O PAPEL DA COMPLEMENTARIDADE NA ADOÇÃO DE TECNOLOGIA AGRICOLA
THE ROLE OF COMPLEMENTARITY IN AGRICULTURAL TECHNOLOGY ADOPTION

Marcela de Mello Brandão Vinholis
Brazilian Agricultural Research Corporation (Embrapa)
Rod. Washington Luiz, km 234, 13560-970, São Carlos, SP, Brazil.
marcela.vinholis@embrapa.br

Hildo Meirelles de Souza Filho
Federal University of São Carlos (UFSCar)
Rod. Washington Luiz, km 235, 13565-905, São Carlos, SP, Brazil.
hildo@dep.ufscar.br

Marcelo José Carrer
Federal University of São Carlos (UFSCar)
Rod. Washington Luiz, km 235, 13565-905, São Carlos, SP, Brazil.
marcelojcarrer@dep.ufscar.br

Fabio Ribas Chadad
University of Missouri
125B Mumford Hall, 65211-6200, Columbia, MO, USA.
chaddadf@missouri.edu

Abstract

The concept of complementarity, introduced by Milgrom and Roberts (1990), was used to evidence the synergic effect resulting from the joint adoption of technologies packages – production intensification and traceability certification. A survey questionnaire was applied to a cross-section sample of 84 farms of the State of São Paulo, Brazil. The empirical analysis of the survey data is performed by means of OLS model. Using the productivity approach, the existence of complementarity is tested by regressing a measure of performance – revenue – on combinations of the complementary activities. The results suggest complementarity in the adoption of both set of technologies.

Key words: Complementarity. Technology adoption. Traceability. Capital-intensive production systems.

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1. Introduction

Brazilian beef cattle farming is marked by its great diversity and technological heterogeneity. While some producers are characterized by the adoption of capital-intensive production systems and high rates of productivity per area and/or per animal, others adopt extensive systems with low technical efficiency (ZYLBERSZTAJN; MACHADO FILHO, 2003; SOUZA FILHO et al., 2010). Such heterogeneity in beef cattle production in Brazil has been justified, historically, by the abundance of land available for production and by the absence of economic and institutional pressures to increase the productivity of production factors. However, this scenario has quickly changed. Since the 1990s, rising prices for arable land (SAUER, 2010) have been observed along with a growing presence of Brazilian beef on the international market (BRASIL, 2012). In order to remain competitive in more demanding markets, it has become necessary to obtain products with a higher level of standardization as well as better quality. In addition, restrictions have grown on the encroachment of beef cattle production on natural forests and/or environmental preservation areas. Consequently, more capital-intensive production systems with higher productivity of production factors have begun to spread.

In addition to environmental requirements, the adoption of food safety mechanisms, such as traceability and certification, has become a fundamental condition to maintain or to have access to new international markets. The food contamination cases and BSE crisis in the 90's highlighted the close interdependence between different stages of the production chain and the limitations of quality control along the food chain (MATOS; ROSSI, 2007; HOBBS, 2004), as well as fostered the diffusion of new legal rules related to food safety and food quality (KRIEGER; SCHIEFER, 2007; FULPONI, 2006; TRIENEKENS; ZUURBIER, 2008). Since 2002, the adoption of individual bovine traceability, associated with its certification, has been required of Brazilian farmers focusing on the European market. However, adherence to this program is low. In October 2010, only 2,207 farms were apt to export to the EU, being 174 located in the state of São Paulo (BRASIL, 2010). This represents 0.7% of farms with more than 50 bovines (BRASIL, 2006).

The concept of complementarity introduced by the seminal paper of Milgrom and Roberts (1990) is an interesting approach to explain the slow and irregular process of technological diffusion (BOCQUET et al., 2007; JAMES JR. et al., 2011). However, this approach has been seldom explored in empirical studies on adoption of agricultural technology. This study aims to identify the existence of complementarity between the adoption of capital-intensive production systems and the adoption of traceability for the exporting of beef to the European Union. Both strategies implicate the adoption of a set of similar management technologies and practices. The effect of complementarity on the financial performance of the livestock activity can contribute to explain the low adoption of traceability.

