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Sustainability

Eco-innovation and technological cooperation in cassava processing companies: structural equation modeling

Eco-inovação e cooperação tecnológica em indústrias processadoras de mandioca: modelagem de equações estruturais

Eco-innovación y cooperación tecnológica en industrias de procesamiento de yuca: modelos de ecuaciones estructurales

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Abstract

The generation of wealth, sustained by productive activities of agro-industries, leads to the production of wastes and uses natural resources, interfering in the environmental pillar of sustainability. The purpose of this study is to investigate whether cassava processing companies generate eco-innovations by means of technological cooperation, and the degree of participation of agents in these interactions. The quantitative method used the structural equation modeling for data analyses. The results indicated a relationship between technological cooperation and the generation of eco-innovation. The model developed showed the significance between variables and exposed the main aspects that generate eco-innovation from technological cooperation. A cooperation process allows a reduction in the burning of fossil fuels, reducing the emission of methane gas, which aggravates the greenhouse effect, also reducing odor, and ultimately, providing financial gains to agribusiness.

Keywords: Structural equation modeling; Agro-industry; Cleaner production; Technological cooperation

Resumo

A geração de riqueza, sustentada pelas atividades produtivas das agroindústrias, leva à produção de resíduos e utiliza os recursos naturais, interferindo no pilar ambiental da sustentabilidade. O objetivo deste estudo é investigar se as empresas processadoras de mandioca geram ecoinovações por meio de cooperação tecnológica e o grau de participação dos agentes nessas interações. O método quantitativo, utilizou-se da Modelagem de Equações Estruturais para análise de dados. Os resultados indicaram uma relação entre a cooperação tecnológica e a geração de ecoinovação. O modelo desenvolvido mostrou a significância entre variáveis e expôs os principais aspectos que promovem a ecoinovação a partir da cooperação.

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O projeto de cooperação permitiu a redução na queima de combustíveis fósseis, a redução na emissão de gás metano que agrava o efeito estufa, a redução do odor e, finalmente, proporcionou ganhos financeiros para o agronegócio.

Palavras-chave: Modelagem de Equações Estruturais; Agroindústrias; Produção limpa; Cooperação tecnológica

Resumen

La generación de riqueza, oriunda de las actividades productivas de la agroindustria, conduce a la producción de residuos y el uso de los recursos naturales, lo que interfiere con el pilar medioambiental de la sostenibilidad. El objetivo en este estudio es investigar si las empresas procesadoras de yuca producen eco-innovaciones por medio de la cooperación tecnológica y el grado de participación de los agentes en estas interacciones. Se utilizó el método cuantitativo, por medio de modelos de ecuaciones estructurales, para el análisis de datos. Los resultados indicaron una relación entre la cooperación tecnológica y la creación de eco-innovación. El modelo desarrollado mostró significancia entre variables y delineó los principales aspectos que promueven la eco-innovación a partir de la cooperación. El proyecto de cooperación permite la reducción de la quema de combustibles fósiles; la reducción en la emisión de gas metano que agrava el efecto invernadero; la reducción del olor y, finalmente, proporciona ganancias financieras para la agroindustria.

Palabras clave: Modelos de ecuaciones estructurales; Agroindustria; Producción limpia; Cooperación tecnológica

Introduction

The decrease in the life cycle of products increased the range and speed of changes in the portfolio of goods and services offered to consumers. Thus, production processes also underwent changes and innovation became an influential factor in the pace of these changes. The minimum requirement for a change of a product or process to be considered an innovation concerns the recognition of this requirement as a novelty. For the novelty to be considered innovative, significant changes in the product or process should be made in relation to the product and process currently practiced in the market (OCDE, 2005).

In addition to production and consumption changes, there is a continuous concern with sustainability. In the environmental aspects, efforts are made to avoid or mitigate negative impacts without hindering economic development using new technologies, from eco-innovations. The term "eco-innovation" appears in the Brazilian literature in different ways, for example, "eco innovation", "eco-innovation", "environmental innovation" and "ecoinnovation". In this study, the term "eco-innovation" was adopted as a standard. The book of Fussler and James (1996) pioneered the concept of eco-innovation. The theme reappears in a study of James (1997), where it is defined as the eco-innovation ability to innovate in products and services without causing environmental impact and damage. Based on this concept, companies began to seek competitive advantages and add value to new forms of cleaner production.

Faced with proposals for sustainability, Lozano (2008, p. 1839) affirms the importance of sustainable development, "Sustainable Development involves the simultaneous pursuit of economic prosperity, environmental quality, and social equity". Given these interests comes technology cooperation.

The phenomenon of cooperation is organized through the National Innovation Systems (NIS) to ensure that each agent assumes its role with the common objective geared for economic development from innovations (Baerz, Abbasnejad, Rostamy, & Azar, 2011). The strategies adopted by companies in the search for innovations have undergone significant changes in recent years generating new perspectives to conventional management models (Bueno & Balestrin, 2012). Therefore, technological cooperation becomes one way to develop innovations (Baerz et al., 2011).

