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GRADUATE EDUCATION, RESEARCH AND INNOVATION: PUBLIC OFFER EFFECTS OF GRADUATES ON THE POTENTIAL FOR INNOVATION BUSINESS

PÓS-GRADUAÇÃO, PESQUISA E INOVAÇÃO: EFEITOS DA OFERTA PÚBLICA DE PÓS-GRADUADOS SOBRE O POTENCIAL DE INOVAÇÃO EMPRESARIAL

POSTGRADO, INVESTIGACIÓN E INNOVACIÓN: EFECTOS DE LA OFERTA PÚBLICA DE LOS POSTGRADOS EN EL POTENCIAL DE INNOVACIÓN EMPRESARIAL

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Abstract

Objective: Understanding the structures involved and the possible effects of policies to expand the supply of graduate labor on the innovation potential of Brazilian companies.

Methodology: For this understanding, the causal diagram technique was used with soft modeling of the System Dynamics approach using the Vensim software.

Originality: The relationship between the supply of qualified labor force for research and the increase in the innovative capacity of organizations does not present a linear relationship but depends on factors that go beyond the determinants of the academic sector. This work responds to the need to theorize about the complexity existing in the relationship between the public support of graduate studies and their returns through applying the scientific workforce in Research and Development activities in the productive sector.

Main results: A conceptual model representing a system formed by the convergence between the structures of the Graduate Program Market and the Graduates' Market was presented. This proposal offers an overview of causal structures formed by the main variables involved in supply/demand by graduates in Brazil.

Theoretical/methodological contributions: The knowledge and use of the System Dynamics approach support understanding complex phenomena, learning, and constructing viable solutions to public problems. Furthermore, it is an approach still incipient in Latin America, such as Brazil, and it is valuable for forming agendas and evaluating public policies.

Practical contributions: Notably, this work encourages an urgent reflection on graduate and research policies articulated with the innovation context, bringing possible implications for the transfer of technologies. A potential instrument for analyzing and projecting the possible effects of these public policies in the context studied was proposed.

Keywords: Evaluation design. Graduate. System thinking. Innovation. Public Policy.

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Resumo
Objetivo: Compreender as estruturas envolvidas e as possíveis vias de efeitos das políticas de expansão da oferta de mão de obra pós-graduada sobre o potencial de inovação das empresas brasileiras.
Metodologia: Para tal compreensão empregou-se a técnica de diagrama causal da abordagem System Dynamics fazendo uso do software Vensim.
Originalidade: A relação entre a oferta de mão-de-obra qualificada para pesquisa e o aumento da capacidade inovativa das organizações não apresenta uma relação linear, ela depende, porém, de fatores que ultrapassam os determinantes do setor acadêmico. Este trabalho atende à necessidade de se teorizar sobre a complexidade existente na relação entre o fomento público da pós-graduação e seus retornos mediante a aplicação da mão de obra científica em atividade de Pesquisa e Desenvolvimento no setor produtivo.
Principais resultados: Foi apresentado um modelo conceitual representativo de um sistema formado pela convergência entre as estruturas do Mercado da Pós-graduação e do Mercado para Pós-graduados. Esta proposta oferece um panorama sobre estruturas causais formadas pelas principais variáveis envolvidas na oferta/demanda por pós-graduados no Brasil.
Contribuições teórico-metodológicas: O conhecimento e o uso da abordagem System Dynamics favorecem o entendimento de fenômenos complexos, favorece o aprendizado e a construção de soluções viáveis para problemas públicos. Além disso, trata-se de uma abordagem ainda incipiente em países da América Latina como o Brasil, e de valor para a formação de agendas e de avaliação de políticas públicas.
Contribuições práticas: Destaca-se que este trabalho fomenta uma urgente reflexão sobre as políticas de pós-graduação e pesquisa, articuladas ao contexto da inovação, trazendo possíveis implicações para a transferência de tecnologias. Foi proposto um potencial instrumento de análise e projeção dos possíveis efeitos dessas políticas públicas no contexto estudado.

Palavras-Chave: Design de avaliação. Pós-graduação. Pensamento sistêmico. Inovação. Dinâmica de sistemas.

Resumen
Objetivo: Comprender las estructuras involucradas y los posibles efectos de las políticas de expansión de la oferta de trabajo de posgrado sobre el potencial de innovación de las empresas brasileñas.
Metodología: Para este entendimiento se utilizó la técnica del diagrama causal con modelado suave del enfoque de Dinámica de Sistemas utilizando el software Vensim.
Originalidad: La relación entre la oferta de mano de obra calificada para la investigación y el aumento de la capacidad innovadora de las organizaciones no presenta una relación lineal sino que depende de factores que van más allá de los determinantes del sector académico. Este trabajo responde a la necesidad de teorizar sobre la complejidad existente en la relación entre el apoyo público a los estudios de posgrado y sus retornos a través de la aplicación de la mano de obra científica en actividades de Investigación y Desarrollo en el sector productivo.
Principales resultados: Se presentó un modelo conceptual que representa un sistema formado por la convergencia entre las estructuras del Mercado de Educación de Posgrado y el Mercado de Graduados. Esta propuesta ofrece un panorama de las estructuras causales formadas por las principales variables involucradas en la oferta/demanda de posgraduados en Brasil.
Aportes teórico-metodológicos: El conocimiento y uso del enfoque de Dinámica de Sistemas apoya la comprensión de fenómenos complejos, el aprendizaje y la construcción de soluciones viables a problemas públicos. Además, es un enfoque aún incipiente en América Latina, como Brasil, y es valioso para formar agendas y evaluar políticas públicas.
Aportes prácticos: En particular, este trabajo invita a una reflexión urgente sobre las políticas de posgrado e investigación articuladas con el contexto de la innovación, trayendo posibles implicaciones para la transferencia de tecnologías. Se propuso un potencial instrumento para analizar y proyectar los posibles efectos de estas políticas públicas en el contexto estudiado.

Palabras clave: Diseño de evaluación. Postgrado. Pensamiento sistémico. Innovación. Política pública.

Introduction

Innovation has been a recurrent subject in specialized literature and public policy agendas when dealing with development (Aghion, Antonin & Bunel, 2021). In the context of globalization, marked by accelerated transportation and information transmission, the international market has become highly competitive, requiring nations to differentiate what they offer significantly.

Therefore, innovating and fostering innovation becomes imperative for development (Emmendoerfer, 2019a; 2019b) since only passively maintaining sustained national economic growth no longer provides secure long-term economic well-being in a country, given the competitive international scenario (Torres, 2011).

The postulates of the economic literature demonstrate the virtuous effect of technical progress on growth (Abramovtiz, 1956; Romer, 1990; Solow, 1957). Such perspectives allow us to understand major world powers' intensive efforts to promote an innovative environment in their economies. Moreover, emerging countries such as India and China see innovation as a necessary element to catch up with the development of other nations and implement economic development strategies (Aghion, Antonin & Bunel, 2021; Fernandes, Garcia & Cruz, 2015).

In this context, Research and Development (R&D) investment has become strategic (Albuquerque, 1998; Nelson, 1992; Rissardi Júnior, Shikida & Dahmer, 2009). Thus, labor specialization through graduate studies and research is considered essential for the promotion of technological change (Romer, 1990), to the point of becoming the focus of public policies to expand qualified labor for innovation (Emmendoerfer, 2019b; Martins & Assad, 2008; Moreira & Velho, 2008).

