Montivideo (Uruguay) and Caracas (Venezuela). For rest of Mercosur it was calculated by the mean of Argentina, Paraguay, Uruguay, and Venezuela. The data was extracted from Google Earth. For more details see https://www.google.com/earth/.

[19] For more details see Miller and Blair (2009). It was also tested the Extraction Method, whose results were similar to the Production Multiplier.

region r. The Input-Output matrices as well as the sectorial labor force were obtained by the GTAP 9 database[20].

iii. Government tax incentive

It is perceived that firms tend to seek the public agency ex ante the decision of a new investment. In this way, they might decide to locate where they receive greater incentives. In our model, this advantage must be expressed in terms of the market share obtained in Brazil and in the rest of Mercosur countries. Since taxes are a burden to the firms, when they are exempted we typically observe lower prices, which lead to an increase in the demand. We will name this percentage gain as $\mu_{j,r}$, and if the firms decide to go to the same region, the share will be equally divided, i.e. $\mu_{j,r}/2$.

In our model, a negative shock of 100% was simulated on the variable to (tax on the product Vehicles and Parts in the regions BRA and RMSUR) - symbolizing the tax exemption - granted to the sector of vehicles and parts. Subsequently, the variation of qds (domestic sales of Vehicles and Parts for each region) was observed[21]. The percentage variation of qds after the shock, for both analyzed regions, were inserted in the payoff matrices. For this, we used the Computable General Equilibrium Model[22], GTAP.

iv. Macroeconomic stability

Any investment in fixed capital must be done from a long-term perspective. In this decision-making process, one must take into account both the microeconomic

[20] The national IO tables provided by GTAP 9. The values are in millions of (2004, 2007 and 2011) current U.S. dollars and has as reference more current 2011. First, the data were aggregated into 11 sectors (Grains and Crops, Livestock and Meat Products, Mining and Extraction, Processed Food, Textiles and Clothing, Motor Vehicles and Parts, Light Manufacturing, Heavy Manufacturing, Utilities and Construction, Transport and Communication and Other Services) and two regions Brazil (BRA) and Rest of Mercosur (RMSUR) using the program GTAPAgg. This same base presents the sectoral expenditure in 5 factors of production (land, unskilled labor, skilled labor, capital and natural resources). For this, the GTAPAgg was used again. For more details see: https://www.gtap.agecon.purdue.edu/databases/v9/default.asp. For more information about input-output, from GTAP see Aguiar & Walmsley (2012).

[21] The objective of the simulation is to verify the percentage effect of the total tax exemption in Vehicle and Parts sector (represented by the variable to = -100 in the BRA and RMSUR regions separately) on the domestic sale of Vehicles and Parts (qds "MotorVcles") implemented through RunGTAP software.

[22] It is a general multi-regional and multi-sectorial equilibrium model. The global database represents the world economy for the year 2011 (version 9). GEMPACK software was used to implement the model. The standard closure and Gragg Solution Method 2-4-6 were applied.

variables, directly linked to the firm's performance, and the macroeconomic and institutional variables, which show the specific factors of the country receiving the investment. The firm, therefore, may decide to locate where there is less macroeconomic uncertainty. We will call this variable ε_r. Of course, the observation of this stability is imprecise, due to the existence of imperfect information.

The macroeconomic indicator will be composed by two contributions: (i) The Trading Economics Credit Rating[23], which assigns a score of 100 to countries whose investment grade is called "high grade" and 0 to countries that are in financial default. In this work, the indicator was normalized to a scale ranging from 0 to 1; (ii) Enabling Trade Index[24] from the years of 2012 to 2014, which measures the favoring of trade in goods and services from borders to final destination. For the composition of the index, it is considered the market access, the administration of bilateral negotiations, the transport and communications infrastructure and the business environment. Originally, the index is provided on a scale from 1 to 7. Here, to simplify the analysis, the values were normalized in the interval between 0 and 1.

3.2 *The payoff matrix*

After presenting all the factors incorporated in the composition of the game payoffs, the matrix that represents the strategic interaction between the players and their respective parameters are arranged as shown in Figure 3.