The objective of this research is to investigate whether agro-industries generate eco-innovations through technological cooperation, analyzing also the degree of participation of each of the agents, university, companies and government in these interactions. The model that defines the interactions between agents in the cooperation process used in this study is based on the Triple-Helix model, which advocates partnership relations, leading the university and enterprises to work together for the same objective (Etzkowitz & Leydesdorff, 2000). In this context, the research seeks to contribute to the discussion about eco-innovation, and it is a pro-active or reactive consequence in relation to the prevention or treatment of environmental impacts generated by bio-digesters used in the industry of starch, flours and starches processing companies (Angelidaki et al., 2009; Deublein & Steinhauser, 2008; Kocar, 2008).

The study of the Brazilian context is justified by the country's leadership in Latin America and for its participation in the economic block composed of Brazil, Russia, India and China (BRIC). Agribusiness is a cornerstone of Brazil's economy, represented by agro-industries, among other sub-sectors. This segment accounts for 22% of the Brazilian GDP, and cassava, beans and orange are some of the most important sectors, along with commodities, generating wealth (Portal Brasil, 2013). According to ABAM (2012), several chemical modifications have generated various types of starch of great use in manufacturing industries, such as in the production of medicines, food, cosmetics, pulp and, even, in textile production, exported in 2012, namely to the United States (35.3%), Bolivia (21%)

and the Dominican Republic (17.6%) (CEPEA-ESALQ, 2013).

This research focuses on the segment of the agricultural industries of Paraná State, Brazil, which process cassava, known as starch, flours and starches processing companies. According to the report released by CEPEA-ESALQ (2013) on comparative figures for 2010 and 2011, the state of Paraná remained the main producer of cassava starch in 2011 in Brazil, generating 70.5% of the total produced in the country, similar to the scenario in 2010. These processors process cassava into starch and its derivatives, generating wastes. Some processors encourage the improvement of innovative production methods, emission reducers that are able to reduce costs (Jaffe & Palmer, 1997).

This study greatly contributes to the enhancement of scientific research on stakeholders of interference in the development of eco-innovations in industries, presenting tangible benefits through a technical cooperation project.

In addition to this introduction, the second section presents the theoretical framework that addresses issues such as innovation, technological cooperation and NIS aspects. The third section includes the method used to obtain the results, which will be presented and discussed in the fourth section. The main findings of the study are shown in the fifth section.

Theoretical framework

Technological cooperation and Brazilian NIS

Dosi (1988) characterizes innovation as a process of search, discovery, experimentation, development, imitation and adoption of new products, processes and new organizational techniques. In a more positivist perspective, for Tidd, Bessant, and Pavitt (2008), innovation is a business advantage able to mobilize knowledge, technological advances and innovations in the provision of products and services.

Innovations generate cost reductions, gains in productivity and quality by creating the potential for extraordinary profits to entrepreneurs; however, it presents high risks, because it displays independent challenges (Quandt, 2012).

Innovation surveys in several countries are fairly rich in terms of quantity and scope of variables investigated. In the context of analysis of possibilities brought by these studies, there are attributes of the innovative process, such as the innovation degree, that can be considered an indicator of innovation quality. This concept is part of the theoretical and methodological criteria to characterize the innovative performance of enterprises in an economy. For example, innovation survey in Europe – Community Innovation Survey (CIS) conducted by Eurostat (2016), as well as Innovation Research – PINTEC performed in Brazil by the Brazilian Institute of Geography and Statistics (IBGE, 2016), both based on the Oslo Manual (OCDE, 2005), explore this attribute – radical eco-innovation, meaning that in the case of the product, whether it is new to the world market, to the national market, or new only to the company itself. In the case of process, whether it is new to the national industry, to the industry in global terms, or if the process is new to the company itself. Thus, radical innovations for the sector will be considered "high innovation rate" and incremental innovations for the sector will be called "low innovation rate".

There are three possible forms of technological cooperation capable of contributing with small and medium-sized enterprises to become more innovative: (i) cooperation between enterprises, (ii) cooperation with the government, and (iii) cooperation with research institutions (Najib & Kiminami, 2011). There are basically two lines that address the cooperation process. One is formed by authors who consider the separation between university and company, due to conflicting objectives. The first line concerns the model of Sábato Triangle (Plonski, 1995). Sábato and Botana (1968), formulated the three agents based on a triangle, emphasizing the government in the upper vertex and the university and company as base elements of cooperation. On the other hand, Etzkowitz (1998) defends the Triple-Helix model, in which unlike the Sábato Trianlge, there is convergence of objectives and relationship between the university and company.

In light of this change of context, in which the company does not consider only its internal environment, seeking potential to innovate, Chesbrough (2003) classifies the closed model of innovation as a vertical control. The open model, defined by the author as "open innovation", arose as a result of four factors responsible for deterring the closed model: (1) the increase in the number of undergraduates and graduates, forming qualified workforce; (2) the growing number of qualified people with job mobility; (3) the proliferation of companies specialized in developing new businesses, technology transfer and market research; (4) the reduction of the lifetime of technologies and the fierce competition of globalized companies. King and Lakhani (2013, p. 48) report a broad view of open innovation in their findings, concluding that "open innovation might not be the right approach for every company, but many organizations can benefit from it. The key to success is careful consideration of what to open, how to open it and how to manage the new problems created by that openness".