However, the academic literature points out that the causal relationship between the expansion of national graduate education and the introduction of graduate labor into innovation activities is not linear but is systemically complex (Cifuentes & Fernandez, 2017; Ghaffarzadegan, Larson, et al., 2017).

This theoretical perspective argues that education is a system within other systems, interconnected by cause-and-effect and separated in a timeline, resulting in unexpected behaviors (Sterman, 2000). This statement would imply that public policies fostering innovation via graduate development, for example, could have their results influenced by many variables, including those from outside the educational field.

In fact, as the works of Lundvall (2008) and Nelson and Phelps (1966) warn, the mere supply of skilled labor in a country does not correspond to a respective increase in national production. This result depends on the productive sector's ability to absorb and convert human capital into technological progress. An example is the specific characteristics of companies that usually hire PhDs.

Garcia-Quevedo et al. (2012) show that the companies that most value PhDs' skills belong to medium-high or high-tech sectors. It can be said that this is a specific type of organization. They are often in the tech business, conduct R&D intensively with University cooperation, and have R&D departments and budgets earmarked for new product development (Garcia-Quevedo, Mas-Verdú, &

Polootero, 2012). This type of business is not the majority of economic agents, and its presence varies significantly among countries' productive sectors.

The Brazilian graduate system is an emblematic case of higher education development. In hopes of developing a skilled scientific-technological workforce, the country built a graduate system that consolidated academic teaching before there was enough space for scientific research in the market (Balbachevsky & Botelho, 2011; Balbachevsky & Schwartzman, 2010). This resulted in graduate employment rate deeply depending on the expansion of the higher education system.

The sequence of public policies linked to the National Graduate Plans led the country to the exponential growth of its population of masters and PhDs (Hostins, 2006; Ivashita & Vieira, 2017; Luna & Luna, 2015). From 1994 to 2017, for example, Brazil experienced a 488% increase in the number of master's degrees and a 657% increase in doctoral degrees (Center for Strategic Management and Studies ["Centro de Gestão e Estudos Estratégicos" - CGEE], 2021; Geocapes, 2021). Brazilian graduate programs awarded 10,482 master's degrees and 2,854 doctoral degrees in 1994. In 2017, the country's rate of graduates with Master's and PhD degrees rose to 61,661 and 21,607, respectively.

On the other hand, the country could not get its scientific labor to flow into the Brazilian industrial sector. Oliveira (2003, p. 23) points out that "not even the large state-owned companies, especially in the areas of communications, petrochemicals, and aviation, demanded the expected scientific and technological knowledge. Most Brazilian graduates work in the Education sector" (CGEE, 2021).

In addition, the public sector remains the leading employer of this skilled labor (Morais, 1992). The private sector's participation in R&D is still comparatively 'timid' and disconnected from public science and technology offerings. This context is an obstacle to advancing the Brazilian innovation system (Albuquerque, 1996; Cruz & Souza, 2014; Fernandes, Garcia & Cruz, 2015).

Technological progress tends to be more intense when more people are dedicated to discovering new ideas (Romer, 1990). Considering the Brazilian context, this paper asks: how can graduate public supply dynamics influence the innovative potential of Brazilian companies? Moreover, what would be the variables and the main systemic interactions highlighted in this process?

This work assumes as a theoretical gap the need to theorize about the complex relationship between public funding of graduate studies and its returns from applying the scientific workforce in R&D activities in the productive sector.

Thus, we will seek to understand the structures involved and public policies' possible effects on the supply of graduate labor in the innovative potential of Brazilian companies.

This objective will be achieved through complex systems modeling, representing and analyzing self-organized and interconnected elements that can provide non-intuitive results (Bueno, 2011; Forrester, 1961; Meadows, 2008; Sterman, 2000).

This study establishes a link between graduate and research policies and the innovation potential in Brazilian companies via a systemic approach. It theoretically contributes by clarifying the actors and structures that determine inter-organizational innovation. On the practical level, it is a potential instrument for analyzing and projecting the possible effects of public policies in this context.

In addition to this introduction, the following pages will present the article's theoretical framework, consisting of the relationship between innovation, development, business incentives to innovate, and scientific labor's role. This is followed by the employed methodology, the constructed model, the complex system analyses, and the conclusion.

Innovation, research, and development as elements of graduate studies

Knowledge, innovation, and economic development

Since the seminal works of Schumpeter (1928; 1976; 2012), the close relationship between innovation and economic development has been recognized. In his theory, innovation is the driving force of growth, capable of effecting structural change in the economy due to its inherent process of creative destruction (Schumpeter, 2012).

From this academic recognition, studies on innovation and its processes grew among researchers, while the theme was emerging in public policy agendas and business strategies (Aghion, Antonin & Bunel, 2021).

Schumpeter (2012) separates the concepts of invention and innovation. While the former refers to novelties not always endowed with economic relevance, the latter involves creating new products or ways to produce, acquiring raw materials, or accessing new markets. There are five types of innovation defined by the author: (i) in the product; (ii) in the production method; (iii) in raw material sources; (iv) in the exploration of new markets; and (v) in the business organization (Schumpeter, 2012). They can be synthesized by the concepts of "product innovation" and "process innovation" (Emmendoerfer, 2019a; Torres, 2011).

The relationship between innovation and development is related to its effect on the economic equilibrium. For Schumpeter, the expectation of extraordinary profits is the main incentive to innovate. Profit generated by innovation triggers a series of investments by imitators, creating new jobs and consumption levels. Such a process results in growth and structural economic changes, which, for the author, is "Economic Development" (Schumpeter, 2012).

Besides the Schumpeterian school, other authors demonstrate the relationship between innovation and economic growth. Abramovitz (1956), one of the first theorists to study the effect of production factors (capital and labor) on growth, highlights the impact of productivity gains on economic development. The author explains that increasing research, education, and health investment can increase a nation's productivity.

Solow (1957) goes further, and his growth model depicts the per capita product variation based on the production factor availability, leveraged by what he calls the technological factor, which consists of knowledge capable of generating more input productivity. Applying his model to the North American economy between 1909 and 1949, the author shows an 87.5% technical change in the economic growth variation under analysis.

Solo (1951) argues that the reasons to innovate go beyond simply seeking extraordinary profit. The author argues that innovation is an integral part of the competition between companies, thus being a natural element since it is directly related to their survival. Moreover, he highlights that companies tend to innovate to be competitive in the market, sustain their growth in the long term, and reduce their market risks.

Thus, innovation tends to be a routine process among new or established companies, justifying R&D activities. This argument departs from Schumpeterian reasoning since it does not recognize innovation's disruptive nature on the economic balance; it is presented as a natural competition process between business organizations (Solo, 1951).

At the same time, many authors have highlighted the role of science, and more specifically higher education, in the national innovation system (Mowery & Rosenberg, 1989; Gibbons & Johnston, 1993; Rosenberg, 1992; Pavitt, 1998). This relationship is because higher education institutions offer qualified and specialized labor for producing goods and services, besides being a source of scientific knowledge where research is produced. Moreover, companies can appropriate skilled workers to generate innovations (in products and processes) and solutions to their operational problems (Velho, 2007).

In his growth model, Romer (1990) emphasizes the role of human capital in generating technological progress. For the author, skilled labor and inventive activity explain the positive variation in national growth. Along these lines, Torres (2011) adopts three premises: (i) technological change is at the heart of economic growth; (ii) technological change depends on people's intentions, and this depends on market incentives; (iii) the cost of creating innovation is fixed, but it can be used several times without additional costs.