[Figure 3 near here]

Where[25]:

$$\beta_{A,1} = W_\rho(\rho_1/2) + W_\pi[0.5(\pi_{A,1}/2) + 0.5(0.5\psi1_{A,1} + 0.5\psi2_{A,1})] + W_\mu(\mu_{A,1}/2) + W_\varepsilon\varepsilon_1$$

$$\beta_{B,1} = W_\rho(\rho_1/2) + W_\pi[0.5(\pi_{B,1}/2) + 0.5(0.5\psi1_{B,1} + 0.5\psi2_{B,1})] + W_\mu(\mu_{B,1}/2) + W_\varepsilon\varepsilon_1$$

$$\beta'_{A,1} = W_\rho\rho_1 + W_\pi[0.5\pi_{A,1} + 0.5(0.5\psi1_{A,1} + 0.5\psi2_{A,1})] + W_\mu\mu_{A,1} + W_\varepsilon\varepsilon_1$$

[23] More information available on: www.tradingeconomics.com/country-list/rating.

[24] The Enabling Trade Index is made up of four sub-indexes: (1) market access; (2) border administration; (3) transport and communications infrastructure; (4) business environment. More information available on: https://www.weforum.org/reports/global-enabling-trade-report-2012/.

[25] Note that $\beta_{A,1} = \beta_{B,1}$, $\beta'_{A,1} = \beta'_{B,1}$, $\beta_{A,2} = \beta_{B,2}$ e $\beta_{A,2} = \beta_{B,2}$.

$\beta_{B,2} = W_\rho \rho_2 + W_\pi[0.5\pi_{B,2} + 0.5(0.5\psi 1_{B,2} + 0.5\psi 2_{B,2})] + W_\mu \mu_{B,2} + W_\varepsilon \varepsilon_2$

$\beta_{A,2} = W_\rho \rho_2 + W_\pi[0.5\pi_{A,2} + 0.5(0.5\psi 1_{A,2} + 0.5\psi 2_{A,2})] + W_\mu \mu_{A,2} + W_\varepsilon \varepsilon_2$

$\beta'_{B,1} = W_\rho \rho_1 + W_\pi[0.5\pi_{B,1} + 0.5(0.5\psi 1_{B,1} + 0.5\psi 2_{B,1})] + W_\mu \mu_{B,1} + W_\varepsilon \varepsilon_1$

$\beta_{A,2} = W_\rho(\rho_2/2) + W_\pi[0.5(\pi_{A,2}/2) + 0.5(0{,}5\psi 1_{A,2} + 0.5\psi 2_{A,2})] + W_\mu(\mu_{A,2}/2) + W_\varepsilon \varepsilon_2$

$\beta_{B,2} = W_\rho(\rho_2/2) + W_\pi[0.5(\pi_{B,2}/2) + 0.5(0{,}5\psi 1_{B,2} + 0.5\psi 2_{B,2})] + W_\mu(\mu_{B,2}/2) + W_\varepsilon \varepsilon_2$

W_ρ, W_π , W_μ e W_ε represent the weights attributed to each of the factors. The sum of all weights equals one unit. It should be emphasized that the weights depend on the nature of the activity studied. This structure is very flexible, since we can define in diverse ways the regions and sectors to be analyzed. When changing any of these components, adjustments must be made[26].

3.3 The empirical model

In this section, an empirical exercise will be presented using the approach described above, in order to validate it as an adequate study instrument for the locational decision. In this way, suppose that two firms (F_A, F_B) belonging to the automotive sector are deciding to locate in some Mercosur country, aiming to meet the potential demand of the market. To do so, our analysis will make the spatial division between Brazil (BRA) and rest of Mercosur (RMSUR). When locating in any of these regions the firms will incur a unique transaction fee among the participants of the block (member countries). Thus, the locational decision will be based on internal attributes of each region.

As explained before, in order to analyze the strategic decision on the location of firms, scenarios were created according to the attribution of weights to the four factors that make up the final payoff to be inserted in the matrix of the game. This framework is in accordance with the mechanical system of Varignon, as presented by Weber (1909). It is known that these are dependent on the specific production characteristics of each firm. In this way, we consider five distinct scenarios, as presented in Table 2.

[26] Equal weights are given to the acquisition of inputs and labor power, as well as the use of skilled and unskilled labor.

[Table 2 near here]

As seen in Table 2, in scenario 1, firm A and firm B give equal importance to observed factors. In scenario 2, the firms emphasize the demand side, observing the potential market. Scenario 3 is where they observe possible gains through productive interdependence. In scenario 4, there is a strong influence of state action through fiscal policy, and finally in scenario 5, firms observe the results of macroeconomic stability presented by region r, which would be closer to the decision strategy of multinational firms. In the next section, we will present the results of the evolutionary game obtained from the empirical model.