The open innovation model of Chesbrough (2003) is a means, for example, by which businesses organize themselves to seek sources of innovation, from partnerships with universities and research institutes. Higher education institutions have, among others, the purpose of advancing on the knowledge frontier, along with the necessities for basic research of enterprises. Chesbrough, Vanhaverbeke, and West (2006) report open innovation as a result of a new paradigm review, concluding that open innovation suggests that inventive output from within the enterprise not be restricted to the current business model, but instead, have the opportunity to go to market through a variety of channels.

However, little commitment is observed from companies and universities to establish consistent and organized relationships based on cooperation to generate innovations. The concept of "interactive learning" defines the capacity of an organization to transmit and receive knowledge, translated as training programs (Instituto de Pesquisa Econômica Aplicada, 2005). For Baerz et al. (2011), the coordination channels for cooperation between industries and research institutes and universities are among the main actors in the innovation cycle in a specific product or service.

Open innovation generates a diversity of options and, therefore, Minshall, Seldon, and Probert (2007) consider that the external sources for innovation can vary, such as suppliers, customers, strategic partners, universities, research institutes and start-ups. However, universities and research institutes do not know the potential customer and market needs, requiring, thus, partnerships with enterprises to achieve industrial ambition (Feng, Ma, Zhang, & Du, 2013).

The link between university and company through the NIS structure faces different hurdles, due to different regional or even structural interests (Manzini, 2012). The fact is that by overcoming some difficulties, the results can be beneficial. It is important to promote actions for universities, in their innovation processes, to be able to meet the purposes of organizational investment. Feng et al. (2013, p. 47) conclude that "while in the pre-market cooperation mode like cooperation develop, joint establish entities, and cooperation technology venture, the research institutions and enterprise have a frequent and close relationship, and communication of information interaction, through which the knowledge can be created and communicated by the endeavor of both sides".

The concept of the National Innovation System (NIS) can be understood as a form of organization that facilitates cooperation. Lundvall (1988), Freemann (1997) and Nelson (1993) conceptualize the NIS as systems characterized by different patterns of cooperation. In a review of the origins of NIS, Fagerberg and Sapprasert (2013) assign a new branch of literature on innovation, called "National Innovation Systems" (NIS), in Portuguese (SNI), a concept developed primarily by Freeman (1987), Lundvall (1988) and Nelson (1993), recognized as precursors of the concept.

For Fagerberg, Mowery, and Verspagen (2009), the NIS does not cover only innovative companies, but all learning and innovation capacity of a country considering organizations, universities and research institutes in the pursuit and application of knowledge. Feng et al. (2013) attribute to the emergence and development of knowledge-based economy the need for greater agility in launching products and technologies, in which universities and research institutes have an important role to assist in the development and competitiveness of NIS. Bueno and Balestrin (2012, *apud* Reed, Storrud-Barnes, & Jessup, 2012, p. 69) emphasize that "cooperation allows ideas from an outer environment to strengthen the innovation performance of enterprises".

The government's role as coordinator of the interaction process between the university and enterprise is crucial for Baerz et al. (2011), since the university and industry generate intensive activities for the sustainable development of a country, which must be managed and organized to produce the interaction. Such agents constitute the triad of company, university, and government with well-defined roles in the NIS.

The research hypotheses were based on the literature review, in which H1 was divided initially into a, b and c. H1 will be used to verify the existence of interference from external agents according to the Triple-Helix model: government incentives, enterprises and universities.

H1.a. There is positive relationship between incentives and government policies and increasing technological cooperation in agro-industries.

H1.b. There is positive relationship between the enterprise and/or partner enterprises and increasing technological cooperation in agro-industries.

H1.c. There is positive relationship between universities and research institutes and increasing technological cooperation in agro-industries.

Additional hypotheses also refer to the process of technological cooperation, seeking to verify the existence of interference of other agents mentioned in contemporary literature and the degree of their participation in the systemic flow of cooperation.

H1.d. There is positive relationship between clients and consumers and increasing technological cooperation in agro-industries.

H1.e. There is positive relationship between suppliers and increasing technological cooperation in agro-industries.

H1.f. There is positive relationship between competing enterprises and increasing technological cooperation in agro-industries.

H1.g. There is positive relationship between environmental consulting companies and increasing technological cooperation in agro-industries.

The hypothesis H2 seeks to know whether there is relationship between the generation of innovation from technological cooperation among the cassava processors.

H2. There is positive relationship between the degrees of technological cooperation that results in the generation of eco-innovation.

Besides H2, according to the classification of the term innovation, initially proposed by IBGE (2016) the term eco-innovation is divided into high innovation rate and low innovation rate. Complementing the classification, eco-innovation is divided into goods products and services. Therefore, H3.a–H3.d complete the definition of hypotheses.

H3.a. There is generation of low eco-innovation rate in goods (products and services).

H3.b. There is generation of low eco-innovation rate in processes.

H3.c. There is generation of high eco-innovation rate in goods (products and services).

H3.d. There is generation of high eco-innovation rate in processes.

Other studies also suggest how to reduce greenhouse gas emissions and more efficient use of energy resources. Wickramasinghe and Gamage (2013) verify the emissions of gases that cause the greenhouse effect, as a matter of economic, ecological interest, and above all a challenge for public policy.

