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Technological innovation system in agribusiness: motors and evolution

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Abstract

Purpose – This paper aims to analyze the evolution and interaction over time of the functions of a technological innovation system (TIS) based on the concept of an innovation motor.

Design/methodology/approach – It is a case study of the innovation system associated with the technology for producing cage-free pullets for laying eggs in Pelotas/Rio Grande do Sul (RS).

Findings – The motors proposed by the TIS approach evolve sequentially and are associated with cumulative causality mechanisms. The study's results identified two functionalities: analysis of the chain as a whole and coordination of the actors involved in the system. The study's results also identified the presence of inflection points at the beginning of each of the motors.

Research limitations/implications – The absence of a more accurate detailing of the market motor in discussions of the evolution of the motors and functions of TIS cage free Pelotas.

Practical implications – Innovation Motors as a new guiding approach for participatory innovation initiatives in rural areas.

Originality/value – Application of the TIS approach in agribusiness and proposition of two new functions for motor analysis, in addition to including inflection points as activation triggers in the evolution between motors.

Keywords Technological innovation system; Agribusiness; Sustainability; Innovation motors; Tipping points

Paper type Research paper

1. Introduction

The criticism that the linear method of technological development is flawed has encouraged scientists to consider better the complex context in which technologies have been applied (Lamers, Schut, Klerkx, & van Asten, 2017). They reached these conclusions because, when analyzing research organizations, they found difficulties in implementing the new technologies developed, especially with a focus on sustainability (Planko, Cramer, Chappin, & Hekkert, 2016).

Subject-matter experts have considered the theoretical approach called technological innovation systems (TIS) as a reference for studying emerging technologies with a focus on sustainability (Kukk, Moors, & Hekkert, 2015). The TIS approach has been considered adequate to explore how organizations can stimulate the creation of productive chains and

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increase the chances of successfully implementing a new technology available to society (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). For example, several studies have been carried out on technologies associated with biotechnology, precision agriculture (Eastwood, Klerkx, & Nettle, 2017; Hall, 2005; Klerkx, Van Mierlo, & Leeuwis, 2012) and sustainable agricultural systems (Lamers *et al.*, 2017).

A TIS can be defined as a "set of actors and institutions in networks that interact in a technological field and/or new product" (Markard, Raven, & Truffer, 2012). A TIS can also be defined as an analytical construct incorporating hitherto independent subsystems of the innovation system (Bergek *et al.*, 2008).

TIS concepts are based on the idea that innovation and technological change determinants do not reside only in research organizations. They consider that the determinants that support and constrain the activities of these organizations are in the broader innovation system (Bergek *et al.*, 2008). Thus, a TIS is usually analyzed in terms of seven functions. System functions are class processes that contribute to technological innovations' development, diffusion and use (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007).

The functions of TIS are the most important processes in building an innovation system. Namely: F1 – entrepreneurial experimentation; F2 – development of knowledge; F3 – dissemination of knowledge; F4 – research orientation; F5 – market formation; F6 – resource mobilization; F7 – creation of legitimacy. The list of seven system functions was established based on a review of several years of literature on systems innovation (Hekkert *et al.*, 2007).

The first theoretical gap identified in research on TIS was associated with three other functions considered fundamental in the evolution of a TIS and have yet to be considered in the analysis. These other three functions are coordination (Markard, Geels, & Raven, 2020; Planko *et al.*, 2016), sociocultural changes (Planko *et al.*, 2016; Markard *et al.*, 2020) and analysis of the system as a whole (Markard *et al.*, 2020; Nevzorona, 2022).

Furthermore, another criticism of the TIS approach is that it is static and pays little attention to the system evolution functions (Lachman, 2013; Planko *et al.*, 2016). It also pays little attention to the interaction between functions, which are included and excluded along the innovation trajectory (Lamers *et al.*, 2017). The concept of a TIS innovation motor (Suurs and Hekkert, 2012; Suurs, 2009) overcomes the criticism of little attention to system evolution by emphasizing the evolution of functions and their relationships over time. The concept of innovation motor is a set of assumptions about how and which functions influence each other at different stages of a TIS's evolution, forming a typology called innovation motors (Suurs and Hekkert, 2012; Suurs, 2009).

