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THE RELATIONSHIP BETWEEN RURAL INSURANCE AND GOOD AGRICULTURAL PRACTICES AND TECHNOLOGIES:

Evidence from soybean producers in São Paulo state, and opportunities for the insurance market

Discussion study

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SUMMARY

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Abstract

Faced with the increase in catastrophic event frequency and intensity, rural producers find themselves more than ever in need to increase their risk management strategies in agricultural activities. This management permeates the most frequent but less catastrophic risks, which can be at least partially managed by adopting good agricultural practices and technologies (BPAT) in the field. On the other hand, there is residual risk arising from less frequent events, but with great destructive power. These events are best covered with rural insurance. Therefore, depending on the basis risk, BPAT and rural insurance could relate in a substitutive or complementary way. Based on a sample of 16,956 Agricultural Production Units (UPAs) in São Paulo State that produced soybeans in the 2016-2017 period, this study aims to shed light on this relationship, evidencing substitution or complementarity effects between rural insurance and BPAT.

The results indicate a complementarity between rural insurance and no-tillage and irrigation, suggesting that UPAs that take out insurance are more likely to adopt such practices. On the other hand, rural insurance proved to be a substitute for crop diversification. These results have direct implications in the dynamics of rural insurance in Brazil, intensifying or reducing adverse selection.

As a way to improve rural insurance in Brazil, the authors believe that it is necessary to build insurance products that take stewardship aspects and technologies into account in pricing the policy. The growth of parametric insurance, as well as technological/institutional innovations such as “ZARC stewardship levels” have great potential to leverage rural insurance and, consequently, BPAT in Brazil, although there are some short-term challenges.

1. Introduction [1]

Record harvests accompanied by heavy losses. According to Arias et al. (2017), extreme weather events caused, on average, a 1% loss of the Gross Value of Agricultural Production, or R$ 1 billion, per year. This is an almost counterintuitive paradox, but one that has been seen in recent years in Brazil, given the growing increase in productivity together with the high risks to which agricultural activity is exposed.

Following this trajectory, risk management instruments in the field have also been evolving, perhaps not at the same speed, but with important structural changes. Part of this evolution can be attributed to risk management instruments such as rural insurance, which, particularly in the last two years, has undergone significant changes, especially in the Rural Insurance Premium Subsidy Program (PSR), whose financial resources earmarked for the grant more than doubled in the 2018-2021 period.

However, rural producers have a range of alternatives at their disposal for managing risk in their properties. Adequate risk management permeates good agricultural practices and technologies (BPAT)[2] in order to provide resilience to the activity. Established BPATs such as no-tillage and crop rotation, succession, diversification and integration, in addition to use of improved seeds and irrigation, among other strategies, contribute to maintaining the microclimate, biodiversity, soil moisture and quality, in addition to directly impacting productivity. Thus, rural producers who adopt BPATs are investing in the activity's natural resilience and, therefore, tend to be less prone to major events that could cause production losses.

[1] The authors thank the São Paulo State Institute of Agricultural Economics – IEA for broad access to LUPA's microdata; the following experts consulted, for their valuable contributions: researchers from ZARC/Embrapa, from the Climate Policy Initiative, from Esalq/USP; and also the Department of Risk Management / Agricultural Policy Secretariat of the Ministry of Agriculture, Livestock and Supply.
[2] As a way of simplifying the terms, the acronym BPAT will be used here when referring to good agricultural practices and technologies.

When defining their risk management strategy, rural producers make the choice intending to minimize potential losses, subject to their budget constraints and aversion to risk. This way, in the decision-making process, management alternatives can interact in a complementary or substitutive way. Producers who adopt strategies aimed at the activity's natural resilience may be less likely to take out rural insurance, for example. Alternatively, producers can face risk management in an integrated manner, combining good practices and rural insurance. If the latter is true, then there is great potential for risk management instruments to be on the good agricultural practice and technology adoption agenda.