Romer (1990) discards the role of intellectual property in the process of technology diffusion, but an interesting point to emphasize is the role of skilled labor and the R&D intensity in his model. They can be defined from the following function:

$$Y = K^{\propto}(AL_y)^{1-\propto}$$

Where Y represents the product or income of the economy, K is capital, A is the idea stock, and L_y is the number of workers, with $\propto$ a parameter varying between 0 and 1. In the model, the idea stock may be shown as:

$A = \delta L_{\alpha}$, where L_{α} corresponds to the number of workers dedicated to discovering new ideas and δ is the success rate. In other words, it is the proportion of newly discovered ideas.

With this, Romer (1990) points out that a nation's economic growth depends on its production inputs, related to the technical progress of its market. This progress may become more intense with more applicable ideas generated by individuals connected to it. Such results tend to be more expressive with R&D-intensive labor, which increases the probability of success in discovering new ideas.

The role of the scientific workforce

Based on Romer's model (1990), it is possible to understand the relationship between knowledge generation and economic growth, the former being determined by the intensity of scientific research applied to a nation's market.

In this context, academic degrees emerge as an essential issue for development. The higher people's skill level in interacting in organizations, the higher the learning outcomes (Lucas, 2015). This result implies that in addition to individuals' skills resulting from work experience and professional training, society's education level implies better results related to human capital.

In other words, years of education expand people's ability to solve problems and sow innovation in the economy. Highly educated people are an important asset to a nation's development. This is because of the role college-educated individuals assume in the economy.

Nelson and Phelps (1966) constructed a growth model assuming that people with higher education contribute to economic growth with two distinct mechanisms. First, they can perform regular work activities more efficiently than the average worker. Second, they are better at introducing new technologies into the economy.

Based on Nelson and Phelps' model, Lundvall (2008) describes two ways higher education can contribute to economic development. Assuming that "Graduates" are those who have obtained any university degree (Bachelor's, Master's, or PhD), the author argues that highly educated people operate as "Balancers" and "Innovators" while doing their jobs.

By "Balancers," Lundvall (2008) refers to the perspectives of Nelson and Phelps (1966) and Schultz (1975), which recognize that people with higher education promote market equilibrium when they exploit existing technical and technological opportunities. This finding is consistent with the Austrian School's approach to entrepreneurial discovery, which describes entrepreneurs as those who identify innovations in the marketplace and exploit them by applying them in organizations (Kirzner, 1997). These actions tend to balance the market as new technologies spread among firms.

The author deepens the theoretical understanding of higher education's role in economic growth by stating that graduates also act as "Innovators" (Lundvall, 2008). By "Innovators", he refers to those who introduce new ideas to the marketplace. These inspirations may be new to the whole world or new to a country, region, or organization.

Unlike the outputs produced by the "Balancers", the innovative operations of "Innovators" tend to generate market disturbances. This perspective is consistent with Schumpeterian theory, which points to the disruptions caused by innovations.

Torres (2011) recalls that countries with higher income levels tend to have more people dedicated to R&D and points to the importance of researchers' exclusive dedication to discovering new ideas to generate innovations, whether through R&D departments in companies, universities, or universities or research institutes.

Regarding innovation content and research, it is worth recalling Nelson's work (1959). The author distinguishes research types into two categories: basic research, aimed at advancing knowledge in general, being the freest and without clear objectives before it begins, and applied research, aimed at solving a practical problem.

Nelson points out that radical innovations are associated with basic research, while incremental innovations correlate more with applied research. This happens because the research objective's disconnection from a specific problem allows researchers to go down paths not yet foreseen. However, the author points out that basic research tends to be riskier and more costly in terms of investment because its return expectations are less tangible in the short term, the opposite of applied research.

Thus, Nelson (1959) points out that governments should oversee basic research, reserving applied research for the private sector. In this regard, Arrow (1962) points out that only a small portion of private companies manage to invest in basic research, thus making the inventive effort inferior to what is socially desired. The author indicates that this gap should be filled by governments, universities, and research institutes, which are not oriented by market logic.

In many countries, governments focus on funding and participating intensively in generating innovations from research and technology transfers to the market (Mazzucato, 2014; Mazzucato & Penna, 2015). In this context, Moreira and Velho (2008) highlight Brazil's strong participation in the generation of technological innovation through intensive training of skilled labor, especially masters and PhDs, and the promotion of R&D in universities and public research institutes.

However, scientific knowledge generation has been restricted to the university sphere; the Brazilian private sector still invests timidly in R&D (Fernandes, Garcia & Cruz, 2015). In addition, the hiring of masters and PhDs by private companies remains lower than public institutions' absorption of this labor force (Cgee, 2016, 2021).

Gibbons and Johnston (1993) state that companies that do not have college-level staff, highlighting the absence of PhDs, rarely seek universities to solve any internal problem with research cooperation. This problem shows the importance of absorbing graduates into the Brazilian private sector and more investment in R&D. According to Carvalho and Madeira (2021), these initiatives can overcome critical factors involving (technology transfer of) innovation in Brazilian companies.

Methodological approach: systemic thinking and system dynamics

'Systemic Thinking' established its theoretical framework in the first half of the twentieth century, presenting itself as a paradigmatic alternative to the mechanistic notion of science, and its epistemological limits are General Systems theory (Bertalanffy, 2010) and Cybernetics (Wiener, 2017). In this perspective, the focus is not on analyzing the parts but their interactions since they promote the complex relationships that shape a system's form and production (Vasconcellos, 2018).

System Dynamics is a methodological approach based, in epistemological terms, on the theory of complexity and non-linearity (Systems Thinking) applied to the social sciences (Forrester, 1961; Richardson, 1991; Sterman, 2000). This paradigm was developed in the 1950s by J. W. Forrester and offered tools for modeling complex environments whose elements are interconnected by time-lagged meshes of causes and effects (Forrester, 1961; Meadows & Robinson, 1985).

It is a methodology that enables research and learning about complex systems. Sterman (2000) represents System Dynamics (SD) as a flight simulator to assist pilots in their aircraft. It allows the development of representative models of complex systems, illustrating the interrelationships and multi-causality among their elements, thus enabling simulation and learning in a context of dynamic complexity.

SD offers the opportunity to construct representative "mini-worlds" of complex systems, identifying the sources of policy resistance and indicating the best ways to intervene in the systems. This explanatory capacity makes this methodology relevant for policy formulation and implementation, whether in the private (Sterman, 2000) or public context, to build and implement effective public policies (Furtado, Sakowski & Tóvolli, 2015) for innovation and entrepreneurship (Borges, Bezerra, Silva, Andreassi & Ferreira, 2018).

In general, System Dynamics assumes that complex systems result from causal structures constituted by multiple positive and negative feedbacks (feedback loops), which occur through material or information flows (Dangelico, Garavelli & Petruzzelli, 2010). Thus, causal models are developed from graphical procedures to represent interactions between the constituent elements of systemic complexity.

Sterman (2000) presents two primary tools for modeling complex systems in System Dynamics: Causal Loop Diagrams (DLC) and Flow and Stock Diagrams (FSD). DLCs are models capable of representing a system's feedback structures. They are known academically as "soft" models and help depict mental models. In DLCs, the variables are connected by loops that denote causality between them, so it is possible to illustrate, from a standard language, the variables and relations that make up the represented system.

Flow and Stock Diagrams introduce material and immaterial flows present in a system into the causal representation, as well as the elements that measure its state (Sterman, 2000). In the modeling process, the FSDs portray the relationships between variables from mathematical equations.