The second theoretical gap was associated with the concept of innovation motors. This concept has been little understood and developed in the literature on TIS (Köhler, Raven, & Walrave, 2020), whose exception is the work of Walrave and Raven (2016). This theoretical gap represents an opportunity, given the need to better understand the dynamics of a TIS. Mainly the functions' evolution and their interactions that support the evolution, since the understanding of the relationships between the functions, over time is still limited (Köhler *et al.*, 2020), especially in the rural area, where no previous studies were found.

Considering the need to advance in understanding the dynamics of a TIS, the authors established the following research question: How do functions and interactions between these functions evolve in a TIS in agribusiness? This article contributes to answering the research question by describing the evolution of the functions and motors of a TIS in the context of an agribusiness technology focused on animal welfare and sustainability. It is the technology for producing cage-free hens for laying eggs.

The technology for producing cage-free hens for laying eggs has been developed all over the world and in the region of Pelotas-RS by Embrapa Clima Temperado-Pelotas/RS. We defined this technology development as our case study. Embrapa Clima Temperado has been developing the technology for producing cage-free pullets for over 20 years. Rural producers in Pelotas and the region have increasingly adopted it.

The results of our research indicate the suitability of functions and motors as appropriate instruments for analyzing the TIS in agribusiness. There was a need to consider new relevant core functions called whole chain analysis (F10) and coordination (F8). Innovation motors evolve sequentially and are associated with cumulative causality mechanisms. Furthermore, the influence of tipping points (TPs) was verified at the beginning of each identified motor.

The originality of this research lies in the following: (1) the application of the concepts of motors and functions of a TIS in agribusiness, (2) the proposition of three new functions for motor analysis, (3) the inclusion of the concept of TPs as an activation trigger in the evolution between the motors which was inferred from the data obtained in the empirical field.

Finally, a managerial contribution is needed, especially for participatory innovation interventions in rural areas. The results suggest that interventions are articulated at the system's upper levels, such as credit, inputs and markets, that is, with articulated actions far beyond those customarily developed in rural communities.

2. Technological innovation system

2.1 Key functions of technological innovation system

Functions of innovation systems are considered classes of processes that contribute to the development, diffusion and use of technological innovations (Hekkert *et al.*, 2007). These dynamic processes occur between the system's structural components (actors, networks and institutions). Each function contributes to building a favorable system around innovative technology (Musiolik & Markard, 2011). The authors describe below the seven functions traditionally discussed in the literature.

Function 1 – Entrepreneurial experimentation: Entrepreneurs are essential in a TIS, because they convert potential innovative ideas into business opportunities (Hekkert *et al.*, 2007; Planko, Cramer, Hekkert, & Chappin, 2017). These entrepreneurs can be either new businesses or established firms looking to diversify their businesses through innovative technology. When testing innovative technology in the market, social learning processes are activated, which makes it possible to gather new information about the reactions of consumers, government, competitors and suppliers (Hekkert *et al.*, 2007; Planko *et al.*, 2017).

Function 2 – Knowledge development: Learning activities such as research, development and learning in a practical context are fundamental to any innovation process. Knowledge must be acquired not only about innovative technology but also about markets, networks and users (Bergek *et al.*, 2008; Hekkert *et al.*, 2007; Planko *et al.*, 2017).

Function 3 – Dissemination of knowledge: Conferences, workshops and alliances encourage knowledge exchange. It is essential not only for the exchange of specific research and development (R&D) knowledge but also for the exchange of knowledge between government, businesses, and the market (Hekkert & Negro, 2009; Planko *et al.*, 2017).

Function 4 – Research orientation: This essential process summarizes all activities and events that convince actors to enter or invest in TIS. A positive expectation toward technological development is the main aspect here, and this expectation may be based on changes in attitudes, entry prices, regulations and policies (Bergek *et al.*, 2008; Hekkert *et al.*, 2007; Planko *et al.*, 2017).

Function 5 – Market formation: One can say that the new sustainability technologies need help to compete with the dominant technologies. Therefore, creating temporarily protected niche markets for the technology to develop and gain market share is necessary. Favorable tax regimes guaranteed consumption quotas, environmental regulations and public procurement policies (Bergek *et al.*, 2008; Hekkert *et al.*, 2007; Planko *et al.*, 2017) can help create these niches.