By adopting technologies and practices that enhance the natural resilience of agricultural activities, producers mitigate part of their exposure to risk. However, impacts arising from possible extreme events require risk-sharing instruments, such as rural insurance, in order to mitigate them. In other words, producers can opt for an integrated risk management, mitigating the most frequent (and less intense) risks with strategies that enhance the activity's natural resilience, as well as the less frequent (but more intense) risks by taking out rural insurance. Similarly, producers could choose only one of the strategies, should they think it is already enough for reducing their exposure to risk.

This relationship of complementarity or substitutability has direct impacts on the risk exposure of insurance companies' portfolios, intensifying or reducing adverse selection. This way, it calls for incorporating stewardship aspects in pricing the policy, in order to attract producers with lower risk while encouraging BPAT adoption.

To evaluate all these presented hypotheses, an econometric exercise was performed for identifying relationships between contracting rural insurance and the propensity to adopt BPATs. For this purpose, microdata from LUPA, the Survey of Agricultural Production Units in São Paulo State were used (MARTINS et al., 2020). This census survey contains valuable information at Production Unit (UPA) level, ranging from stewardship characteristics to rural property owners' socioeconomic characteristics. Therefore, a model capable of evaluating the relationship between rural insurance and BPATs was built. Four agronomic practices and technologies were considered: no-tillage, use of improved seeds, use of irrigation, and crop diversification. The model was estimated for production units whose main activity was soybeans in the 2016-2017 harvest.

This work is divided as follows: **i)** this introduction; **ii)** a short literature review, presenting the main interrelationships between insurance and BPATs; **iii)** the methodology used; **iv)** results, and **v)** final considerations.

2. Literature review

2.1. DETERMINING FACTORS FOR RURAL INSURANCE AND BPAT ADOPTION IN BRAZIL

In addition to underscoring the relationships between rural insurance and BPATs, this exercise also contributes to the literature on determining factors for demand for risk management instruments and BPATs. This literature, albeit somewhat scarce, especially regarding rural insurance, is essential for an adequate design of public policies as well as for understanding the determining factors in producers' decision-making process regarding the adoption of good practices in the field. With regard to determining factors for contracting rural insurance, only one work was identified for Brazil. Using a Logit model for a sample of 175 rural producers in São Paulo State, the authors found that factors such as education, access to technical assistance and property size positively affect the propensity to contract rural insurance (CARRER et al., 2021).

Some studies addressed the determining factors for adopting different BPATs. For 172 rural producers, Foguesatto & Machado (2021) evaluated how socioeconomic and psychological factors (environmental values and perception of climate change) affect the propensity to adopt green manure, crop rotation, crop-livestock integration and reforestation. On the other hand, using data from the Census of Agriculture by rural establishment, Fortini (2018) evaluated the determining factors for adopting BPATs: terracing, planting in contour lines, crop rotation, recovery of pastures with crops, and shifting cultivation. In addition, the author assessed the impact of using these BPATs on productivity and profit.

Studies were also identified with the same objective of evaluating which factors affect the decision-making process for adopting BPATs, such as irrigation in citrus farming in São Paulo State (ROSSI, 2017), no-tillage in soybean crops in Goiás State (DA SILVA; TEIXEIRA, 2019), integrated systems such as crop-livestock in Mato Grosso State (GIL; GARRETT; BERGER, 2016), crop-livestock-forest integration in São Paulo State (VINHOLIS et al., 2018), crop diversification in the São Francisco river valley (OLIVEIRA FILHO et al., 2014), and as a strategy for family farming in Brazil (SAMBUICHI et al., 2016).

2.2. Rural insurance and BPATs[3]

In view of the high exposure of agriculture to risks of various kinds, rural producers have several strategies and instruments at their disposal for mitigating these risks. Decision-making on which strategy (or on a combination of them) to adopt can directly affect the dynamics of land use, thus generating potential positive or negative externalities. As a risk management instrument, rural insurance's impacts on social, productive and environmental aspects have still been little addressed in the literature, with ambiguous results (MÜLLER; JOHNSON; KREUER, 2017). Rural insurance can, on the one hand, be an inducer of technologies and good practices in the field, as it can work in exactly the opposite direction, depending on the degree of moral hazard of the insurance system as a whole.