4 Results

This section brings the results of the empirical exercise. We analyze the payoff matrix and the phase diagram in order to discuss scenarios one through five in sequence. The region in blue on the phase diagrams represents that the speed of convergence to the steady state is decreasing, i.e. the system is slowly evolving to the stationary region. In red is the region where the maximum speed that the system evolves to the evolutionary stable points is observed.

Scenario 1 – Homogeneous weights

Note in the left side of Figure 4, that if we assign homogeneous weights to all factors and if the Brazilian government grants tax exemption, the Nash Equilibrium of the game coincides with the Evolutionary Equilibrium. In other words, the coordinate (1,1) emerges as the only asymptotically stable point. Therefore, there is a dominant strategy for both representative firms, which is to locate in Brazil. Thus, both firms will compete for the Brazilian market share and none of them has incentives to install their plants in RMSUR. On the other hand, from the right side of Figure 4, it is possible to conclude that if the tax exemption is given in RMSUR, the evolutionary stable strategy is the point (0,0). Thus, the best response for both firms is to decide to locate in RMSUR.

[Figure 4 near here]

Figures 5(a) and 5(b) shows the phase diagrams, where we can see the dynamics of the game over time when firms are facing scenario 1 with the tax exemption given in Brazil and in RMSUR, respectively. Notice that through the phase diagrams we can predict the strategic behavior of firms.

[Figures 5(a) and 5(b) near here]

Therefore, for any initial conditions of the game, i.e. for any initial proportion of firms of types A and B, respectively, giving homogeneous weights to the observed factors, the evolutionary stable strategy is to decide to locate where the government tax exemption is granted. This result suggests that since the decision maker is not able to distinguish which of the factors considered will most strongly affect his choice of location, the expected benefits accruing from the tax exemption will be decisive for the outcome of the game.

Scenario 2 – Emphasis on the potential market

In case the firms attribute greater weight to the region's sales potential and if the tax exemption is given in Brazil, what we observe from the left side of Figure 6 is that the asymptotic equilibrium of the game corresponds to the coordinate (1,1). Thus, both representative firms will decide to build their new plant in Brazil. In Figure 7(a), the phase diagram is presented, and we can see the dynamic of the game under the situation mentioned above.

[Figure 6 near here]

However, if the tax exemption is granted by the rest of Mercosur countries, what is configured is an anti-coordination game. Under these circumstances, typically, when analyzing the results based on the Nash Equilibrium approach, we verify the existence of two N.E. in pure strategies, given by the points (1,0) and (0,1). There also exists an N.E. in mixed strategy (p^*, q^*). From the refinement provided by evolutionary game theory, it is possible to eliminate one of the N.E., once we see in Figure 7(b) that the point (p^*, q^*) corresponds to a saddle point. Thus, it is not asymptotically stable.

[Figures 7(a) and 7(b) near here]

Therefore, we managed to eliminate the Nash equilibrium in mixed strategy of the game, which allows us to infer that the best response for a representative firm is to adopt the (pure) strategy opposite to that chosen by its opponent. In practice, what we observe is an equilibrium where one type of representative firm located in BRA and another in RMSUR. This result suggests that, from the perspective of potential demand, it is not always an optimal decision to locate and compete in the market where there is a tax exemption. It also reinforces the importance that market potential has on firm's decision-making process. Countries with a high economically active population and a considerable average income may be more relevant for the decision maker.

Scenario 3 – Emphasis on the local productive interdependence

In this scenario, where greater weight is attributed to the gains obtained through productive interdependence, the same asymptotic equilibriums of the previous scenario were found. Thus, given a tax exemption in Brazil, both representative firms will choose it as the destination region. Once the government tax exemption is given in RMSUR, a game of anti-coordination is set up again and, therefore, the best response of a firm will be to choose the region opposite to that chosen by its opponent. Thus, the ESSs' of the game are given by the points (1,0) and (0,1) (p^{*}, q^{*}) is said to be a saddle point.

[Figure 8 near here]

As seen in the previous scenario, the results presented in Figure 8 suggests that, from the perspective of local productive interdependence, it is not always an optimal decision to locate and compete in the market where there is a tax exemption. In other words, the region where a greater integration in terms of the productive process is observed may be more attractive even when there is no fiscal incentive for firms. It could be justified in terms of the facility in acquiring inputs as well as the hiring of workers. The phase diagrams for a tax exemption in BRA and RMSUR are presented in figures 9(a) and 9(b), respectively.