This paper is organized as follows. The subsequent section describes the theoretical and empirical literature on complementarity. Section 3 contextualizes the complementary variables and the factors that affect the synergic effect between them. The productivity approach used to evidence the existence of complementarity is presented in section 4. The results are then presented in section 5, while section 6 presents the conclusions.

2. Theoretical approach

The adoption of technology is influenced by a set of factors which can accelerate, slow down or even render unfeasible the adoption by certain groups of firms (SUNDING; ZILBERMAN, 2001). The study on the decision whether to adopt a technology can be carried out from different approaches. Bocquet et al. (2007) describe two approaches. The first is related to technological diffusion, in which exogenous determinants either foster or hinder the adoption. The theoretical and empirical investigations on this approach are dedicated to the identification of these factors. The second approach arises from the concept of complementarity developed by Milgrom and Roberts (1990). The authors formalize the intuitive idea of synergy, i.e., the idea that the whole is greater than the sum of the parts (MILGROM; ROBERTS, 1995). According to this approach, new technology is adopted in order to optimize the firm's strategy, as well as other organizational and technological practices (BOCQUET et al., 2007).

Following this idea, Gómez and Vargas (2012) state that some technologies should not be analyzed in isolation. On the contrary, the adoption of a given technology is sometimes better explained when one takes into account that it forms a system with the employment of other technologies. Joint adoption helps the firm to build systems in which complementary relationships between the parts can arise. Complementarity exists when a modification in one or more elements of the system leads to a modification in another. Suppose the firm has already adopted three management practices (A, B, and C) that are complementary to a new management technology (X). This means that the probability of the new management technology (X) being adopted by the firm increases when the three management practices (A, B, and C) are present. This does not mean that the new management technology (X) cannot be adopted without the presence of the other three practices (A, B, and C) (JAMES JR. et al., 2011). In general, the complementary elements of a system tend to move together systematically and consistently in response to contextual changes. Changes favoring the increase in one element of the system tend to also increase the occurrence of the others. (MILGROM; ROBERTS, 1995).

In order to adapt to contextual changes, the firm is more likely to achieve higher performance in new activities which are complementary to other activities previously established. Thus, one of the skills involved in this process of decision-making is to recognize synergies in new available technologies or complementarities with existing activities (MILGROM; ROBERTS, 1995).

Previous work on complementary technologies has provided empirical evidence on the existence of such complementarities between different technologies. Bocquet et al. (2007) found that the probability of information technology adoption is significant and positively associated to the presence of other organizational practices. EDI adoption is complementary to an organizational design which combines tools to enhance employees' incentives, formal contracts with customers and suppliers, and quality improvement procedures. Zhu (2004) provided evidence that superior performance (revenue generation, cost reduction, asset return and inventory turnover) of retail firms can arise from combining e-commerce capabilities with IT infrastructure. Aral et al. (2012) found evidence of complementarity between information technology, performance pay, and human resource analytics practices when these practices are implemented jointly rather than separately. Gómez and Vargas (2009) provided evidence that the adoption of one of the technologies employed in manufacturing (numerically controlled machines, computer aided design and robotics) is positively related to the introduction of the other two. However, there are few studies seeking evidence of complementarity in the adoption of agricultural practices.

3. Empirical hypothesis

The beef cattle production system in Brazil is predominantly extensive. However, the adoption of more capital-intensive production systems has increased, mainly in the Southeast and Midwest. The intensification process is stimulated by the raise in land price, the competition with profitable agricultural crops (SOUZA FILHO et al., 2010) and the pressure to avoid beef cattle production in permanent preservation areas and natural forests (IGREJA et al., 2008). Beef cattle production has been considered one of the villains of deforestation in Brazil and of emissions of greenhouse gases. Such emissions are especially evident in areas with degraded pastures (OLIVETTE et al., 2011). Although there is no consensus in the literature regarding the effects of production intensification on mitigating environmental problems, it has been considered an alternative which allows for crop expansion without further deforestation (BOWMAN et al., 2012).