One can say that flows correspond to the model change rates, i.e., the ratios of inputs and outputs that determine the stocks. These, in turn, are state variables in complex systems. Mass (1980) states that stocks are critical elements to represent the dynamics of a complex system. This is because they (i) characterize the bases of all systemic action; (ii) allow the construction of systems with inertia and memory; (iii) are delay-generating resources; and (iv) show the imbalances in a complex system (Sterman, 2000).

These elements are crucial for building models in System Dynamics and represent the possibility of implementing Systemic Thinking through a consolidated method. Jay Forrester developed SD to solve complex problems in industrial organizations (Forrester, 1961; Kasper, 2000; Meadows, 2008), so it is a suitable approach for understanding social systems (Bueno, 2011).

Causal loop diagram

This paper aims to understand the structures involved and the possible effects of public policies expanding the graduate labor supply on the innovative potential of Brazilian companies. To this end, it uses System Dynamics (SD) since this methodology enables the modeling of complex systems (Sterman, 2000).

This work seeks to support the dynamic hypothesis that the growing public supply of graduate labor in the market tends to positively influence investment in R&D by the private sector in the long run. However, this relationship depends on the interaction of several other factors and economic agents, which are difficult to capture with a linear view of this issue. In this sense, we use a systemic Causal Diagram model, which involves the cause-and-effect relationships between the variables under analysis.

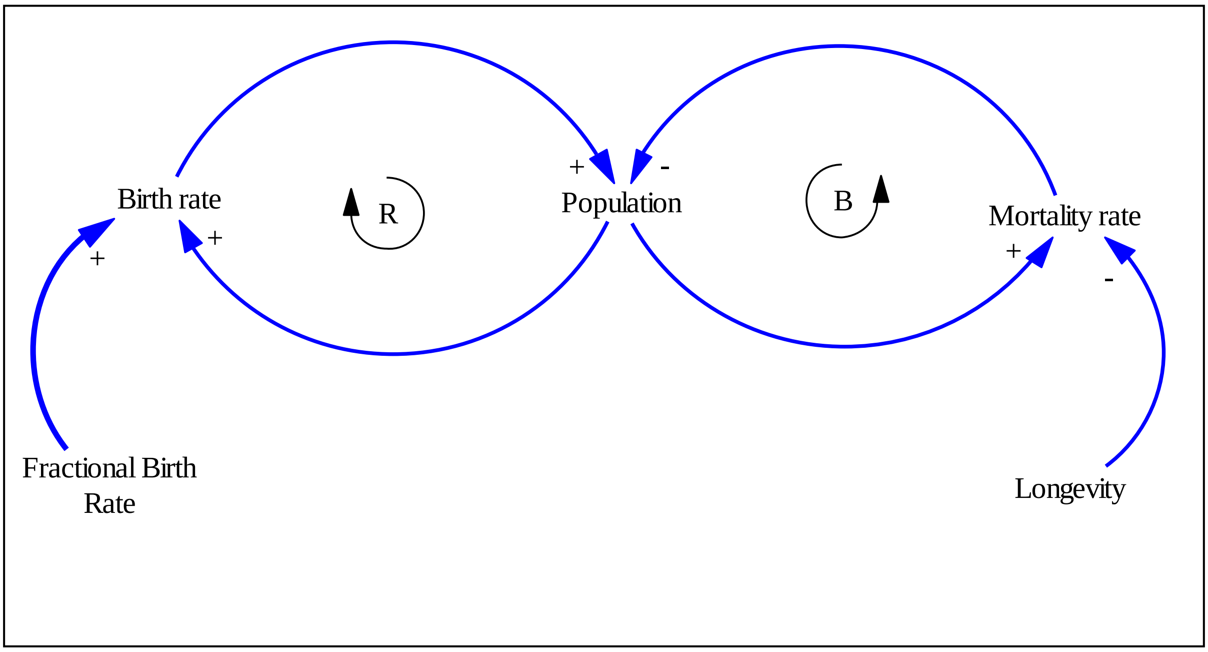
Causal Loop Diagrams (LCD) are suitable for this study because they can materialize a mental model that elucidates a research problem using a clear methodology. It is also an essential tool for explaining the causal relations involved in the object of study.

Sterman (2000) defines Causal Diagrams as a set of variables connected by ties, denoting causal influence among them. In his book "Business Dynamics", the author describes the diagram notation widely accepted in academia, which will be recalled in the present research.

In SD models, variables are related by links that represent causality from their meaning. Thus, causal links accompanied by the plus sign (+) or "S", indicate positive relationships between the two variables involved. In contrast, ties between variables accompanied by the minus sign (-) or "O" point to an inverse relationship between the elements. Figure 1 illustrates the relationships represented by these symbols.

Figure 1

Causal diagram example



Source: Elaborated by the authors.

As seen in Figure 1, an arc links the "Birth Rate" to the "Population" variable, indicating that the former causes variations in the latter. The positive sign on the link shows that both vary in the same direction, i.e., higher birth rates tend to increase the population. On the other hand, the relationship between the Death Rate and Population is inverse, indicated by the negative sign, thus demonstrating an inverse behavior between these two variables.

The symbols "R" and "B" denote the cycle behaviors formed by causal relations (feedbacks). The first indicates a "Reinforcement" cycle (R), i. e., in the indicated subsystem, there is an explosive growth trend or persistent drop. In this sense, "Birth Rate" and "Population" tend to increase or decrease in the long term. The "B" sign indicates a "Balance" cycle, which represents interactions whose results tend toward a certain threshold (goal-seeking). In the example presented, the population tends to stabilize depending on the mortality rate.

From the modeling of several systems, the SD literature has identified a series of structures and standard behaviors among them, which are used as references for the construction of new models (Kim, 1994). These predetermined models have been named "Systemic Archetypes", and they serve to build new models, as they can identify relationships in complex circumstances.

Senge (2018) was one of the authors who popularized using archetypes in System Dynamics. His work presented many practical applications of systemic archetypes in the business environment, contributing to the spread of systems thinking. The author relies on "soft" models for his studies' construction and offers several scientifically valid insights.

In this work, we will apply two archetypes already consolidated in the academic literature on System Dynamics, which are the "Investment and Underinvestment" structure, representing the systemic interactions that provide continuous growth capacity of the system's outputs and the continuous need for investments in infrastructure (Sterman, 2000). The "Limits to Growth" Archetype will also be applied, representing the forces that promote exponential behavior and prevent a system's indefinite growth (Kim, 1994).

Authors such as Forrester (1990) and Sterman (2000) advocate using simulations in System Dynamics to go deeper into research based on this approach. However, its application is not imperative since constructing causal diagrams is a reliable explanatory tool in complex systems (Kasper, 2000).

For the model elaboration, the specialized literature points to the need for software suitable for this approach (Sterman, 2000; 2002). The main ones are iThink® from Isee Systems and Vensim® from Ventana Systems, which have a graphic interface for simplified equation operation. In this research, the Vensim software was chosen due to its availability in the researchers' institution of origin.

The Brazilian context

Graduate programs reap the rewards of various incentives triggered by nations' science and technology policies. For instance, to stimulate R&D investments, many countries set national targets for private and public investments as a share of the Gross Domestic Product (GDP).

In 2018, global R&D spending reached a record high of nearly $1.7 trillion, representing 2.274% of the world's GDP, according to the United Nations Educational, Scientific, and Cultural Organization ([UNESCO] Institute for Statistics, 2021). Notably, many developing countries have found a way to catch up economically by increasing their technological-industrial capabilities and investments in human capital and industrial technology (Lee, 2009; Yong et al., 2010).