Bonilla, Almeida, Biagio, Giannetti, and Huisingh (2009) highlight the following environmentally relevant aspects: (a) more efficient and conscious usage of raw materials; (b) more efficient and conscioususage of non-renewable and renewable energy sources and energy technologies; (c) reduced emissions and impacts; (d) expanded implementation of closed-loop systems of materials, both intra and inter companies (end-of-life strategies promotion); and (e) accelerated integration of renewable sources to as many processes as possible.

Some countries, such as Germany and Denmark, represented by its industries, are investing in Africa in order develop solar energy, reducing carbon emissions, with the possibility to use cheaper production of renewable energy sources in these developing countries (Wickramasinghe & Gamage, 2013). Pancera (2013) evaluated the reality for sustainable innovation in the renewable energy sector in Bolivia and conluded that it is necessary to know the conditions that originate initiatives for innovation in developing countries in order to understand that eco -innovation occurs in a wide variety of different contexts, usually incremental, requiring the support from several players.

Dependent and independent variables were obtained from the review of other models with quantitative analysis between technological cooperation and innovation generation, focusing on cooperation versus eco-innovation. Srholec (2009) summarizes some of the major works that provide direct evidence of technological cooperation on innovation through research, such as NIS (2008), developed by different authors in research conducted in the European Union (Becker & Dietz, 2004; Najib & Kiminami, 2011; Srholec, 2009).

Methodology

The research method is quantitative, exploratory descriptive and causative. The research scope comprises all cassava processors affiliated to the Associação Brasileira dos Produtores de Amido de Mandioca (ABAM) and the Sindicato das Indústrias Produtoras de Mandioca do Paraná (SIMP), totaling 50 enterprises, including processors of starch, flours and starches processing companies. However, to provide the sample, 33 starch processors responded to the questionnaires, restricting the number of the sample, considering the share of 66% of the total available.

Of the total, three starch processors served as the basis for the pre-test of questionnaires. Because it was not necessary to change the structure of the questionnaires of the pre-test for the effective research, the responses of the three starch processors were considered in the data analysis along with the responses of the other 30 respondents. Chin (1995) confirms that the method to be used for smaller samples consists of PLS. Differently, the LISREL should be applied, for mathematical reasons, to samples that include large numbers of indicators by factor, generating estimates of structural paths. Another argument defines that for most studies of technological bases, the estimate of structural paths is more suitable in the PLS model. Thus, the objective of the PLS is to maximize the variance, while the LISREL estimates parameters of the causal model (Chin, 1995).

We selected PLS-SEM as the appropriate method for two reasons. First, PLS is focused on predictive analysis. Specifically, the objective of PLS-SEM is to maximize the variance of the endogenous variables explained by the exogenous variables (Hair, Tomas, Hult, Ringle, & Sarstedt, 2014). The predictive focus is appropriate to meet the objectives of the current study. Second, PLS does not require meeting the assumptions of normality for the data distributions (Hair, Sarstedt, Ringle, & Mena, 2012). Although there are limitations to PLS-SEM (e.g. results tend to overestimate the item loadings (lambdas) and underestimate path coefficients and R^2 (structural relationships)), CB-SEM also has limitations (e.g. results tend to overestimate structural relationship and under estimate lambdas, suggesting that PLS-SEM actually offers a conservative test of the hypotheses).

The questionnaires, containing 12 questions, were answered using *Google docs* after four rounds of telephone contact. The questionnaire was constructed based on the literature review and the research hypothesis. The scales for the construction of the questionnaire were established from 0 to 10. Within the range established, 0 represents no results, that is, "disagree" and 10 is the highest result, "totally agree". Other similar scales were discarded once new independent variables were included in addition to those treated in the model of Najib and Kiminami (2011).

According to Kerlinger (1980), the models are determined by the objectives of project and their construction depends on the theoretical scope in which the model is inserted. Thus, Fig. 2 delineates the model of quantitative research, establishing the latent variables, represented by a rectangle and the expressed variables, represented by an ellipsis and the relationships produced between them.

In this research, as well as in the model of Najib and Kiminami (2011), the independent variables of government incentives, partner companies, in addition to universities and research institutes exert certain impact on the process of technological cooperation within the segment addressed, creating, therefore, hypotheses H1.a–H1.g. From the process of technological cooperation, the second hypothesis – H2 – was obtained, seeking to verify the generation of eco-innovation in cooperation processes.

The model proposed in this work adds other agents to the model elaborated by Najib and Kiminami (2011), namely customers, competitors, suppliers, and environmental consulting companies. The purpose is to expand the explanation of the degree of influence of technological cooperation in generating eco-innovation, strengthening the open innovation as a way that consolidates gradually. The model will be presented in the fourth section more precisely in Fig. 1, where the research results will be shown.

Research results and discussion

The total sample comprised 33 respondents, from which 24 (73%) enterprises claimed to be independent, and only eight (27%) claimed to be part of a group. Initially, the multicollinearity of the sample was verified according to Cooper and Schindler

Table 1
Multicollinearity and normality of independent variables: high degree of relationship between the dependent and independent variables.