The recovery of land price to mid-90s levels is associated with the advance of profitable agricultural crops, such as sugarcane, in traditional grassland areas (BINI, 2013). The census data summarized in Table 1 shows the increase in harvested area of sugarcane over grassland area in the state of São Paulo. Sugarcane area increased by about four times between the agricultural censuses of 1970 and 2006, while grassland area decreased by about 40%. However, the number of bovine heads increased slightly (15%), influenced by the adoption of technologies for intensification of beef cattle production (PINO, 2009). The number of bovine heads by hectare increased from 0.79 to 1.51. The intensification allowed for production expansion and compensated for the retraction of pasture areas, which indicates an improvement in production efficiency (IGREJA et al., 2008).

Table1. Census data.

São Paulo State, Brazil	1970	1975	1980	1985	1996	2006
Sugarcane area (hectares)	580.487	689.485	1.073.120	1.694.994	2.124.499	2.990.211
% Total area	2,84	3,35	5,32	8,37	12,23	17,90
Grassland area (hectares)	11.463.597	11.354.907	10.306.302	9.926.264	9.061.514	6.899.378
% Total area	56	55	51	49	52	41
Number of bovine	9.110.633	11.451.139	11.685.216	12.210.369	12.306.790	10.433.021
Number of bovine/hectare of pasture	0,79	1,01	1,13	1,23	1,36	1,51

Source: Brasil, 2006.

In Brazil, beef cattle production is fragmented into three phases: breeding, raising and fattening. The breeding phase comprises the period ranging from the birth of the calf up until weaning; the raising, from weaning up until the animal has reached 300 kg of weight, and the last phase ranges to up until the slaughter. The state of São Paulo focuses on the fattening phase due to the rise in land price, the great number of slaughterhouses (23%) and the port infrastructure, which in 2011 exported 72% of total Brazilian beef (BRASIL, 2012). Farms specialized in the fattening stage owned 19% of the herd, and 8% were fattened in the feedlot system (708,513 bovine) (BRAZIL, 2006).

According to EMBRAPA (2005), feedlots present the highest technological intensity of any production system. The animals are confined during the finishing phase for a period ranging from 60 to 120 days, depending on the entry weight of the animals and the feedlot's level of technological intensification. The main objective of this system is to optimize animal weight gain, in order to reduce the production cycle and increase the productivity both per area and per animal. There are farmers who perform more than one cycle of fattening on feedlot per year.

The risk and complexity of capital-intensive production systems, such as feedlots, are high. This scenario, in contrast with extensive production systems, presents a cost structure that requires planning and strict production management; otherwise profitability is jeopardized (CORREA et al., 2000). Thus, the adoption of capital-intensive production systems implicates the adoption of a set of advanced management tools, such as inventory control, livestock performance control, production cost spreadsheets, training of employees and risk management mechanisms. Physical and temporal specificity are inherent to feedlot activity (VINHOLIS, 2013).[1] In order to avoid the spot market financial risk and the opportunistic behavior in the relationship with slaughterhouse, the previous sales planning is required and other sale mechanisms can be adopted, such as the future contract traded on the stock market and the forward contract negotiated with the slaughterhouse.

Parallel to the production intensification, the increase in exports of Brazilian beef has brought challenges related to food safety. The implementation of bovine traceability along the supply chain is one of them. Some beef importers have demanded traceability as a condition for market access, such as the European Union (EU). This demand has had an impact on the national food safety regulatory milieu.

In 2002, The Brazilian System of Identification and Certification of Bovine and Bubaline Origin (SISBOV) was created in order to meet the requirements for traceability. This system, based on voluntary adoption, is coordinated by the Ministry of Agriculture, Livestock and Food Supply (MAPA). This tool has been adopted in order to keep records that allow for the tracing of beef origin along the supply chain. The traceable unit is the bovine animal, and its identification is unique nationwide. The information is centralized and stored in a National Data Base (BND), managed by the MAPA.