[Figures 9(a) and 9(b) near here]

Scenario 4 – Emphasis on the government exemption tax

What is observed in the game payoff matrix for scenario 4 (Figure 10) is the configuration of an equilibrium where the region selected by both representative firms is exactly the one in which there is the fiscal incentives. This result reinforces the relevance of the fiscal incentive in the decision-making process on location by firms.

[Figure 10 near here]

This can be visualized in the phase diagram presented on Figures 11(a) and 11(b). For the tax exemption given in Brazil, the asymptotic equilibrium of the game is given by the coordinate (1,1) and, for the fiscal incentive given in RMSUR, what is observed by the diagram is that the equilibrium is obtained in the coordinate (0,0).

[Figures 11(a) and 11(b) near here]

Scenario 5 – Emphasis on the macroeconomic stability

When firms attribute greater weight to macroeconomic stability, for a given tax exemption in Brazil we observe that both representative firms will be located there. On the other hand, given a shock in RMSUR, a game of anti-coordination is characterized (see Figure 12).

[Figure 12 near here]

Once again, the interior point (p^{*}, q^{*}) does not set up an ESS and the mixed strategy can be eliminated from the set of solutions. The evolutionary stable strategies are given by the coordinates (1,0) and (0,1). Thus, as shown before, the best strategic decision for a firm is to play the strategy opposite to that chosen by its opponent. This

result suggests that, given a fiscal incentive granted in the RMSUR, the macroeconomic stability observed in Brazil when compared to the other countries belonging to the trading bloc, can bring greater benefits to the firm. The phase diagrams for a tax exemption in BRA and RMSUR are presented in figures 13(a) and 13(b), respectively:

[Figures 13(a) and 13(b) near here]

5 Conclusion

In this paper we proposed an evolutionary game theory model to explain the decision-making process about the location pattern of firms. In this context, we analyzed the automotive sector in Mercosur Countries, where under a government tax exemption, the representative multinational firms had to decide between Brazil and rest of Mercosur countries for building a new plant. We also designed scenarios where firms assigned weights to the factors (market potential; local productive interdependence; government tax incentive; and macroeconomic stability) that influence the location decision.

The results obtained from the dynamic game suggest that when firms give homogeneous weights to the factors, the equilibrium occurs with both competing in the market in which there was the governmental tax incentive. Once the factors are assigned with different weights, the long-term equilibrium of the game changes, which provides evidences that competing the market where there is a tax exemption is not always an optimal location decision. This may contradict the common sense about these issues.

The largest contribution of the Evolutionary approach can be seen in Scenarios 2, 3 and 5, specifically when the tax incentive is given in RMSUR. What is observed is the formation of an anti-coordination game. By eliminating the Nash equilibrium in mixed strategies (p^*, q^*) of the set of best responses, only the pure strategies BRA and RMSUR are supported as ESS. In this way, firms that compete in this market can make a more controlled and less risky decision on which region to settle. Put another way, firms can infer about which game, in fact, is played in order to achieve the long-term dynamic equilibrium and correctly decide in which region they must install their new plant.

In terms of investment policy, the outcomes essentially expose the importance of these policies when inserted in a favorable economic environment. In other words, the results suggest that, besides the tax exemption, the firms attribute a significant relevance to market potential, local productive interdependence and macroeconomic fundamentals. This may justify the results observed in Scenarios 2, 3 and 5, in which, despite tax incentives offered by the other Mercosur countries, there is still an ESS characterized by firms locating in Brazil.

One limitation of this work was the fact that it did not use the information derived from the regional input-output matrix in a disaggregated form for each of the Mercosur countries. By doing so, it would be possible to say which country would be chosen for the installation of the automotive plant due to a government tax incentive. For future research, a modeling to be developed can consider stochastic elements in the EGT model proposed in this paper by using an Agent Based Simulation approach. Another possibility is to advance in the framework presented here in terms of the factors considered in the decision-making process, as well as the elaborated scenarios, available regions and expand the study to other sectors of the economy.