The specialized literature shows that an increase in hiring masters and PhDs by the private sector tends to boost the number of innovations created by companies (Velho, 2007).

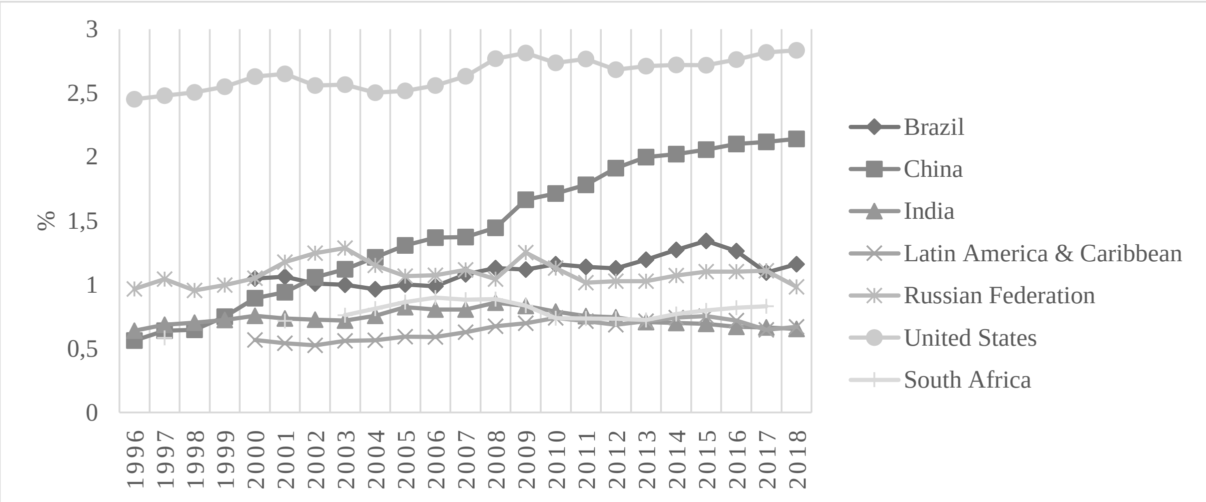
The Brazilian graduate program has grown exponentially since its institutionalization in the 1960s (Conselho Federal de Educação, 2005). This period initiated a series of National Graduate Plans (PNPG) prepared by the Coordination for the Improvement of Higher Level Personnel ([CAPES], 2022). This institution started in the military dictatorship to form a technical-scientific workforce to assume academic and research positions in industries. However, it survived the country's re-democratization, focusing its efforts on the development of the academic sector.

This process occurred because national industries did not absorb the supply of a strong labor market for graduates (Balbachevsky & Schwartzman, 2010; Hostins, 2006; Ivashita & Vieira, 2017). In 2017, approximately 41% of Brazilian masters and 75% of PhDs were engaged in Education activities. Activities in Public Administration, Defense, and Social Security were the next most common that year. They represent 33.7% of master's and 12.6% of PhD jobs (CGEE, 2021).

Activities related to the Manufacturing Industry accounted for 4.2% of masters and only 1.3% of PhDs employed in 2017 (CGEE, 2021). It corresponds to categories such as Factories of Chemical Products, Pharmaceuticals, and Computer Equipment, among others, which believe this workforce has potential for developing innovations.

Figure 2

Total Expenses in P&D (% in relation to GDP)



Source: Elaborated by the authors based on data from the World Bank. Retrieved in: https://data.worldbank.org/indicator.

Figure 2 depicts total R&D spending among the BRICS as a percentage of GDP and how this compares to the numbers from the US and Latin America & the Caribbean.

Romer (1990) recalls that countries with higher economic growth tend to invest more in R&D, which can be corroborated by the statistics presented. It is possible to see that Brazil has a relatively higher proportion of investment when compared to BRICS like India and South Africa, except for China. Notably, Brazilian R&D investment levels are higher than the average in Latin America and the Caribbean.

However, historically, a significant part of the national R&D investment is mainly from the Brazilian public sector (Fernandes et al., 2015), which is very different from the best-placed countries (like China or the US) in the graph.

Velho (2007) highlights the sustainability of new ways of supporting R&D in the country. This concern was resumed by Galvão et al. (2016), who view the National System of Science, Technology, and Innovation's (SNCTI) dependence on public contributions with concern since this relationship also tends to sustain the labor market for graduates outside the activities of direct State action.

The Brazilian public sector plays a vital role in producing knowledge in the country (Mazzucato; Penna, 2016). It is positioned as a major provider of skilled labor (masters and PhDs) and scientific research that can generate innovations in the private sector. However, the literature notes strong disconnections between public research, higher education institutions, and existing market demands, which configure one of the innovative system disconnections in Brazil (Albuquerque, 1998; Matos & Teixeira, 2019).

Graduate policy in Brazil and its potential effects on entrepreneurial innovation

The Brazilian graduate and research policy, which has considerably increased the Brazilian qualified R&D workforce (Cgee, 2015), creates conditions that positively influence companies' innovative potential in the national supply. Considering that the "innovative potential" is the ability of the private sector to develop innovative products and processes via investments in internal R&D (Góis Sobrinho & Azzoni, 2016; Paula, 2019), expanding the scientific workforce increases the number of individuals capable of contributing to this process.

In order to represent this premise in a conceptual model, we sought to analyze the convergence between two distinct markets: (i) the graduate program market, which consists of the interactions between the supply and demand of masters and PhDs by the public sector, and; (ii) the graduates' market, which relates supply and demand to the entrepreneurial innovation process. The following subsections will be dedicated to describing these diagrams.