Indicators of independent variables	n = samples	Mean	Standard deviation	KS test of Kolmogorov–Smirnov	VIF
Low product eco-innovation rate	33	6.00	3.588	1.127	2.556
Low process eco-innovation rate	33	6.97	3.046	1.160	2.500
High product eco-innovation rate	33	2.15	3.554	2.090	3.130
High process eco-innovation rate	33	2.85	3.751	1.848	3.388
Enterprise or group cooperation	33	8.42	2.851	1.814	1.998
Government cooperation	33	3.97	3.423	1.208	3.771
University cooperation	33	4.00	3.391	0.883	2.929
Client cooperation	33	3.88	3.160	0.874	3.412
Suppliers cooperation	33	6.15	3.318	1.127	3.469
Competitors cooperation	33	2.85	2.863	1.345	1.818
Environmental consultancy cooperation	33	6.79	3.314	1.429	3.304

Source: Research data (2013).

Table 2
Variable of eco-innovation: cooperation factors contributing to eco-innovation.

Variable	Description of the question
Low product eco-innovation rate	Did the company introduce a new or significantly enhanced product (goods or service) with the aim to minimize environmental impact, BUT THAT ALREADY EXISTED in the domestic market?
Low process eco-innovation rate	Did the company introduce a new or significantly improved PROCESS with the aim to minimize environmental impact, BUT THAT ALREADY EXISTED in the domestic market?
High product eco-innovation rate	Did the company introduce a new or significantly enhanced product (goods or service) with the aim to minimize environmental impact, BUT THAT DID NOT YET EXIST in the domestic market?
High process eco-innovation rate	Did the company introduce a new or significantly improved PROCESS with the aim to minimize environmental impact, BUT THAT DID NOT YET EXIST in the domestic market?

Source: Research questionnaire (2013).

(2008), which shows the degree of relationship between the independent variables. The VIF (Variation Index Factor) was limited to a tolerance of VIF < 10, since the smaller this ratio, the lower the degree of multicollinearity of the variables of their individual independence. Table 1 shows that all variables presented VIF < 4, especially with shadowing, the lowest and the highest results.

The results of multicollinearity show that the indicators that explain independent variables practically do not null each other, that is, there were no options that represented the same source of information among the alternatives that were made available to respondents. Regarding normality, tested in the Kolmogorov–Smirnov test, indicated by Costa Neto (1997), all variables can be considered within the normal range, represented by ($p > 0.05$), no sample could be considered as abnormal ($p < 0.05$). Eco-innovation was classified into four indicators, divided high eco-innovation rate and low eco-innovation rate and innovation of products/services and processes (Table 2).

Deslee (2012) concluded "*The development of their performance through a sustainable attitude, can be engaged through a system of participative innovation*." Table 3 shows the technological cooperation construct of variables. In addition to the three variables most commonly mentioned in the classical literature (company, university and government), the variables of customers, suppliers, competitors, and environmental consultancies were also included, according to the indicators of limiting model in this study.

Table 3
Variables of technological cooperation: main stakeholeders the cooperation procedure.

Variable	Description of the question
Enterprise or group cooperation	Did the company itself or another company from the group develop projects internally in the company or even with other companies of the group?
Government cooperation	Did the public sector through government incentives provide innovation generation due to resources and government incentives?
University cooperation	Did partnerships with universities and/or research institutes generate innovation?
Client cooperation	Did suggestions and partnerships with clients or consumers generate innovations?
Suppliers cooperation	Did partnerships with suppliers generate innovations?
Competitors cooperation	Did partnerships with competitors generate innovations?
Environmental consultancy cooperation	Did partnerships with environmental consulting companies generate innovations?

Source: Research questionnaire (2013).

The method of data processing, as shown in Fig. 1, aimed to know the analysis of extracted variance (AVE), proposing some general indicators and discriminant validity, such as the composite reliability, determination coefficient (R^2), Cronbach's alpha, commonality and redundancy, to confirm the reliability with beta above 0.5%, minimum value required according to Davis (1964, p. 24 *apud* Maroco & Garcia-Marquez, 2006).

However, the analysis of the results showed the possibility of splitting the model into low eco-innovation rate and high eco-innovation rate. Therefore, the model would undergo a change regarding the analysis that indicates sufficiency of the

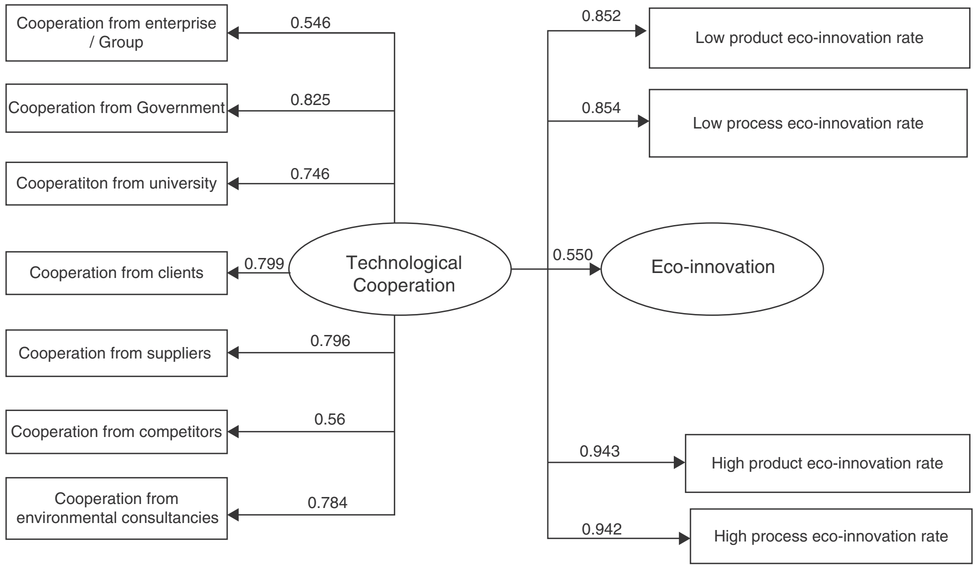

Fig. 1. Loads of path of the structural model.
Source: Own elaboration using *software SmartPSL* (2013).

technological cooperation variable in explaining the generation of low eco-innovation rate, as shown in Fig. 2.