Function 6 – Resource mobilization: This fundamental process concerns the necessary resources for the correct functioning of the TIS. Entrepreneurs must mobilize financial and human resources to build the innovation system and develop complementary resources, such as complementary products, services and network infrastructure (Bergek *et al.*, 2008; Hekkert *et al.*, 2007; Planko *et al.*, 2017).

Function 7 – Create legitimacy: Innovation focusing on sustainability often needs help to overcome the innovation inertia caused by the current production system. The current production system is often reluctant to change. Therefore, coalitions and lobbying are needed to champion innovative technology to obtain resources and favorable tax regimes and to place innovative technology on the political agenda (Hekkert *et al.*, 2007; Planko *et al.*, 2017).

2.2 New key functions associated with TIS

Three new key development functions of a TIS have been suggested: coordination (Markard *et al.*, 2020; Planko *et al.*, 2016), sociocultural changes (Planko *et al.*, 2016; Markard *et al.*, 2020) and the analysis of the system as a whole (Markard *et al.*, 2020). These three new function proposals are discussed below.

Effort coordination function (F8): This function is seen as a function that contributes to the acceleration of the construction of a TIS because the diffusion of innovations often requires alignments between several activities (Markard *et al.*, 2020; Planko *et al.*, 2016). A set of activities is seen as important in this TIS coordination effort.

Planko *et al.* (2016) highlight seven activities. The first two are creating a shared vision and setting common goals among TIS participants. The third activity involves standardizing products and services. Standardization is vital to reduce production costs and build a reliable system, allowing buyers and consumers to choose from available brands (Planko *et al.*, 2016). The fourth activity is the creation of open innovation platforms within TIS, intending to increase the innovation speed of complementary products (Planko *et al.*, 2016). Finally, three activities will be used in the system orchestration. One refers to management; the second is to align the individual participants' efforts, which requires defining the roles of TIS participants to create the necessary resources to face the regime; the last activity is the creation of transparency, which is crucial, as it can avoid overlapping roles and resources when optimizing the TIS (Planko *et al.*, 2016).

Sociocultural changes function (F9): Innovations, especially those focusing on sustainability, need to be well-rooted in society (Markard *et al.*, 2020; Planko *et al.*, 2016). It means that entrepreneurs must strive for the desired changes in consumer decision-making. Therefore, these entrepreneurs need to change ingrained values and norms in favor innovative technology. A set of activities is associated with the function of sociocultural changes. As for entrepreneurs' businesses, they must: (1) induce more collaborative actions among their employees, (2) induce changes in consumer value and (3) act in the educational system to train professionals with skills to work in innovative technology.

Planko *et al.* (2016) and Markard *et al.* (2020) highlight that policymakers can change consumer behavior by providing more information about innovative technology, creating performance standards for products, reducing fees and creating subsidies that aim to encourage the adoption of new sustainable technology.

Whole system analysis function (F10): Markard *et al.* (2020) and Nevzorona (2022) highlight this function by stating that innovations aimed at sustainability need to align the system as a whole. For this to happen, it is necessary to overcome two critical issues: (1) the need to foster complementary interactions between multiple innovations; (2) the need to promote changes in the system architecture.

The need to have a global vision in agribusiness is familiar and can be seen in the production chain concept. According to Batalha and Silva (2008, p. 32), the definition of a production chain starts with the identification of a final product "[. . .] after this identification, it is necessary to chain, from downstream to upstream, the various technical, commercial and logistical operations necessary for its production." Through the application of the production chain concept, one can see how complex the production process is, which implies aligning and innovating in the various links of the production chain as a whole, aiming at the success of the chain that one wishes to promote.

From the new functions, which have been considered vital in TIS, the following proposition is made: P1 – the functions of coordination, sociocultural changes and analysis of the system as a whole are essential in the evolution of rural TIS.

2.3 Innovation motors

Suurs (2009) highlights that the discussion on innovation motors originates in studies on organizational change, specifically in the notion of motor used by Poole, Van de Ven, Dooley, and Holmes (2000).

Suurs and Hekkert (2012) and Suurs, Hekkert, and Smits (2009) studied the notion of innovation motor in TIS, and they identified four types of function combination as they appear in the sequence.