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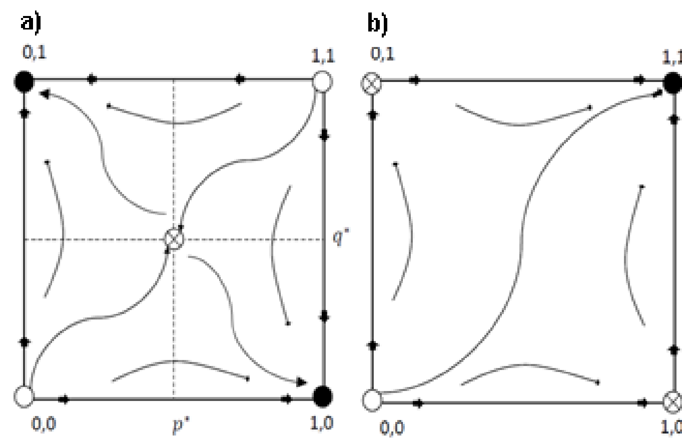
Figures

Figure 1. Two-dimensional game matrix representation

		Population 2	
		$e^1\ (q)$	$e^2\ (1-q)$
Population 1	$e^1\ (p)$	$(0\ ,0)$	a_1, b_2
	$e^2(1-p)$	a_2, b_1	$(0\ ,0)$

Source: Elaborated by the authors.

Figure 2. Phase diagrams for case I (a) and case II (b)



Source: Elaborated by the authors.

Figure 3. The Payoff Matrix

		F_B	
		BRA	$RMSUR$
F_A	BRA	$(\beta_{A,1}, \beta_{B,1})$	$(\beta'_{A,1}, \beta_{B,2})$
	$RMSUR$	$(\beta_{A,2}, \beta'_{B,1})$	$(\beta_{A,2}, \beta_{B,2})$

Source: Elaborated by the authors.

Figure 4. Payoff Matrix for Scenario 1

Tax exemption in BRA

F_A \ F_B	BRA	$RMSUR$
BRA	$(\mathbf{0.3}, \mathbf{0.3})$	$(0, 0)$
$RMSUR$	$(0, 0)$	$(-0.76, -0.76)$

Tax exemption in RMSUR

F_A \ F_B	BRA	$RMSUR$
BRA	$(-0.77, -0.77)$	$(0, 0)$
$RMSUR$	$(0, 0)$	$(\mathbf{0.025}, \mathbf{0.025})$

Source: Elaborated by the authors.

Figure 5(a). Tax exemption in BRA

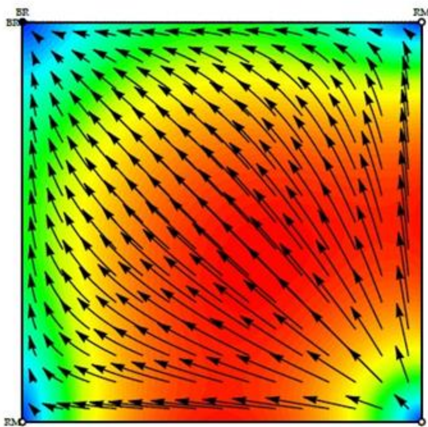
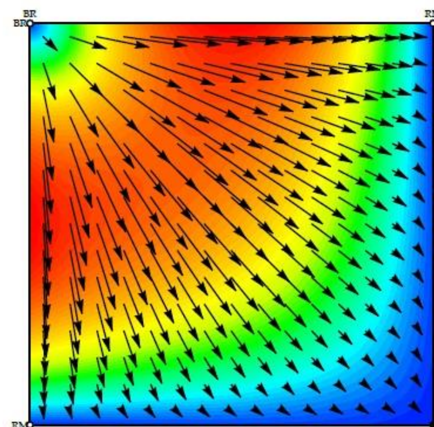


Figure 5(b). Tax exemption in RMSUR



Source: Elaborated by the authors, using Dynamo.

Figure 6. Payoff Matrix for Scenario 2

Tax exemption in BRA

F_A \ F_B	BRA	$RMSUR$
BRA	$(\mathbf{0.33}, \mathbf{0.33})$	$(0, 0)$
$RMSUR$	$(0, 0)$	$(-0.82, -0.82)$

Tax exemption in RMSUR

F_A \ F_B	BRA	$RMSUR$
BRA	$(-0.39, -0.33)$	$(\mathbf{0}, \mathbf{0})$
$RMSUR$	$(\mathbf{0}, \mathbf{0})$	$(-0.82, -0.82)$

Source: Elaborated by the authors.