Fig. 2 shows the beta square root, which according to Field (2013, p. 344) the R^2 tells us how much variance is explained by the model compared to how much variance there is to explain, that is, is the proportion of variance in the outcome variable that is shared by the predictor variable.

In Table 4, the results show a beta value below 0.5 for the indicator of high eco-innovation rate, which obtained only 0.28. This is evidenced by the low degree assigned to this phenomenon in the results of quantitative research. However, the independent variable of low eco-innovation rate continued above 0.5 (0.575). The beta square root for low eco-innovation rate increased from 0.30 to 0.33 the explanation of eco-innovation based on the technological cooperation.

In other countries and in other sectors, such as the swine culture, bio-digesters have already been used in Brazil. For the cassava processing mills, the implementation of bio-digesters as well as the changes caused by this new product have been regarded as high eco-innovation rate. Previous studies have

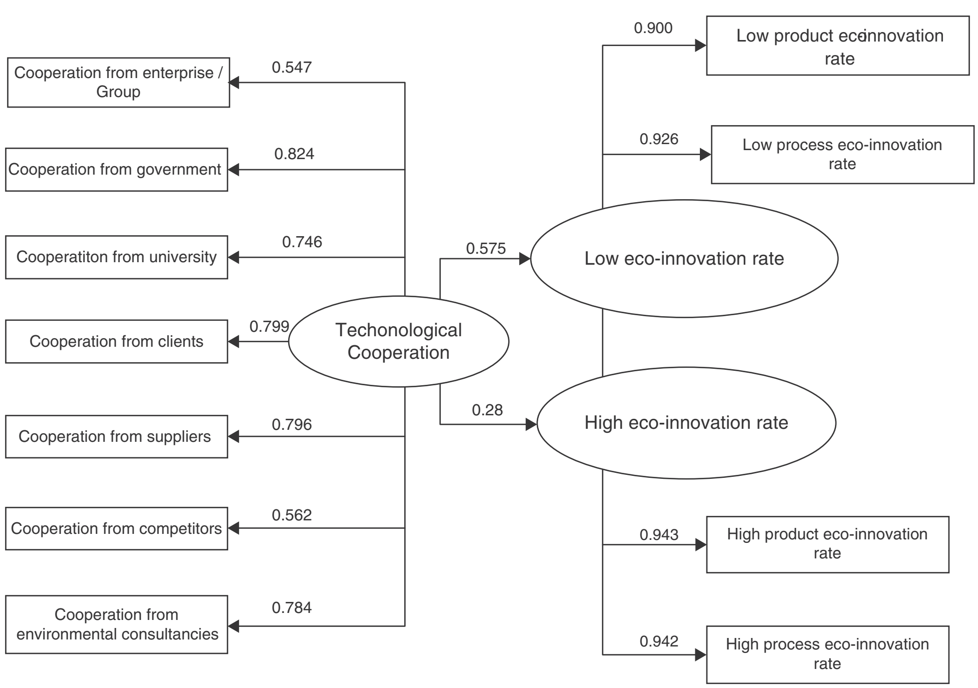

Fig. 2. Loads of paths of the alternative structural model, determining the composite reliability model.
Source: Own elaboration using *software SmartPSL* (2013).

Table 4
Beta R^2 analysis.

Constructs	Low eco-innovation rate	High eco-innovation rate
Square root	0.330	7.8%
Beta	0.575	28%

Source: Own elaboration using *software SmartPSL* (2013).
Note: For the definition of the coefficient of determination (R^2) see Nunally and Bernstein (1994).

already pointed to that possibility, although the use of bio-digesters was still non-existent in Brazil. Results showed that cassava flour has great capacity for methane production, thus, bringing revenue to the processing plant. However, studies on costs and feasibility are necessary for the installation of bio-digesters, a practice that has not been used by industry of cassava starch in the country (Felipe, Rizatto, & Vandalsen, 2009).

Specifically in the industry of cassava processing, the use of bio-digesters with the ability of extracting and using the methane gas (CH4) – derived from an organic biomass that until then represented an issue and costs as to its correct environmental disposal – in replacement for wood burning in the boiler – was high eco-innovation rate, since several studies on initial development and subsequent incremental improvements of organic biomass use for energy production derived from studies linked to the same project that originated this paper. Obviously, it is understandable that this technology was not developed from this work.

However, the investigation of elements linked to the results of this change indicates a much greater transformation than just low eco-innovation rate that were even originated, to a lesser extent, from the integration of bio-digesters. Other aspects not mentioned in great detail here, but reported in other research phases, showed, in addition to the environmental benefits, financial gains from wood purchase as well as social gains such as availability of energy production of the boiler, intended to social projects for the surrounding community.