The conformity of the traceability system is certified by the MAPA, which is responsible for the accreditation of private third-party certification agencies. The certified farm is inspected periodically and systematically by such agencies, under penalty of certification suspension. The compliance is of these inspections is confirmed by a MAPA audit. Only then is the farm able to export beef to countries that require traceability.

[1] Related to Williamson´s (1989) conception of specificities.

The implementation of traceability leads to the adoption of practices such as individual identification of animals, records of the animal's history, inventory control and the adoption of information technologies, such as software and electronic devices for cattle management (NANTES; MACHADO, 2005; COCARO; JESUS, 2008). The implementation of these technologies requires time, training of employees and acquisition of equipment, which means investments are to be made by the farmer.

However, there is no guarantee of the appropriation of quasi-rent arising from this investment. The premium price paid for the traced animal varies according to the supply and demand of these animals. The adoption of risk management tools, such as forward contracts, stimulated by the adoption of the feedlot system, allows the inclusion of a clause to ensure the payment of a premium price for the traced animal. On one hand, the contract reduces the uncertainty regarding the receiving of the premium price. On the other hand, the premium price contributes to minimize the finance risk of the feedlot system. The animal price is a significant share of the feedlot production cost (ARIEIRA et al., 2007). A tiny variation in cattle price can determine the economic viability of the feedlot system.

Both strategies - intensification of production and certification of bovine traceability – require the adoption of a set of close management practices and technologies, training of employees and similar management skills. In addition, both are susceptible to economies of scale. The larger the scale of production, the lower the total unitary cost in feedlots (LOPES et al., 2007) and the lower the total unitary cost in the certification of traceability (SARTO, 2002; MENDES, 2006; LOPES et al., 2008). Thus, the existence of complementarity resulting from the joint adoption of intensive production systems and certification of bovine traceability is proposed.

However, few empirical studies demonstrate the existence of complementarity in the adoption of agricultural technologies. Huffman and Mercier (1991) investigated the influence of the management complexity of different rural activities on the adoption of computers and computer services. The authors found that the greater the management complexity, such as in large livestock farms, the greater the likelihood of adoption of the technologies. They concluded that the adoption of computer and related services were complementary inputs to the complexity of rural activity management. Melo (2012) proposes a model of financial risk management for the feedlot activity in Brazil. The variable 'premium price paid by traced animal' is identified as one of those with the greatest impact on the economic viability of the business strategy named 'Boitel'[2]. In general, this business strategy consists in fattening of cattle by means of the feedlot system. The result provides evidence that the synergic effect between the adoption of traceability and the feedlot system is a possibility.

4. Method

The sample comprises cross-section data on 84 farms, visited during the period from February to August 2011. The interviews were carried out personally with the farm owner and had an average duration of two hours.

[2] "Boitel" is a business strategy which consists of the sale of stays for cattle for other farmers (MELO, 2012).

In order to verify the existence of complementarity between the adoption of capital-intensive production systems and certification of bovine traceability, the performance of a multiple log-linear regression model with the survey data was considered. It is specified as follows:

Ln Revenue$_i$ = f(schooling, relationship; size; certification; feedlot; certification&feedlot; ε)

Wherein *Ln Revenue* is the continuous dependent variable. In order to evidence the existence of complementarity between explanatory variables, Athey and Stern (1998) use a measure of performance or productivity as the response variable, named productivity approach. This approach has been used on several other empirical studies on on searching for complementarity evidence (CASSIMAN; VEUGELERS, 2006; ARAL et al., 2012; CLARK; HUCKMAN, 2012; TAMBE et al., 2012). In this study the response variable is the natural logarithm of the 2010 livestock revenue. The revenue is influenced by the cattle price and the amount of beef sold. Certification allows for the receiving of a premium price, whereas the intensification of production allows for standardized carcasses. Both strategies can positively affect cattle price, which in turn influences revenue. Also, the intensification of production is susceptible to economies of scale. Larger bovine herds can positively impact revenue.