Figure 7(a). Tax exemption in BRA

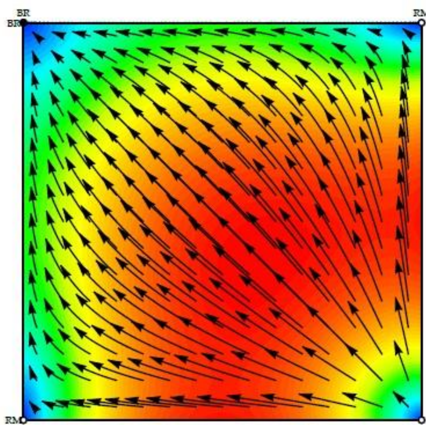
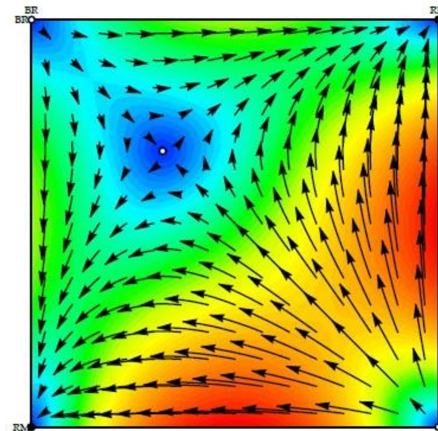


Figure 7(b). Tax exemption in RMSUR



Source: Elaborated by the authors, using Dynamo.

Figure 8. Payoff Matrix for Scenario 3

Tax exemption in BRA

		F_B	
		BRA	*RMSUR*
F_A	*BRA*	**(0.11 , 0.11)**	(0 , 0)
	RMSUR	(0 , 0)	(−0.75 , −0.75)

Tax exemption in RMSUR

		F_B	
		BRA	*RMSUR*
F_A	*BRA*	(−0.60 , −0.60)	**(0 , 0)**
	RMSUR	**(0 , 0)**	(−0.22 , −0.22)

Source: Elaborated by the authors.

Figure 9(a). Tax exemption in BRA

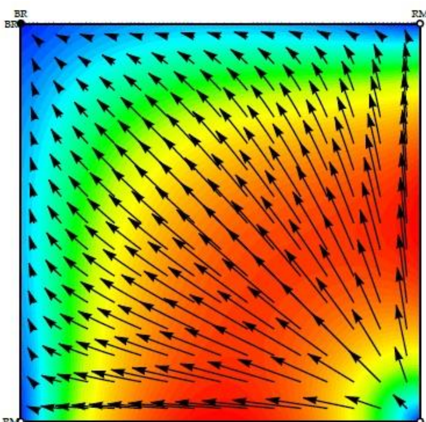
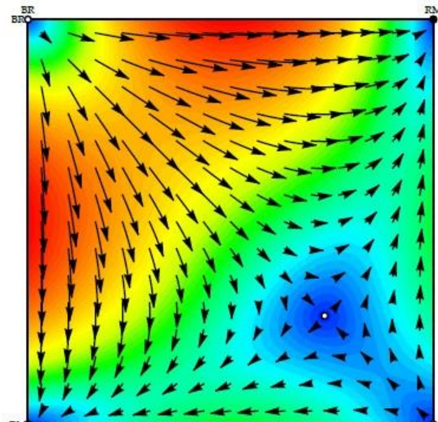


Figure 9(b). Tax exemption in RMSUR



Source: Elaborated by the authors, using Dynamo.

Figure 10. Payoff Matrix for Scenario 4

Tax exemption in BRA

		F_B	
		BRA	$RMSUR$
F_A	BRA	$(\mathbf{0.53}, \mathbf{0.53})$	$(0, 0)$
	$RMSUR$	$(0, 0)$	$(-0.95, -0.95)$

Tax exemption in RMSUR

		F_B	
		BRA	$RMSUR$
F_A	BRA	$(-1.62, -1.62)$	$(0, 0)$
	$RMSUR$	$(0, 0)$	$(\mathbf{0.63}, \mathbf{0.63})$

Source: Elaborated by the authors.