Similarly to rural insurance being part of a set of options for risk management, BPATs are also part of the list of options available to producers in managing the activities' risk management. Producers who adopt conservation practices have a greater degree of resilience since they invest in "natural insurance". If taken into consideration as risk management strategies, conservation practices and using technologies in the field can be substitutes or be complementary to rural insurance (and vice versa).

[3] For a broad discussion of the relationship between rural insurance and BPATs, see the study made by Agroicone (HARFUCH; LOBO, 2021) here : https://www.agroicone.com.br/wp-content/uploads/2021/08/Agroicone_Seguro-rural-no-mundo-e-alternativas-paro-o-Brazil_ENG.pdf

In short, it is possible to list three ways in which rural insurance can affect producers' decision-making with regard to using inputs, agronomic practices and technologies, which lead to risk escalation:

1st Way - Taking into account that rural producers are averse to risk, since insurers share the risk with producers, there is room for the latter to adopt more productive practices and technologies, subject to different risks (such as market fluctuation) to the detriment of those that are less productive and less risky;

2nd Way – "Stop the car on the street" effect. Since production risks are shared with the insurer, producers may feel less likely to adopt best agronomic practices since, in case of losses, they would be insured. The degree of moral hazard in the insurance system directly affects the 2nd Way;

3rd Way – Since BPATs (especially the conservationist ones) and rural insurance are risk mitigation strategies, they can substitute or complement each other. BPATs enhance natural resilience, mitigating more common but less catastrophic risks. On the other hand, rural insurance protects producers against infrequent events, but with a high catastrophic potential. It is up to the producers to assess their risk and assess whether they use concomitant strategies or whether one is preferred over the other.

Table 1 in the following page presents a summary of the identified literature addressing the relationship between rural insurance and BPAT adoption.

Table 1 – Review of literature addressing the relationship between rural insurance and BPATs

Location	Methodology	Sample	Type of insurance	Crop	BPATs	Statistically significant relationship	Source
US Corn Belt	Generalized linear hierarchical model	4.778 Producers	Not specified	Corn	Crop diversification	None	(ROESCH MCNALLY; ARBUCKLE; TYNDALL, 2018)
México	Linear and ordered Logit model	277 Producers	Multiple types of insurance with multiple coverage	Corn	Improved seeds	1st Way – induces use	(FREUDENREICH; MUSSHOFF, 2018)
China	Logit	646 Producers	Not specified	Corn & wheat	Sustainable soil stewardship	3rd Way - complementary	(WANG et al., 2016)
USA	Mixed methods - Logit & qualitative research	719 Producers	Not specified	Corn	Soil cover crop and no-tillage	3rd Way - complementary	(FLECKENSTEIN et al., 2020)
Chile	Bi-varied Probit	Agro census - 256.711 Producers	Not specified	Wheat	Improved seeds, biological pest control and irrigation	3rd Way - substitutes (irrigation)	(SALAZAR et al., 2019)
USA	Probit & Linear regression	865 Producers	Revenue Insurance	Wheat	Fertilizers & pesticides	2nd Way – reduces fertilizer use	(MISHRA; NIMON; EL-OSTA, 2005)
China	Logit & Differences in Differences (DID)	344 Producers	Parametric Insurance	Rice	Improved seeds	1st Way – induces use	TANG et al., 2019)
France	Probit	243 Producers	Parametric Insurance	Corn	Irrigation	3rd Way - substitutes	(FOUDI; ERDLENBRUCH, 2012)
India	MQO & instrumental variables (VI)	540 Producers	Parametric Insurance	Wheat	No-tillage	3rd Way - complementary	(KRAMER; CEBALLOS, 2018)

Source: results from the study's bibliographic search

2.2.1. Incorporating BPATs in the context of rural insurance

Although there are some pilot projects or surveys that highlight the relationship between insurance and BPATs (as shown in Table 1), little has been identified of concrete initiatives that explicitly link rural insurance products and incentives to practices and technologies. In an integrated view of risk management in order to preserve the insurability of agricultural activities in the long term, it is essential to incorporate stewardship, technology and conservation practice aspects in the context of rural insurance. Some initiatives in this regard are presented below.