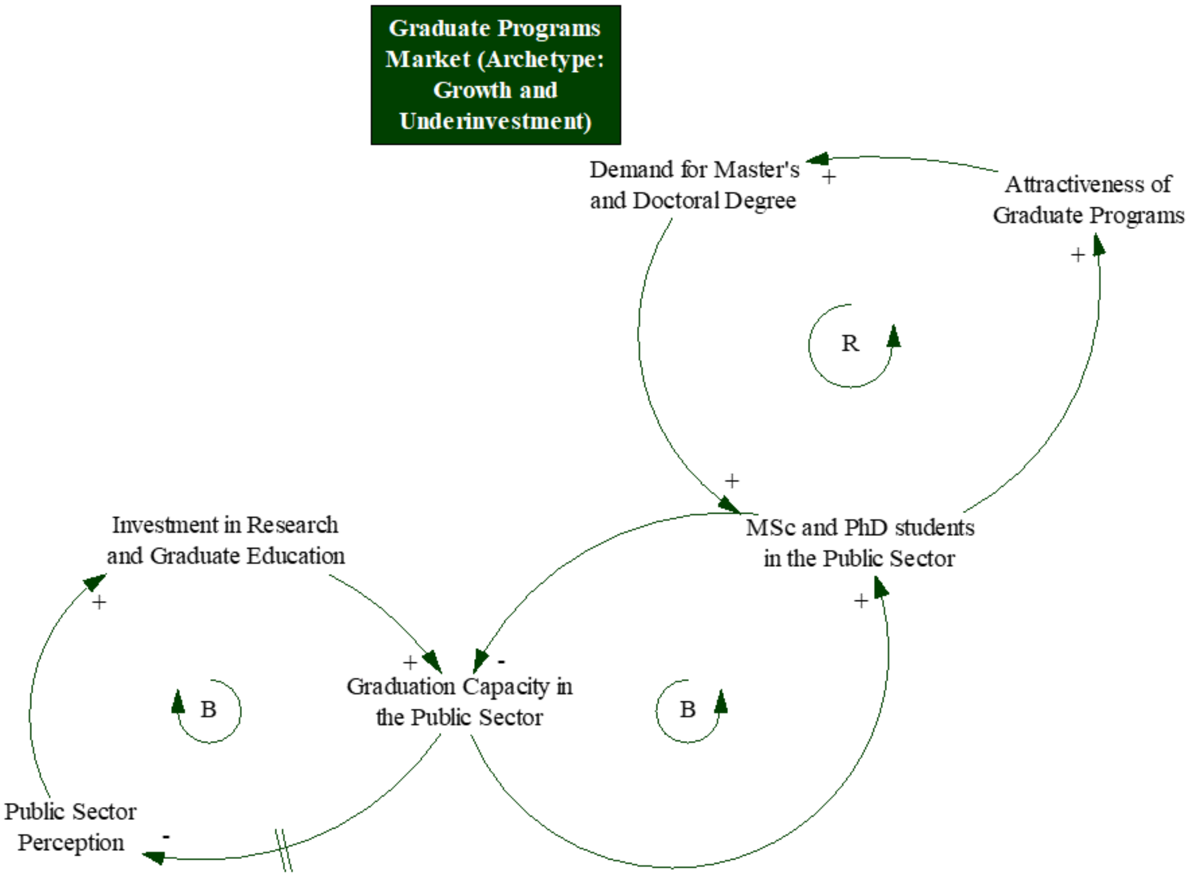
The graduate program market

Figure 3 represents the first market to be described. The graduate market is based on the "Investment and Underinvestment" archetype, which assumes that all growth in a system tends to reach its limit. Therefore, planning and postponing this limit via investment is necessary (Kim, 1994).

In the market under analysis, the number of graduates and the graduate market demand form a reinforcing cycle. This convergence occurs because the model is based on the premise that greater contact with masters and PhDs tends to encourage more individuals to choose graduate studies as a career option in the short term (Lundvall, 2002, 2008).

Figure 3

Graduate program Market



Source: Elaborated by the authors.

The model illustrates that the growth of graduate students (masters and PhDs) enrolled in public institutions meets its limit at the supply capacity of graduate program in the public sector. In fact, public resources are scarce, limiting the growth of vacancies offered by graduate program due to a lack of physical, financial, or human resources. This relationship is represented by the balance cycle (B), which identifies the feedback relationship between the variables "masters and PhD students in the public sector" and the "graduation capacity of the public sector".

The lower the capacity to meet the social demand for graduate studies, the greater the government response in investing in structures to supply vacancies in graduate programs. Society's persisting demand for graduate program tends to sharpen governments' perception over time.

This process is called public agenda formation, which determines the public policies to be implemented by governments (Burstein, 2016; Mainardes, 2006; Wood & Peake, 1998). Agenda formation is slow and gradual as it depends on stakeholders' political interests and articulation (Secchi, 2017). Thus, the relationship between " graduation capacity of the public sector " and "public sector perception" in the model is marked by "two strokes," indicating the lag (or delay) between the cause and effect of low capacity to meet public demand.

From this partial model, it is possible to infer that the first public investments to open graduate programs in Brazil have the potential to trigger a systemic feedback process, characterized initially by subsequent increases in master's and PhD program seats.

Since public resources are scarce, the supply of graduate program vacancies will eventually reach its limit. The existing delay between the capacity limit and public policy agenda creation tends to cause late investments, generating oscillations in the number of graduates, according to the identified archetype.

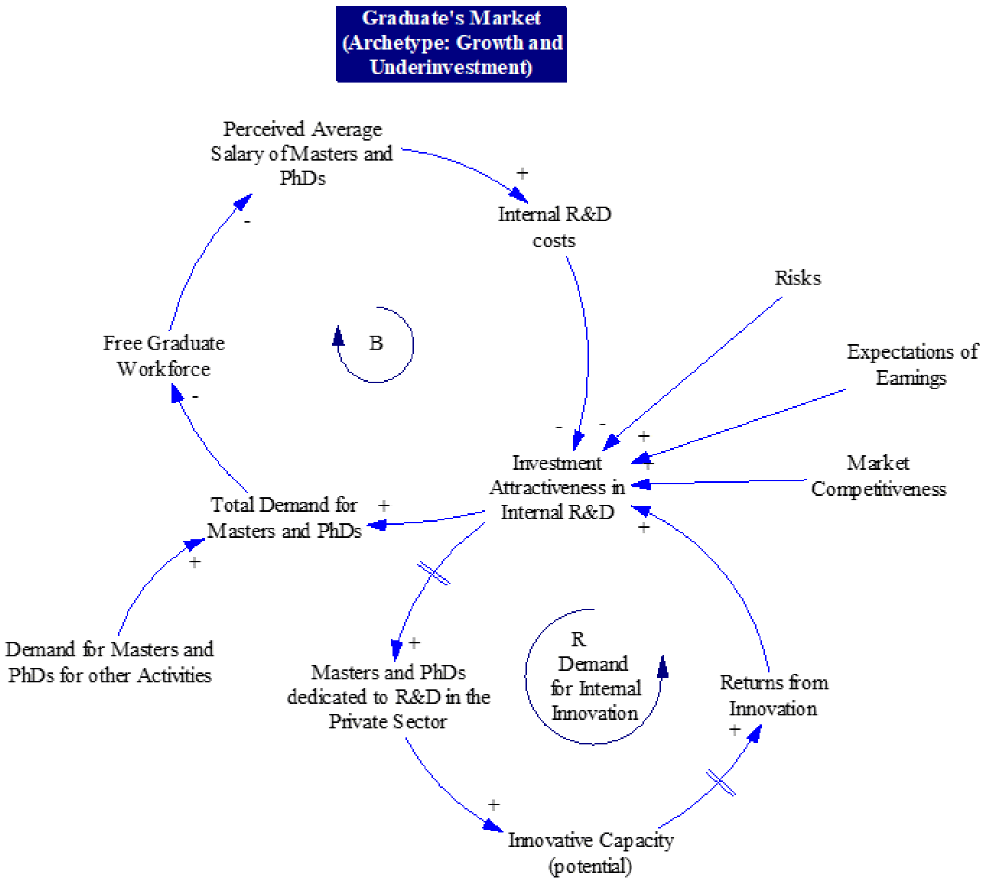
The Graduates' market

The second subsystem refers to (ii) the graduates' market. It is based on the "Limits to Growth" archetype (Kim, 1994; Sterman, 2000), to be illustrated in Figure 4.

The "Limits to Growth" archetype is similar to the last archetype presented (Investment and Underinvestment). It is based on the premise that resources are scarce, so a system cannot generate unrestrained exponential growth in the long run (Kim, 1994).

Figure 4

Graduates' Market



Source: Elaborated by the authors.

In the model created to illustrate the skilled-labor demand dynamics, the feedback, which may cause exponential growth of graduates dedicated to R&D in the private sector, is represented by the causal loop entitled "Demand for Internal Innovation".

In this loop, the number of masters and PhDs dedicated to R&D in the private sector depends on the attractiveness of innovative investment, which relies on variables exogenous to the model, such as future profit expectations (Baptista et al., 2015; Garcia-Quevedo et al., 2012; Maldonado, 2008; Schumpeter, 2012), market competitiveness (Solo, 1951), and internal research investment risk (Lundvall, 2008; Nelson, 1959).