There are some assumptions for the multiple regressions. Homoscedasticity or equal variance of the error terms is one of them. Here, the chart analysis of the predicted values x residues values is performed, in order to verify this condition. The Kolmogorov/Smirnov and Shapiro Wilk tests are performed in order to verify the condition of normal distribution of the model residuals. In order to control for the effects of multicollinearity, the correlation matrix was calculated for the explanatory variables.

The overall significance of the multiple regression, that is, to test the hypothesis that all slope coefficients are simultaneously equal to zero (H_0) or not (H_1), is verified by performing the F test. If $F > F\alpha$ (k - 1, n - k), H_0 is rejected, otherwise it is not rejected. Alternatively, if the p value of the F statistic is low enough, we can reject H_0 (GUJARATI, 2006). Thus, if the hypothesis H_0 is true, the model does not fit well, since the coefficients are statistically equal to zero. Table 2 shows the definition of the explanatory variables.

Table 2. Definition of explanatory variables.

Variable	Definition
schooling	Years of formal education
relationship	Membership and active participation in association events linked to livestock and participation in non-formal groups associated with livestock = 1, otherwise = 0
size	Total area in hectares of own farms
certification *D1(dummy 1)*	Adoption of traceability and its certification and no feedlot = 1, otherwise = 0
feedlot *D2(dummy 2)*	Adoption of feedlot* and no traceability = 1, otherwise = 0
certification&feedlot	Adoption of feedlot* and certification of traceability = 1, otherwise = 0

D3(dummy 3)	

*More than one cycle of fattening on feedlot per year.

Source: survey data.

The variables *schooling*, *relationship* and *size* are used as control. In order to evidence the existence of complementarity between the variables *certification* and *feedlot*, a dummy variable of interaction (*certification&feedlot*) is introduced in the model. It captures the synergic effect of the joint adoption of both strategies. It is expected that the variables *certification*, *feedlot* and *certification&feedlot* have a positive effect on the response variable *Ln revenue*. The greater and significant impact of the variable *certification&feedlot* compared to the effect of the other two explanatory variables adopted in isolation highlights the existence of complementarity arising from the joint adoption of capital-intensive production systems and the certification of bovine traceability. Complementarity exists when there is a synergic effect resulting from the joint adoption of two or more technologies (MILGRON; ROBERTS, 1990).

5. Results

Table 3 shows the regression results. The p-value of the test for the general significance of the estimated regression, that is, the *F* statistic, was low enough to reject the hypothesis that all the regression coefficients are equal to zero. R^2 is a measure of the goodness of fit of the regression data set. The adjusted R^2 of the estimated regression is 0.74.

Table 3. Multiple regression.

Variable	coef.	*p*	Standard error
Intercept	8,6458	0,0000	0,6632
Schooling ***	0,1111	0,0664	0,0597
Relationship ***	0,1087	0,0707	0,0593
Size *	0,5118	0,0000	0,0629
D_1 (certification) ***	0,1070	0,0966	0,0636
D_2 (feedlot) **	0,1158	0,0465	0,0572
D_3 (certification&feedlot)*	0,4671	0,0000	0,0642
Adjusted R^2	0,7396		
F (6,77)	40,2972		
p-value	0,0000		
Std. Err. of Estimate	0,8550		

* Coefficients significant at 1%*, 5%**, and 10%***.

Source: survey data.

The residuals of the model follow a normal distribution as shown in Figure 1. The points are close to the identity line. Also, the *Kolmogorov-Smirnov* and *Shapiro Wilk* tests satisfy the normality assumption. Figure 2 shows that the *p*-value of both tests is greater than 0,05. The residuals also meet the assumption of constant variance (homoscedasticity) as shown in Figure 3. There is no evidence of a systematic pattern between residual and predicted values.