2.3. Insurance produts directed to agronomic practices

In terms of insurance structures that address the issue of adopting BPATs in building insurance products and policy differentiation, it is possible to highlight two US initiatives in this regard: i) insurance products for land-covering crops; ii) insurance products intended for organic producers or in transition.

The former are intended for producers who adopt cover crops with the intention of soil conservation and improvement, increasing the efficiency of water use, reducing the incidence of pests and improving the crops' natural nutrient cycle. In addition to institutional recognition that the practice is sustainable, the program protects and encourages producers to adhere to this stewardship strategy in consortium or after the main crop has been harvested. In some states, such as Iowa and Illinois, there are crop insurance premium subsidy programs for those growers who use cover crops, with states offering a subsidy of US$ 5 per planted acre.

Insurance products aligned with organic production require third-party certification (to minimize moral hazard and the need for auditing). For properties in transition, the requirement for accessing the insurance product is presenting the organic production system transition project. Insurance policy premium prices are defined differently between organic and non-organic products, with different subsidy conditions. In addition, there is a pilot profitability protection program, which encompasses all products into a single policy and is also eligible for properties with organic production.

2.4. PSA as a means of payment for rural insurance policies

An innovative parametric insurance product was recently launched in Brazil. The product was built by Newe in partnership with Instituto Arapyaú and ZCO2/BlockC, and is geared to cocoa in southern Bahia State, using a rainfall index to define the trigger for compensation. So far, there is nothing different from the range of available parametric products. However, payment for this insurance policy is made via Payment for Environmental Services (PSA). Since cocoa is grown in the cabruca system, an agroforestry system in which native trees of the Atlantic Forest biome provide shade for the cocoa trees, this system is an important source of carbon storage. This stored carbon was quantified and traded via the carbon market by the institutions participating in the pilot project. These credits sold were used to pay the premium for the parametric insurance product, whose policy was made in each participating producer's name.

This highly innovative initiative merged concepts of carbon credit and rural insurance, fostering both the activity's natural resilience, providing value to the agroforestry system via carbon, and insurability for extreme drought events via index insurance.

2.5. BPATs linked to a rural insurance product

The R4 Rural Resilience Initiative is one of the most important large-scale projects with regard to an integrated agricultural risk management strategy aimed at small producers in both climate and income vulnerability. The project was built on a partnership between the World Food Program (WFP) and Oxfam America and has reached more than 180,000 farmers in 10 poor countries in Africa.

The project takes a holistic approach to advancing resilience, including insurance products that are conditional on BPAT adoption.

Participating countries take several initiatives to improve producers' natural resilience. Those producers who are unable to take out rural insurance may even choose to engage their workforce in natural resource protection and restoration initiatives that increase resilience, such as reforestation and watershed protection, in exchange for insurance. In addition, there is a whole apparatus to disseminate conservation technologies and practices that will serve as eligibility criteria for rural insurance, which in most cases consists of index insurance.