The variable "Investment attractiveness in Internal R&D" in Figure 3 derives from the endogenous variable "Returns from Innovation" which represents innovations' historic profits in companies. This causal relationship illustrates possible causes of growth trends in internal R&D Investment in private organizations or declines in capital flow applied to corporate R&D.

This relationship shows that the higher the returns on past innovative investments, the more R&D becomes attractive as a future investment option. The opposite would also be true; a historical decline in "Returns" would reduce the "Attractiveness" of internal R&D investment.

Therefore, this causal relationship would be responsible for the number of graduates dedicated to R&D in the private sector since the "Attractiveness of Internal R&D Investment" would positively affect the variable "Masters and PhDs dedicated to R&D in the Private Sector", which, in turn, would affect organizations' "Innovative Capacity (potential)". Finally, this would close the cycle by influencing the organizations' future "Returns from Innovation".

This sequence of connections (reinforcing feedback loops) represents the forces that shape companies' ability to innovate via investment and R&D graduate hiring. Moreover, it implies that variation in any elements that make up the chain and relationships tends to continue in the future in the same direction and magnitude.

In other words, the more innovative capacity is fostered in a company, the more its future capacity is developed. The increase in returns on hiring graduates for R&D tends to stimulate its continuous expansion over the years. This proposal aligns with theoretical perspectives that attest to hiring graduates by innovation-oriented companies (Lundvall, 2008; Nielsen, 2007).

However, the model’s feedback forces tend to be limited by other structures of reality. Otherwise, there would be an indefinite rise or fall in the innovative potential of companies and the number of graduates hired for R&D. The process limits are given by the "Balance" causal loop (letter "B" in Figure 3), which connects to the first link through an endogenous variable to the model, the "Internal R&D costs", which directly affect the attractiveness of R&D investment. In other words, the incentive to innovate is affected by comparing the expected return and cost of investment (Schmookler, 1962), an idea included in this model.

In conclusion, the feedback loop balance in question establishes the counterpart to the systemic effects of the escalating demand for researchers in the labor market. In addition to the reinforcing "Demand for Internal Innovation" feedback loop, the increase in the Attractiveness of Internal R&D in firms also tends to increase demand for PhDs and Masters, which tends to put pressure on the wages of these graduates, and, ultimately, to increase the costs of this skilled labor. The result of this causal sequence is the progressive increase of the "Internal R&D Cost", which acts as a limiting component for the unlimited growth of hiring graduates for R&D in the private sector and, consequently, the "Innovative Capacity" of organizations.

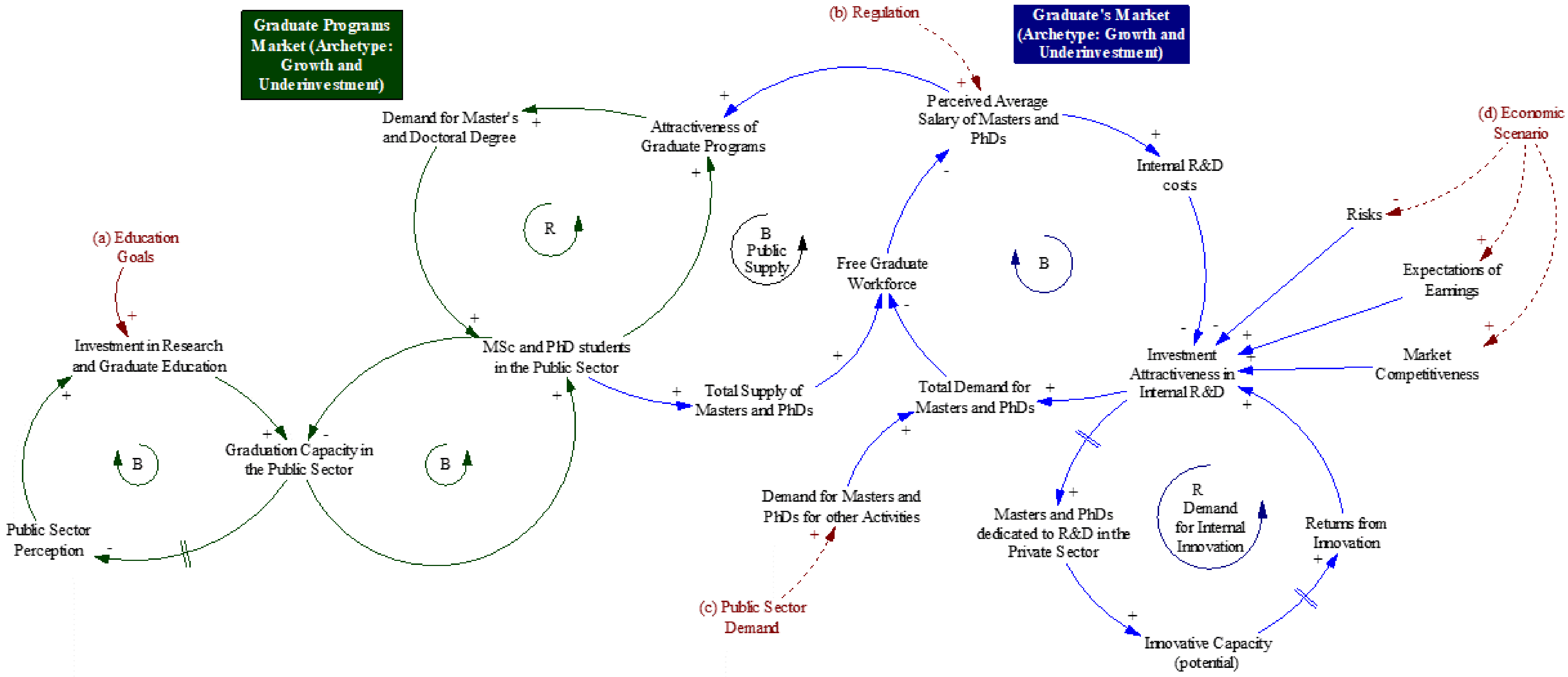
Noticeably, the Brazilian public sector is the primary employer of masters and PhDs, especially those absorbed by the public education system (Alves, 2009; CGEE, 2021; Galvão et al., 2016). The report of the Center for Strategic Management and Studies, which provides market data for these categories, indicates that the market absorbs masters more than PhDs due to PhD's high academic/research nature and the low demand for R&D activities in the private sector (CGEE, 2016, 2021).

Market relationships

The construction of a systemic hypothesis that would bridge the gap between graduation, research policies, and the innovative potential of the Brazilian private sector was possible due to the junction between the two markets described above. The result is shown in Figure 5.

Figure 5

Integrated causal model



Source: Elaborated by the authors.

The model presented in Figure 5 unites both markets based on graduates' supply and demand dynamics. The junction between the previously described systems allows for reflection on possible forces acting on the supply of graduate labor and its distribution in the labor market, especially for developing private-sector innovations.

In the proposed system, the variable "Free Graduate Workforce" unites the public supply of graduates with the total demand for this type of workforce. It corresponds to the number of graduates searching for job opportunities in the Brazilian market. This variable is crucial for maintaining the system since it influences the dynamics in both subsystems, which interact and generate a new context of relationships.

The outputs from the "Graduate Program Market" subsystem create the possibility of expanding R&D investment capabilities in the private sector, providing the "Graduates' Market" subsystem with characteristics of a new "Investment, Sub investment" archetype. This occurs because the public supply of masters and PhDs alters the limits of skilled labor costs.