Figure 11(a). Tax exemption in BRA

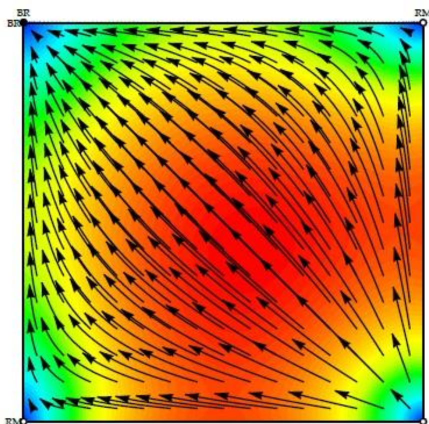
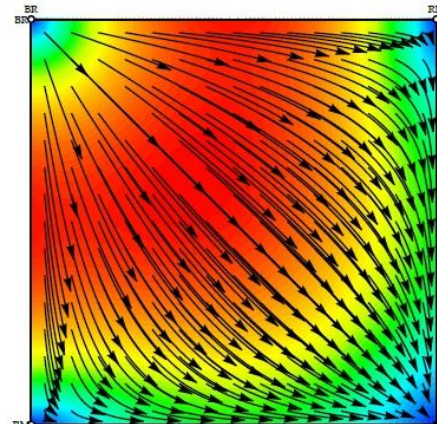


Figure 11(b). Tax exemption in RMSUR



Source: Elaborated by the authors, using Dynamo.

Figure 12. Payoff Matrix for Scenario 5

Tax exemption in BRA

		F_B	
		BRA	$RMSUR$
F_A	BRA	$(\mathbf{0.23}, \mathbf{0.23})$	$(0, 0)$
	$RMSUR$	$(0, 0)$	$(-0.54, -0.54)$

Tax exemption in RMSUR

		F_B	
		BRA	$RMSUR$
F_A	BRA	$(-0.49, -0.49)$	$(\mathbf{0}, \mathbf{0})$
	$RMSUR$	$(\mathbf{0}, \mathbf{0})$	$(-0.01, -0.01)$

Source: Elaborated by the authors.

Figure 13(a). Tax exemption in BRA

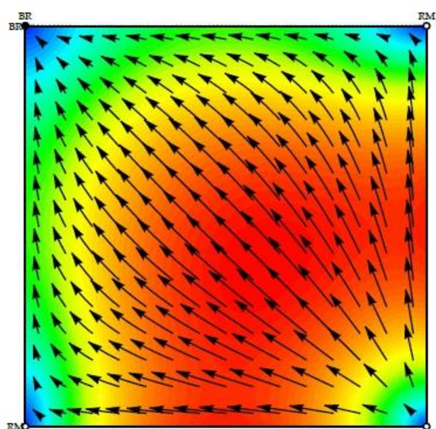
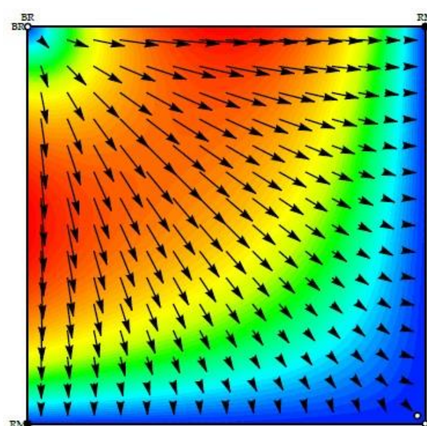


Figure 13(b). Tax exemption in RMSUR



Source: Elaborated by the authors, using Dynamo.

Tables

Table 1. Cases analyzed in the two-dimensional game

Case	Payoff Structure
I	$a_1, a_2, b_1, b_2 > 0$
II	$a_1 > 0, a_2 < 0, b_1 > 0, b_2 < 0$

Source: Elaborated by the authors.

Table 2. Evaluated Scenarios

Factors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
a) Market Potential	0.25	0.50	0.17	0.17	0.17
b) Location Interdependence*	0.25	0.17	0.5	0.17	0.17
b.1) Production Multiplier	0.50	0.50	0.50	0.50	0.50
b.2) Cost of labor factor**	0.50	0,50	0.50	0.50	0.50
b.2.1) Qualified labor	0.50	0.50	0.50	0.50	0.50
b.2.2) Unqualified labor	0.50	0.50	0.50	0.50	0.50
c) Government tax incentive	0.25	0.17	0.17	0.50	0.17
d) Macroeconomic Stability	0.25	0.17	0.17	0.17	0.50
Sum (weights)	1.0	1.0	1.0	1.0	1.0

Notes: * (b) is formed by (b.1) + (b.2) and ** (b.2) is formed by (b.2.1) + (b.2.2).
Source: Elaborated by the authors.