The first motor is called the motor driven by science and technology (Suurs and Hekkert, 2012; Suurs, 2009). This motor refers to a pattern in the innovation system in which the development and dissemination of scientific knowledge are central, supported by research projects and supporting policies (Walrave and Raven, 2016). The motor is triggered by social and environmental problems (Suurs and Hekkert, 2012; Suurs, 2009), a common activation trigger. The production and dissemination of scientific knowledge format the first experiments and some entrepreneurial activities, which may increase or decrease, depending on whether the results confirm initial expectations (Walrave and Raven, 2016). This motor is dominated by the knowledge development (F2), knowledge dissemination (F3), research guidance (F4) and resource mobilization (F6) functions. The role of entrepreneurial activities (F1) are also essential in the science and technology motor (Suurs and Hekkert, 2012; Suurs *et al.*, 2009).

The second motor is called the entrepreneur motor. It refers to a pattern of the innovation system whose central dynamic is constituted by the increase of active entrepreneurs in the innovation system (Markard *et al.*, 2020). Suurs and Hekkert (2012), Suurs (2009) and Walrave and Raven (2016) explain that, in this motor, the beginning of a virtuous cycle of technological development lies with entrepreneurs, who lobby (F7) for better economic conditions and thus, make technological development possible.

Suurs *et al.* (2009) explain that the entrepreneur's role is to translate knowledge into business opportunities and, eventually, innovations. Suurs and Hekkert (2012) make it clear that, in some cases, this dynamic is strengthened by market niches (F5). These niches involve small markets usually not developed within the TIS (Suurs and Hekkert, 2012; Walrave and Raven, 2016). The periphery of this motor is made of motor connections driven by science and technology (Suurs and Hekkert, 2012).

The third motor is called system construction (Suurs and Hekkert, 2012; Suurs, 2009) and refers to a pattern of the innovation system which is characterized by the increase of system actors to act in networks, infrastructural development and attempts to reconfigure institutions (Walrave and Raven, 2016).

The network starts attracting broader social support, for example, for the institutionalization of new incentive policies, or the construction of physical infrastructure. The motor is comprised of entrepreneurial motor relationships but with more additions and emphasis on creating legitimacy (F7), market formation (F5) and research orientation (F4). It is considered the valley of death in the TIS evolution process (Suurs and Hekkert, 2012; Walrave and Raven, 2016).

The fourth is called market motor (Suurs and Hekkert, 2012; Suurs, 2009) and refers to a pattern of the innovation system where there is a substantial market demand, which is enough to keep all entrepreneurs associated with TIS (Walrave and Raven, 2016). Social and political actors have already legitimized TIS, which is no longer explicitly questioned. All functions are essential, but creating legitimacy is less important (Suurs and Hekkert, 2012; Walrave and Raven, 2016).

From the review of the types of innovation motors, which experts have associated with the process of evolution of TIS, we prepared two propositions: (1) P2 – Each innovation motor is characterized by the dominance and interaction of its own essential functions; (2) P3 – the science and technology, entrepreneur, systems construction and market motors evolve sequentially.

3. Methodology

The research strategy was classified as a qualitative study of a single case analysis. The search characterizes a qualitative case study to know in depth about a situation that is supposed to be unique (Yin, 2017).

The authors defined the case as the TIS associated with the production process of cage-free chickens. The authors chose this case because the technology for the production process of cage-free chickens has been developed for over 20 years and is currently being increasingly adopted by rural producers and demanded by the market.

The spatial domain was defined as the starting point for the city of Pelotas-RS and the actors and institutions in other cities with interactions based on it. Having decided on the case and the spatial domain, we proceeded to identify the structural components of the system. These included not only companies but also rural producers and some of their suppliers, universities and fostering institutes, as well as public bodies and organizations with common interests.

The snowball technique was used to identify the actors, where the first actor selected indicates the following actors who will be able to compose the TIS. This procedure is based on the significant uncertainties involved. When the analysis is carried out in an emerging TIS, a definitive focus can be challenging to choose and changes may be necessary over time (Bergek *et al.*, 2008).

For data collection, a script was used, which guided the conduct of the interviews, document analysis and participant observation. The interview and document analysis script are based on the seven functions of Hekkert *et al.* (2007), with the addition of the three functions proposed by Planko *et al.* (2016) and Markard *et al.* (2020).