This interaction identifies the agents of *stricto sensu*[1] graduate supply as the starting point for creating a population of graduates, flowing from the academic sector to the industrial sector. In academia, the first subsystems for graduate population growth emerge. Since it is necessary to hire masters and, especially, PhDs to train academics, educational institutions structure their systems so as to offer graduates, who will, in turn, be demanded by those same institutions (Ghaffarzadegan, Xue, et al., 2017; Larson et al., 2014; Menon et al., 2018).

Ghaffarzadegan et al., (2014, 2017) state that academic institutions tend to produce a surplus of graduates, that is, to demand relatively less than their supply capacity. In this sense, what tends to occur is an increase in the supply of masters and PhDs looking for jobs outside their academic institutions of origin. In other words, an accumulation of "Free Graduate Labor".

From the connections expressed in the model, it is possible to infer that the graduate academic population, the "Graduate Program Market", transfers to R&D activities in the productive sector, increasing companies' Innovative Capacity. This process occurs via accumulating free masters and PhDs in the labor market.

In this sense, a possible increase in the graduate supply promoted by the Brazilian public sector would tend to increase the number of "Free Graduate Workforce", which, consequently, would pull down the average salary practiced in the "Graduates' Market ". This process could reduce the cost of R&D, affecting the attractiveness of R&D investment by the private sector.

However, identifying these interactive forces in the system is not deterministic concerning the increase in business' Innovative Capacity. In practice, the factors that affect the decision-making process of hiring skilled labor for innovation are confronted with the effects of exogenous variables such as

[1] In the mid-1960s, the Federal Education Council (*Conselho Federal de Educação* - CFE) wrote the Sucupira Opinion, the first regulation that institutionalized Master and PhD program as the two levels of graduate studies known as *stricto sensu*.

risks, profit expectations, and market competitiveness, which tend to influence internal R&D strongly. Furthermore, the delay between increasing innovative capacity and returns can act as a powerful barrier to investment since creating innovative products and processes does not occur quickly and linearly, requiring long-term patience and persistence (Nelson, 1959; Torres, 2011).

In Brazil, for example, the increasing supply of graduate labor is accompanied by the continuous expansion of graduate demand in the academic sector (CGEE, 2021; Galvão et al., 2016). This phenomenon softens increased unemployment and its effects on wage variation. Furthermore, the country's productive sector has historically had little interest in hiring researchers to perform R&D activities for innovation (Balbachevsky & Schwartzman, 2010, 2011, Schwartzman, 2001).

The low researcher insertion in the productive sector is explained in some works by Brazil's lengthy economic closure, which led to low corporate exposure to broad competition, as well as businesses' preference to import technologies due to high investment risks related to national R&D (Bagattolli, 2008; Oliveira, 2003; Souza & Marinho, 2015).

Final considerations

This research results proposed a theoretical-conceptual model capable of illustrating the systemic relationships between public policies for graduate research and the innovative potential of the private sector, manifested by the absorption of skilled labor for internal R&D development. The System Dynamics methodology modeled the set of complex interactions inherent to the object of study.

There are two guiding questions in this research. First, how can the dynamics of the public graduate supply influence the innovation potential of Brazilian companies? Second, what variables and main systemic interactions should this process highlight? With these questions in mind, it is possible to state that these elements can be identified by joining the two markets that establish an endogenous relationship between the skilled labor supply and the graduate demand to build innovative corporate potential.

It has been shown that the Graduate Program Market and the Graduates' Market are connected and interdependent structures. This relationship implies that, once the supply of graduate labor begins, a stock of masters and PhDs is formed in search of job opportunities in the economy. This process tends to influence the cost structure of hiring skilled labor, affecting the allocation of human capital among internal R&D activities in organizations.

The innovative potential of business organizations depends, first of all, on forming a qualified labor force in the market. This potential was one of the goals achieved by national public policies for graduate program in Brazil through the National Graduate Plans (PNPG). In turn, the flow of graduates to R&D activities does not occur naturally or deterministically.

On the other hand, this tendency can be neutralized by variables external to the model, which reduce the attractiveness of this type of financial investment, such as high investment risks, low expectations of future profits, and weak market competitiveness.

It was presented that the allocation of graduates from public administration and education to the productive sector occurs timidly and slowly in Brazil. Considering the proposed model, what are the explanations for this scenario?

Considering the Brazilian reality and the connections proposed in the model, at least two basic elements are notable. The academic literature has densely recorded the first: Brazilian industry has not historically developed a National Innovation System connected with university outputs (Góis Sobrinho & Azzoni, 2016; Mazzucato & Penna, 2016; Souza & Marinho, 2015).

This context points to the imbalance between the graduate supply policy and the national demands for R&D in the Brazilian productive sector. The II National Graduate Plan, in force between 1982 and 1985, describes the market imbalance already at the public policy's inception by stating: "The productive sector, both state and private, mainly because of its dependence on foreign capital and technology, does not absorb the high-level professional capacity or the research results that the system produces" (Brazil, 1982, p. 182).

Some authors credit this dependence to low competitiveness and the high costs and risks of investing in internal R&D in Brazil (Bagattolli, 2008; Souza & Marinho, 2015). Exogenous variables in the model represent this perspective.

Second, one must consider the expansion of higher education in Brazil in recent decades (Dias, 2009; Fávero, 2006; Nascimento & Verhine, 2017). Besides increasing the graduate workforce, increasing higher education supply heats the labor market since it affects the demand for graduates for academic activities (Larson et al., 2014). This process results in the concentration of graduates in education activities while increasing competition for this labor force in the labor market.

Given the above, the causal diagram constructed from exogenous variables exposes some insights into the variables to be targeted by public policies, such as:

(a) Education Targets: prior investment in education and setting high goals, unlinked to internal dynamics, may favor a continuous flow of masters and PhDs, thus affecting the costs of R&D investment in the private sector (Morais, 2022).
(b) R&D wage regulation: graduates' wages in scientific research tend to be regulated (Cgee, 2016). The freedom given to the market may allow for faster responses in absorbing graduate labor.
(c) Public Sector demands: the Brazilian public sector is the main employer of graduate labor. The subsequent increase in this demand tends to pressure R&D investment costs, reducing its attractiveness.

(d) Economic scenario: the dynamism of a country's economy is the primary determinant of the entrepreneurial attitude of its companies since it tends to affect long-term prospects, a premise for any investment in R&D (Aghion, Antonin & Bunel, 2021; Lundström & Stevenson, 2006).

Among all the topics mentioned, we highlight the priority of establishing economic and innovation policies that promote sustained growth in the long-term, focused or integrated with the different types of Brazilian entrepreneurship (Aviram, Cohen & Beeri, 2019; Borges et al., 2018). Given the quest for market surplus, better social outcomes tend to be earned by extending returns rather than reducing costs.

This work was built based on a Causal Diagram in system dynamics, which analyzed the various interactions in the model. Based on this, we suggest that future research deepens the modeling by applying stock and flow diagrams. This path is natural for the methodology in question. It will build a quantitative model of scenario simulations for decision-making in public policy based on the variables proposed here.

Authors' contributions

Contribution	Morais, M.C.A.	Emmendoerfer, M.L.	Protil, R.M.
Contextualization	X	X	X
Methodology	X	-----	X
Software	X	-----	X
Validation	X	X	X
Formal analysis	X	X	X
Investigation	X	-----	-----
Resources	X	X	-----
Data curation	X	X	X
Original	X	X	X
Revision and editing	X	X	-----
Viewing	X	X	-----
Supervision	-----	-----	X
Project Management	-----	X	-----
Obtaing funding	-----	X	-----

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