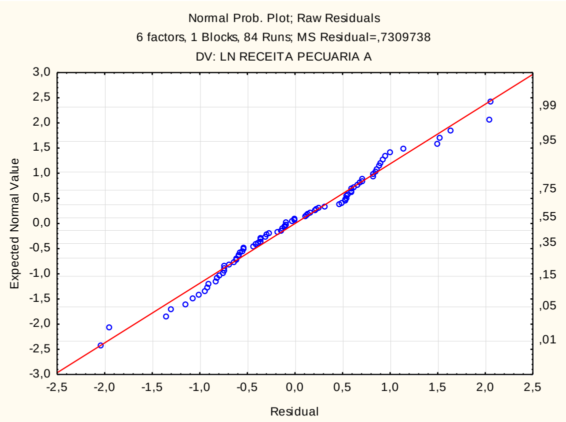


Figure 1. Normal probabilistic plot of regression residues.
Source: survey data.

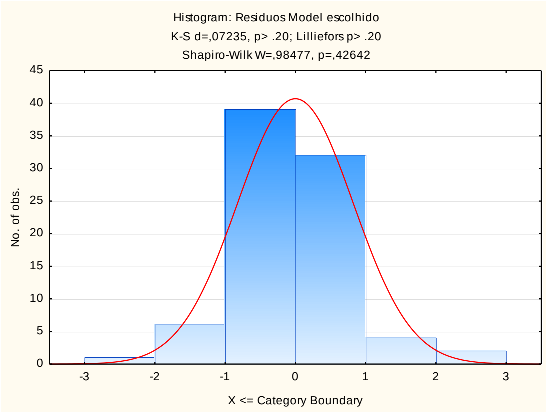


Figure 2. Histogram of residuals.
Source: survey data.

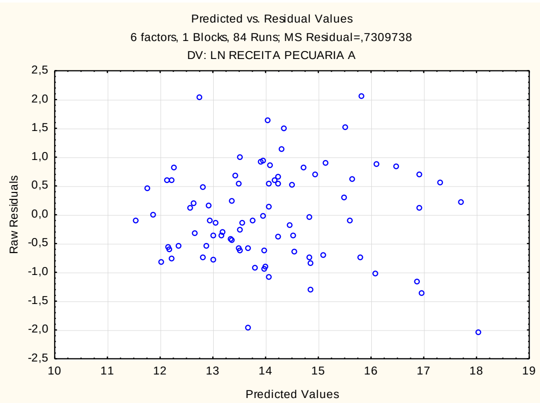


Figure 3. Predicted vs. residual values of regression.

Source: survey data.

The interpretation of the coefficient of a dummy explanatory variable in the log-linear regression model follows the approach by Halvorsen and Palmquist (1980). The percentage effect of the change of a dummy variable on the dependent variable (*Y*) follows the equation $100*g = 100 *\{\exp(c) - 1\}$, wherein *c* is the coefficient of a dummy explanatory variable and *g* is the relative effect on *Y* of the presence of the factor represented by the dummy.

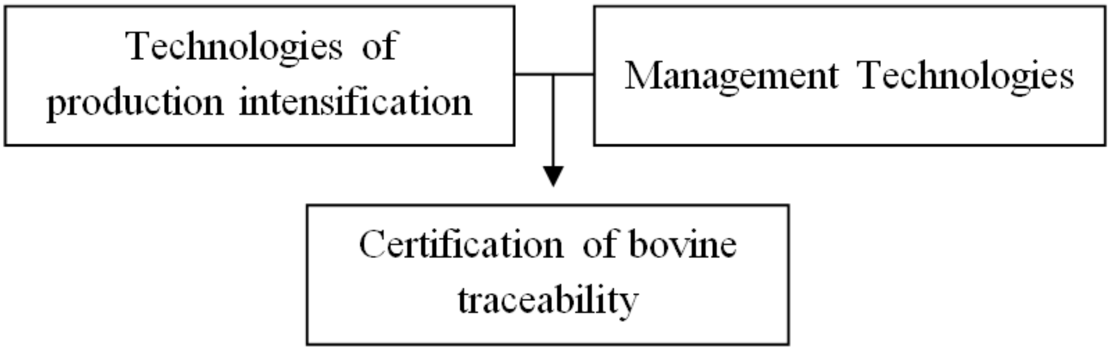
The results of the estimated parameters of the model are in agreement with the theory. The parameters present the expected sign. The goal of the regression was to highlight the complementarity between the adoption of a capital-intensive production system and the certification of bovine traceability. Here, the adoption of the feedlot system is used as proxy for a capital-intensive production system. The dummy variable (D_2) *feedlot* is statistically significant at the 5% level and has a positive impact on revenue. The adoption of the feedlot system increases revenue in 12%. The dummy variable (D_1) *certification* is statistically significant at the 10% level and has also a positive impact on revenue. The certification of bovine traceability increases revenue in 11%. When the set of technologies associated with such strategies is jointly applied (D_3), the estimated parameter in the regression is statistically significant at the 1% level (impact of 59% on the livestock revenue). This confirms the existence of complementarity.