Four interviews were carried out with key people who were incredibly familiar with the early formation of the TIS as they were responsible for the first experiments in the region. They also worked in promotion, licensing and training activities in innovative technology in addition to being connoisseurs of the recent history of the analyzed TIS: a) interviewee 1 – researcher in Agroecology at the Brazilian Agricultural Research Corporation – Brazilian Agricultural Research Corporation (EMBRAPA); b) interviewee 2 – Professor of Poultry in technical education at a professional agricultural technical education school; c) interviewee 3 – Extension Worker from the *Empresa de Assistência Técnica e Extensão Rural (Technical Assistance and Rural Extension Company)* – Emater/Ascar; d) interviewee 4 – Extension Worker from *Empresa de Assistência Técnica e Extensão Rural – (Technical Assistance and Rural Extension Company)* Emater/Ascar.

The documents considered in data collection comprised: (1) a thesis; (2) five official government documents; (3) three minutes of a network meeting involving TIS members; (4) a law; (5) eleven pieces of news from local newspapers and media. In addition, participant observation was carried out in twelve activities involving the analyzed TIS. The selection of documents was carried out through the interviewees' indication. They reported that these documents were relevant for describing the TIS evolution. Documents were also collected, characterized or cited as relevant in the participant observation activities (twelve activities) involving the TIS. Data were collected over the years 2019 and 2020.

The procedural method, or sequence analysis (Abbott, 1995) suggested by Suurs and Hekkert (2012), was used to analyze the collected data. The procedural method conceptualizes development and change processes as sequences of events and explains the products of a process as the result of an order of events (Abbott, 1995). Events are central elements of what subjects do or happen to them (Abbott, 1995). Hekkert *et al.* (2007) recommend that all mapped events be allocated to functions via a schema, allowing the researcher to verify the functions' validity. Along the TIS trajectory (1999-2020), 41 events were identified and classified.

To carry out the study, we sought to follow the research judgment criteria proposed by Yin (2017). As for the quality of the results, we used multiple data sources, such as interviews, documents, legislation and participant observation (Yin, 2017). As for the internal validity, the observed results were initially compared, with the existing theory about the functions, with the innovation motors later and the confidentiality of the collected data (Yin, 2017). As for the external validity, we compared the results obtained and interpreted during the research with the co-author of the research, who, we believe, has more comprehensive knowledge about the case studied and is an expert in the theoretical approach of TISs (Yin, 2017). The data analysis script composed of theoretical categories (10 functions of the dynamics of a TIS) reviewed in sections 2.1, and 2.2 (Yin, 2017) corroborates the reliability of the research.

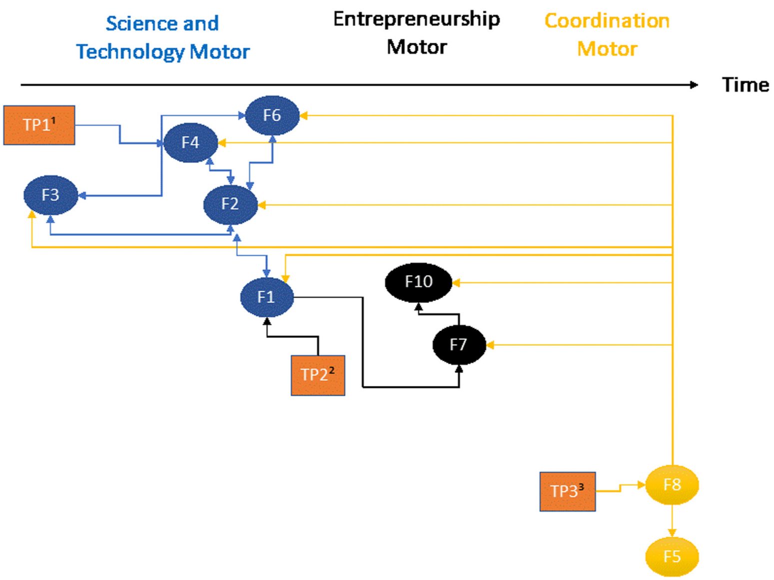
4. Results and discussion

4.1 Description of the evolution of the motors and functions of TIS cage free Pelotas

This section describes the evolution of innovation functions and motors based on the events identified and classified according to the ten functions reviewed in Sections 2.2 and 2.3. Three motors were identified. TIS cage free Pelotas (Phase I) began with the creation of the science and technology motor in 1999, later by the entrepreneurship motors (Phase II in 2017), and then by the system construction motor (Phase III in 2019). Figure 1 summarizes the described evolution of the functions and motors identified in the TIS *cage free* Pelotas. Each of the three motors identified is described below.