Table 5 complements the analysis of convergent connection between two measurements that seek to express the same concept. Both AVE results for the constructs obtained result greater than 0.5. For Maroco and Garcia-Marquez (2006), the ideal results for Cronbach's alpha be acceptable is between 0 and 1 and the proposed reliability should be greater than 0.6, provided that the proposed model remain within the required limits. The indicators of Cronbach's alpha and composite reliability registered positive numbers.

R^2, which explains the connection between the construct of technological cooperation and its influence on eco-innovation generation, reached 33%, which has effect "large/good" according to Wetzels, Odekerken-Schroder, and Van Oppen (2009). These values show a sufficient index, once the model of Najib and Kiminami (2011) reached R^2 of 15%. Redundancy showed 0.069 and 0.274 for low eco-innovation rate, respectively. Redundancy reinforces a closer proximity of the model to explain low eco-innovation rate, with a high redundancy value for high eco-innovation rate.

According to Queiroz (2011), the purpose of the *bootstrap* test is, based on repetitions, considering deviation and standard errors, to calculate data statistical assumptions found in the empirical research. In this study, 33 samples were used with 200 repetitions. In addition to the calculations of the deviation and standard errors, the *T*-test (*Student*) solves the problem of statistical significance. Thus, corroborating with the previous analysis, the values of the Student *T*-tests of the regression coefficients were greater than 2.98 ($p < 0.05$), proving the predictive validity of the model (Hayduk, 1987 *apud* Ventura, Silva, Da Pinho, & Rigolon, 2010), rejecting the null hypothesis.

Fig. 2 and Table 4 show that all relationships were positive and significant. The relationship between the construct technological cooperation and eco-innovation was strong ($\beta = 5.75$; $p < 0.01$). There is an explanation of the eco-innovation phenomenon from the technological cooperation in the segment analyzed. The results obtained in this study were inherent in the hypotheses and initial objectives proposed, based heavily on literature review.

On the one hand, the technological cooperation and its indicators confirm the degree of participation of different strategic partners, showing degrees of specific participation. On the other hand, eco-innovation was elaborated from concepts already concluded in research on innovation. Concepts, such as high eco-innovation rate, Schumpeter (1997) and classification of different types of innovation, OECD (2005), were used to produce a model able to explain 30% of trends between the latent variables. The construction of a model able to show the influence of technological cooperation in generating eco-innovation represents a meaningful result. Thus, after obtaining the key constructs, relationships between them were represented by the method of structural equation modeling (SEM), proving the hypotheses proposed (Table 6).

Regarding the results of the quantitative research, given that most enterprises of the sector are small-sized, family-structured and still do not export the production, it is considered a great opportunity of expansion and modernization for the segment. Such developments can be strongly driven by the volume of low or high innovations rate, released to the market segment, propelling technical change and economic development. However, the quantitative results showed that approximately 30% of the eco-innovation generated in the sector already comes from cooperation. The main positive results regarding eco-innovation refer to the reduction in the emission of greenhouse gases, reduction in fossil fuel burning, odor reduction, reduction and better quality of wastewater, soil irrigation with fertilizing potential, among others.

All hypotheses to prove the model were confirmed. The hypotheses H3.a–H3.d showed a greater tendency to generate low innovation rate than high innovation rate (Fig. 2). Therefore, few high eco-innovations rate were found in the survey data, highlighting the pioneering enterprises in the use of bio-digesters, irrigation from effluents and, most significantly, the development of a new device for the industry, adapted to specific conditions of cassava cultivation.

Therefore, the model presented shows consistency and contributes with science to describe, explain and measure the

Table 5
General indicators of distinct discriminants.

Constructs	AVE	Composed reliability	R^2	Cronbach's alpha	Redundancy
Technological cooperation	0.534	0.887		0.853	
Low eco-innovation rate	0.888	0.940	0.078	0.873	0.069
High eco-innovation rate	0.834	0.909	0.331	0.802	0.274

Source: Own elaboration using *software SmartPSL* (2013).

Table 6
Test of resampling *Bootstrapping* with two variables.[a]

Paths	Original loads	Mean loads with 200 repetitions	Standard deviation	Standard error	*T* test	Significance
Enterprise cooperation → Technological cooperation	0.55	0.52	0.18	0.18	2.98	$p<0.1\%$
Government cooperation → Technological cooperation	0.82	0.78	0.12	0.12	6.63	$p<0.1\%$
Client cooperation → Technological cooperation	0.80	0.78	0.11	0.11	7.48	$p<0.1\%$
University cooperation → Technological cooperation	0.75	0.73	0.15	0.15	5.11	$p<0.1\%$
Supplier cooperation → Technological cooperation	0.80	0.78	0.13	0.13	6.08	$p<0.1\%$
Competitor cooperation → Technological cooperation	0.56	0.54	0.15	0.15	3.79	$p<0.1\%$
Environment consultancy cooperation → Technological cooperation	0.78	0.78	0.10	0.10	7.98	$p<0.1\%$
Low product eco-innovation rate	0.85	0.83	0.12	0.12	7.17	$p<0.1\%$
Low process eco-innovation rate	0.85	0.84	0.12	0.12	7.13	$p<0.1\%$
High product eco-innovation rate	0.67	0.63	0.19	0.19	3.51	$p<0.1\%$
High process eco-innovation rate	0.69	0.65	0.19	0.19	3.63	$p<0.1\%$
Technological cooperation → Eco-innovation	0.55	0.61	0.09	0.09	5.96	$p<0.1\%$