The control variable *size* is statistically significant at the 1% level, whereas both the variables s*chooling*, used as a proxy for the farmer's knowledge, and *relationship* are statistically significant at the 10% level. Larger farms have greater bargaining power to deal better prices on input purchase and livestock sale, which positively impacts revenue. The active participation in a wide relationship network facilitates the access to important market information and increases the bargaining power for trading. Higher levels of education provide individuals with further capacity for interpretation and use of information, as well as better condition for price negotiating and adoption of new production techniques, which can also affect revenue.

Figure 4 summarizes the systemic relationships found between the adoption of capital-intensive production systems and certification of bovine traceability. The adoption of intensive production systems requires the adoption of a set of management technologies, such as contracts to manage the financial risk, as well as zootechnical control of herd. The individual who works by means of this structure of production and management technologies is more likely to adopt traceability and its certification. The SISBOV certification requires the adoption of bovine traceability. Traceability involves the movement records of the herd, inventory control, and the adoption of information technologies. This set of technologies and management practices resembles and requires similar skills to those adopted for the intensification of beef cattle production.

Complementarity is also fostered by the manner in which traceability regulation in Brazil is designed. The minimum time required for the animal to be traced before slaughter is 90 days in production regions qualified for export. This period coincides with the average time for the fattening of cattle in the feedlot system.

Figure 4. Systemic relationships between capital-intensive production system and bovine traceability.



6. Conclusions

Recent changes in Brazilian beef cattle farming demonstrate intensification in production. This process is stimulated by the rise in arable land price, the progress of profitable crops and environmental requirements. Simultaneously, challenges related to food safety, such as bovine traceability, are on the agenda in order to maintain and access new markets. However, the adoption of such technology occurs slowly and irregularly. The presence of synergy, i.e. complementarity, between a new practice with others previously adopted is an approach used to explain technology adoption. Thus, this study provides empirical contribution by demonstrating the existence of complementarity in the adoption of agricultural technology.

The synergic effect between the adoption of capital-intensive production systems and the certification of bovine traceability was evidenced. The adoption of intensive production system is associated with the adoption of a set of complementary management technologies, such as controls for livestock performance, production cost spreadsheets and risk management tools. This technological package shows synergic effect with the requirements for the adoption of bovine traceability and its certification. The latter requires the individual identification of the herd, inventory control and training of employees. The uncertainty involved in the payment of the premium price for the traced bovine can be minimized through the mechanisms of risk management adopted in the feedlot system. Moreover, both strategies are susceptible to economies of scale. This synergy fosters and facilitates the adoption of bovine traceability and its certification. This result is related to traceability regulation in Brazil, in which the minimum time required to trace the animal before slaughter coincides with the average time to fatten steers in the feedlot system.

In terms of policy implications, this article provides indications regarding the types of farmers that could face difficulties in the adoption of traceability and its certification. These are small farmers with low production scales, which raise herds in less extensive production systems. Such is the profile of most Brazilian farmers. These results can be useful for policies which aim to provide incentives for the diffusion of innovation in agriculture.

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