Phase I, which created the science and technology motor, was characterized by the first TP (TP1[1]), a social demand to generate income for a local community of rural producers in extreme poverty. Based on this demand from EMBRAPA, a research project (F4) was created to develop a technology for raising and handling cage-free birds for these vulnerable families. From the project onwards, the knowledge development (F2) started with the installation of demonstration units to validate the previously designed creation model. The results of the demonstration units pointed to the need to reorient the research (F4), including research on the preparation of low-cost poultry feed, as well as on the automation of processes within the poultry house, which culminated in knowledge development activities (F2). Setting up the demonstration units and the knowledge generated by the new research projects required the mobilization of resources (F6) from other local institutions that contributed to creating a training course for producers (F3). The entrepreneurial experimentation function (F1) was also present at this stage, with the formalization of the first production establishment in compliance with sanitary, environmental and fiscal norms for this type of production.

Phase II, which created the entrepreneurship motor, began with a second TP, characterized by the need for local rural producers to generate more income in their businesses. These producers were characterized by the presence of idleness in breeding



Source(s): Prepared by the authors (2020)

Figure 1. Evolution of TIS *cage free* Pelotas functions and motors

facilities (aviaries) due to the stoppage of the activities of the local cooperative, which used to produce in the traditional system (TP2[2]). This TP fostered several initiatives of entrepreneurial experimentation (F1) in the technology of producing eggs from cage-free bird. Subsequently, these entrepreneurs began to lobby the local government body to create legitimacy (F7) for the innovative technology. The lobby aimed to place new ventures on the local government's agenda to solve identified problems and obtain resources that favored production. In response to the producers' lobby, the local government body initiated a set of analysis and negotiation actions to structure the chain as a whole (F10). As examples of this initiative to structure the chain as a whole, we mention the agreement with a local slaughterhouse to slaughter the discarded birds, the promotion of one of the producers to carry out the chicken-rearing stage and the setup of a feed factory.

Phase III, which created the system construction motor, also started at a TP (TP3[3]). This TP indicated the local government's need for strategies to develop the cage-free egg production chain. From this search, they decided to create a network involving producers and public private bodies led by the local government. The network objective was coordinating actions (F8), and promoting the technology. Soon after the network creation, TIS participants began to develop two new functions: market formation (F5) and resource mobilization (F6). Market creation actions involved holding meetings with local traders to attract new customers and meetings with managers of public bodies to generate specific demands on the part of these public bodies. Resource mobilization actions included new actors with distinct roles in the newly created network.

In addition to activities associated with market formation (F5) and resource mobilization (F6), the network also began interacting with the other two motors: entrepreneurship and science and technology.

In interaction with the entrepreneurship motor, the network expanded the legitimation actions to create legitimacy (F7), which took place through (1) the dissemination of the network creation, (2) the importance of innovative technology in producing cage-free chicken eggs, (3) the creation of a law by the local government to encourage entrepreneurs,

(4) disclosure in local and national newspapers, in agricultural fairs activities and (5) the creation of a logo for the created network.

The chain structuring actions as a whole (F10) involved the continuity of actions initiated in the entrepreneurship motor and the development of new options to encourage the creation of a feed mill. In the entrepreneurial experimentation actions (F1), new projects were designed for other rural producers to enter production with the innovative technology.

In interaction with the motor of science and technology, the network influenced the research direction (F4), with the proposal to reactivate the lowest-cost feed research project, this time with the current producers. The network also influenced knowledge development actions (F2), such as creating a research line on production costs. The network also influenced knowledge dissemination actions (F3), such as promoting producers participating in long-term training courses, short-term courses on alternative food and marketing strategies.

4.2 Discussion of the evolution of motors and functions

The discussion of the evolution of the motors and functions of the TIS cage free Pelotas was organized in two moments: 1) analysis of each of the motors individually: science and technology motor; entrepreneurship motor; system construction motor and 2) motor sequence analysis (Table 1).

When comparing the description of the science and technology motor [4] of the TIS cage free Pelotas with the motor proposed by Suurs and Hekkert (2012), it appears that the first corroborates the description of the second and that the development functions knowledge (F2), knowledge dissemination (F3), research orientation (F4) and resource mobilization (F6) (Suurs and Hekkert, 2012) dominate the motor.