Critical values for T (32 gl) = $p<10\%=1.30$; $p<5\%=1.68$; $p<1\%=2.43$; $p<0.1\%=2.75$.
Source: Research data (2013).
[a] Critical values for: $p<5\%=1.96$; $p<1\%=2.53$.

proposed phenomenon, despite some limitations. The consistency is based on the degree of explanation of the relationships between the constructs and the comprehensiveness of the sample before the universe proposed.

Similarly to this study, Bueno and Balestrin (2012, p. 526) confirmed the success of cooperative practices as one of the main results of their research, which concluded that "in each of these stages, different external agents were accessed, namely consumers, univeristies and suppliers, allowing to explore new knowledge, develop new concepts and implement new technologies to the new product".

Final considerations

This research aimed to investigate whether cassava-processing industries generate eco-innovations through technological cooperation, also to verify the degree of participation of each of the agents in their interactions. The results allowed, in light of the theoretical approach, to achieve specific objectives:

a) Analyze the objects of technological cooperation used in agro-industrial sector of cassava processing as a means of promoting eco-innovation. Among them, most notably, government support, partnerships with environmental consulting firms and partnerships with suppliers of machines and equipment used in practice.
b) Describe the way interactions occur among agents: company, university, and government in the segment cassava processing. Initially, qualitatively, this objective was structured to know the relationship between the three main agents of NIS, highlighting the main obstacles and the main difficulties to generate greater economic development, thus achieving the second objective.
c) Identify the relationship between the generation of eco-innovations and technological cooperation in the sector. The method of structural equation modeling confirmed a positive degree of participation of the objects of technological cooperation in generating eco-innovation. The analysis of significance of paths proves this important relationship and demonstrates the degree of influence that the independent variables together exert on the dependent variable. In this respect, 30% of correlation obtained with the construction of the proposed statistical model refers to circumstances, which if developed, may be able to promote the development of innovation in order to contribute to the continuous improvement of production processes. Thus, the third specific objective was achieved. Cooperation with other enterprises and institutions, in addition to promoting productive efficiency, allows to move faster in technological creation, adding expertise not available to in a single company (Hasenclever & Tigre, 2002) conferring competitive advantage to these businesses (Prochnik & Araújo, 2005). Cooperation, therefore, is of fundamental importance to innovation, since firms in isolation may often have difficulties to gather all the necessary competence to generate eco-innovations, which requires the establishment of cooperative relationships with other organizations due to factors, such as the lack of resources for investment in P&D, among

others. This is the essence of cooperation: use other agents to produce more economical results with multiple views.

d) Identify whether the interactions between university and enterprise resulted in some eco-innovations in the sector analyzed. The bootstrapping analysis of paths allowed to know the degree of interaction between university and enterprise. The qualitative research presented, as a result of three interviews, the opinion of the managers involved with the proactive cooperation project strategy, stating that they recognize the benefits of cooperation and are willing to participate again. As eco-innovations resulting from the process of cooperation, considering all proposed agents, some of the main benefits were described: reduced consumption of raw material, reduction in fossil fuel burning, better treatment of effluents from production, environmental benefit generated from a college work, the generation of crop irrigation.

In regard to the research hypothesis: "what is the influence of technological cooperation on the generation of eco-innovation in the sector of cassava processing?" the theoretical foundation and the statistical treatment of the data allowed the development of an effective model to verify the influence of technological cooperation on the generation of eco-innovation. The definition of the universe and the obtaining of the sample researched allowed to achieve the proposition that delimited the agricultural industries of cassava processing in Paraná State, restricting to starch, starches processing companies and flours manufacturers. The hypothesis H2 allowed to conclude the significant influence between the two phenomena.

The methodological procedures and statistical calculations are a series of concepts, which may inspire further research and serve as a metric for comparison with other studies. To assist in the construction of the description of limiting aspects of the study, Selltiz, Wrightsman, and Cook (1987) recommend two actions. One is to present characteristics of the methodology that may have influenced the results, and the other is the discussion about implied characteristics in the sample in relation to the universe, which can prevent generalization. Although the indicators for construction of the questionnaires were adapted from literature, and the relationship of the variables were built based on other models already validated, the 11-point scale (0–10) to measure the degree of each indicator that composed the expressed variables may have hampered the responses of respondents because this analysis requires greater criterion in the degree of response.

The creation of new hypotheses is important to investigate the motivation that lead enterprise to seek eco-innovations, verifying whether they are related to mimetic, coercive or normative isomorphism. The difficulty in generating knowledge can be overcome with encouraging for basic research at universities. However, the sharing of knowledge, which leads to positive results in the Brazilian agribusiness, relies heavily on an efficient way of organizing and distributing information. This research is expected to inspire new researchers to continue advancing toward further development of the Brazilian NIS guided by the concepts of open innovation, expanding, therefore, managerial and academic contributions.

Conflicts of interest

The authors declare no conflicts of interest.

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