Table 1. Comparative analysis between innovation motors and their evolution

Evolution phase [7]	Motor	Traditional motor functions	New functions identified
Tip Point I (Mey & Lilliestam, 2020)			
I	Science and technology [4]	F1: Entrepreneurial experimentation (incipient) F2: Knowledge development F3: Dissemination of knowledge F4: Research orientation F6: Resource mobilization (Suurs and Hekkert, 2012)	No new function
Tip Point II (Mey & Lilliestam, 2020)			
II	Entrepreneurship [5]	F1: Entrepreneurial experimentation F7: Creation of legitimacy (Suurs and Hekkert, 2012)	F10: Analysis of the system as a whole (Markard *et al.*, 2020; Nevzorona, 2022).
Tip Point III (Mey & Lilliestam, 2020)			
III	Coordination [6]	F1: Entrepreneurial experimentation F2: Knowledge development F3: Dissemination of knowledge F4: Research orientation F5: Market formation F6: Resource mobilization F7: Creating legitimacy (Suurs and Hekkert, 2012).	F8: Coordination (Markard *et al.*, 2020; Planko *et al.*, 2016). F10: Analysis of the system as a whole (Markard *et al.*, 2020; Nevzorona, 2022).

Source(s): Prepared by the authors (2020)

The entrepreneurial experimentation (F1) function was incipient, with only one enterprise formalized. The market formation function (F5) was absent, as it was restricted to the production and commercialization of demonstration *units*. Likewise, the legitimacy creation function (F7) was limited to the small number of actors participating in this motor (Suurs and Hekkert, 2012). Furthermore, the new functions identified in the literature of coordination (F8), sociocultural changes (F9) and assessment of the chain as a whole (F10) were also absent.

When comparing the description of the entrepreneurship motor [5] of the TIS cage free Pelotas, the results partially corroborate proposition 2, as differences and similarities were identified in the composition of the motor.

Suurs and Hekkert (2012) define the entrepreneurship motor as similar to the science and technology motor with the addition of entrepreneurial experimentation (F1) and legitimacy creation (F7) functions. Regarding the similarities found in the entrepreneurship motor, the TIS cage free Pelotas in the entrepreneurship motor phase was characterized by many initiatives of entrepreneurial experimentation (F1), associated with initiatives of legitimacy creation (F7), which Suurs and Hekkert (2012) also highlighted.

Regarding the differences found in the entrepreneurship motor, the TIS cage free Pelotas was characterized by the presence of the chain analysis function as a whole (F10) (Markard *et al.*, 2020; Nevzorona, 2022) due to the lobby promoted by entrepreneurs.

The function of analysis of the chain as a whole F10 was associated with the solution of bottlenecks identified in the production chain to make new ventures productively viable, for example, a place to dispose of birds after the end of the production cycle and food at lower costs. The presence of the new chain analysis function as a whole (F10) partially corroborates proposition 1 as another important key function, mainly in agribusiness, where the complexity of the production process is perceived due to the multiple steps that must be articulated throughout the manufacture of any product until it reaches its final consumer.

Regarding the system construction motor [6] of the TIS cage free Pelotas, the results partially corroborate proposition 2, as differences and similarities were identified in the composition of this motor.

Suurs and Hekkert (2012) define the system construction motor as a motor involving all functions. An essential addition concerning the two previous motors is the market making function (F5), and the similarity is that the market formation function (F5) appears as one of the functions of TIS. This motor also involves relationships with all other functions (Suurs and Hekkert, 2012).

The difference found in system construction is related to the coordination function (F8), which was proposed as a critical function in this motor and corroborated the proposal (Markard *et al.*, 2020; Planko *et al.*, 2016). In addition, the chain structuring activities as a whole (F10) initiated in the entrepreneurship motor were maintained in this motor. Planko *et al.* (2016) justify the need for the coordination function, as they consider that many actors are involved in the construction system, each with its own agenda and its own strategic plan. However, Planko *et al.* (2016) argue that the system as a whole benefits more if resources are combined and efforts are aligned. With coordination, individual efforts can be helpful (Planko *et al.*, 2016).

Regarding the analysis of the sequence of motors [7] of the TIS cage free Pelotas, the results partially corroborate proposition 3, as a similarity and a difference were identified.

Regarding similarity, a sequence in the creation of innovation motors can be seen in science and technology motor => entrepreneurship motor => system construction motor. This result is in line with the conclusions of Suurs (2009). Suurs (2009) explains that the sequence of motors is in line with the concept of cumulative causality and that the structural conditions under which a vicious circle emerges are affected by its previous dynamics. More specifically, he explains that with each motor change, the previous structural configuration will reinforce the activities that constitute the next (motor) cycle, which can be seen in the trajectory of the TIS *cage free* Pelotas.

Regarding the difference, a TP can be seen at the beginning of each motor and not only in the science and technology motor. For the creation of the science and technology motor, Suurs (2009) cites as an example the social demands for innovative technology. However, Suurs (2009, 2012) does not emphasize these TPs in the trajectory of TIS, nor does he define the term.

In the literature, TP have been defined as discontinuities in a system trajectory development, which fundamentally change its structure and dynamics (Mey & Lilliestam, 2020). In other words (Mey & Lilliestam, 2020), define a TP as the one that separates state A from state B of a system. We observe this phenomenon in all changes in the type of motor, as we see a conjunction composed of an entrepreneurial-type social intervention combined with a perceived context, such as an internal or external economic crisis in the system (Mey & Lilliestam, 2020).

Our findings also corroborate the presence of the TPs phenomenon along the stages of the innovation process in other evolutionary studies from different areas of research, such as biophysical systems, environment/human interaction and social systems (Mey and Lilliestam, 2020). It even occurs in the area of innovation, however, with different names (Bergek *et al.*, 2015; Dias & Ramirez, 2020; Dias, 2011). In a way, Suurs (2009) also recognizes the possibility of TPs in other phases and that it is crucial to understand that TIS can evolve into any other virtuous cycles only if external factors are present.

Finally, from the explanations about the sequence of the motors, related to cumulative causality and inflection points, it is inferred as a possible explanation for the absence of the market motor in the TIS cage free Pelotas. In conclusion, it is still worth mentioning the absence of the function of sociocultural changes (F9) proposed by Planko *et al.* (2016) and Markard *et al.* (2020) in none of the three motors described in the TIS cage free Pelotas, as it involves changes in the mental groups of consumers and organizations (Suurs and Hekkert, 2012), this should be an essential function in the market motor. For this reason, it cannot be verified.

5. Final considerations

This research aimed to analyze the evolution of functions and their interactions over time in a TIS within agribusiness. The authors found that throughout the evolution of the TIS cage free in Pelotas, the framework associated with the functions and motors is suitable for the analysis of the evolution of the TIS since given they verified the presence of three motors: initially (Phase I), by the creation the science and technology motor, started in 1999; then, by the entrepreneurship drivers (Phase II), started in 2017; and by the system construction motor (Phase III), started in 2019; and finally, the absence of market motor (See Figure 1 in Section 4.1).

As the main theoretical contributions of the research to the literature that analyzes the evolution of TIS, the following stand out:

(1) The suitability of functions and motors as an appropriate tool for analyzing TIS in agribusiness.

(2) Entrepreneurship motor is characterized by the presence of the chain analysis function as a whole (F10) due to the lobby promoted by entrepreneurs to solve local problems associated with the solution of bottlenecks identified in the production chain. Such a solution aims at the productive viability of their undertakings.

(3) The coordination function (F8) is crucial for TIS analysis in the system construction motor.

(4) Innovation motors evolve sequentially and are associated with cumulative causality mechanisms.

(5) The influence of TPs for the activation of each of the identified motors was verified.

As an empirical contribution to the rural environment, knowledge about the evolution of functions and their interactions over time can contribute to the solution of one of the main problems associated with participatory innovation initiatives since these innovation initiatives focus exclusively on the rural community level and as is known these groups generally face difficulties in overcoming more structural barriers to innovation that require interventions at higher levels of the system. Difficulties include poor access to extension services, land, credit, high-quality inputs and markets (Lamers *et al.*, 2017).

For future research, it is worth highlighting the need to assess the results found in other TIS, aiming at a theoretical generalization. Still, regarding the results found, it is better to understand how it will be possible to structure the coordination process of these spaces and the role of the different actors in this process. Finally, the main limitation of the research may be the absence of the market motor, which the current stage of development of the researched TIS fully justifies. However, it is worth noticing that it is difficult to identify, *a priori*, the research process at the stage where the TIS is.

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