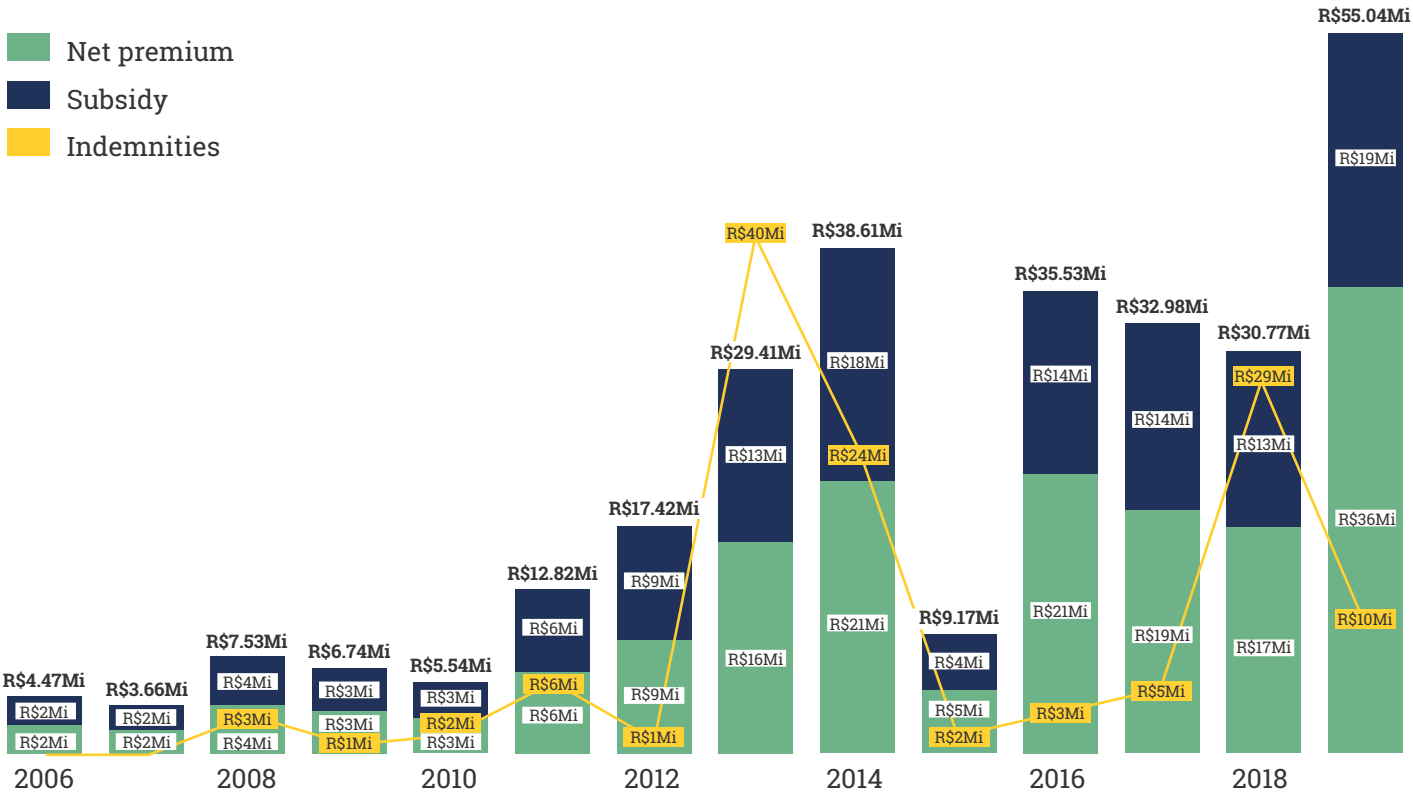
3. Rural insurance for soybeans in São Paulo State

Rural insurance in Brazil, as in most countries with a consolidated insurance system, is part of the federal agricultural policy, with subsidized policy premium. The Subsidy Program for the Rural Insurance Premium (PSR) was created in 2006 and has gained scale in recent years, reaching almost R$ 860 million in subsidies in 2020. In all, around 104 thousand producers were benefited in 2020 in a 13 million-hectare area, with R$ 1.94 billion in collected premiums.

From 2006 to 2020, R$ 3.77 billion in premiums were collected in Brazil. Of these, about 42.2% of the total collected refer to soybeans, which is the main insured crop in Brazil. In São Paulo State, soybeans are also the main insured crop, with R$ 289 million in premiums paid (24.66% of the total) in the same period. The major factor generating indemnity payments is drought, which accounts for around 80% of the indemnities paid for soybeans in the state.

Figure 1 shows the evolution of the net premium, subsidized amount and indemnities (line) for soybeans in São Paulo in 2006-2019.

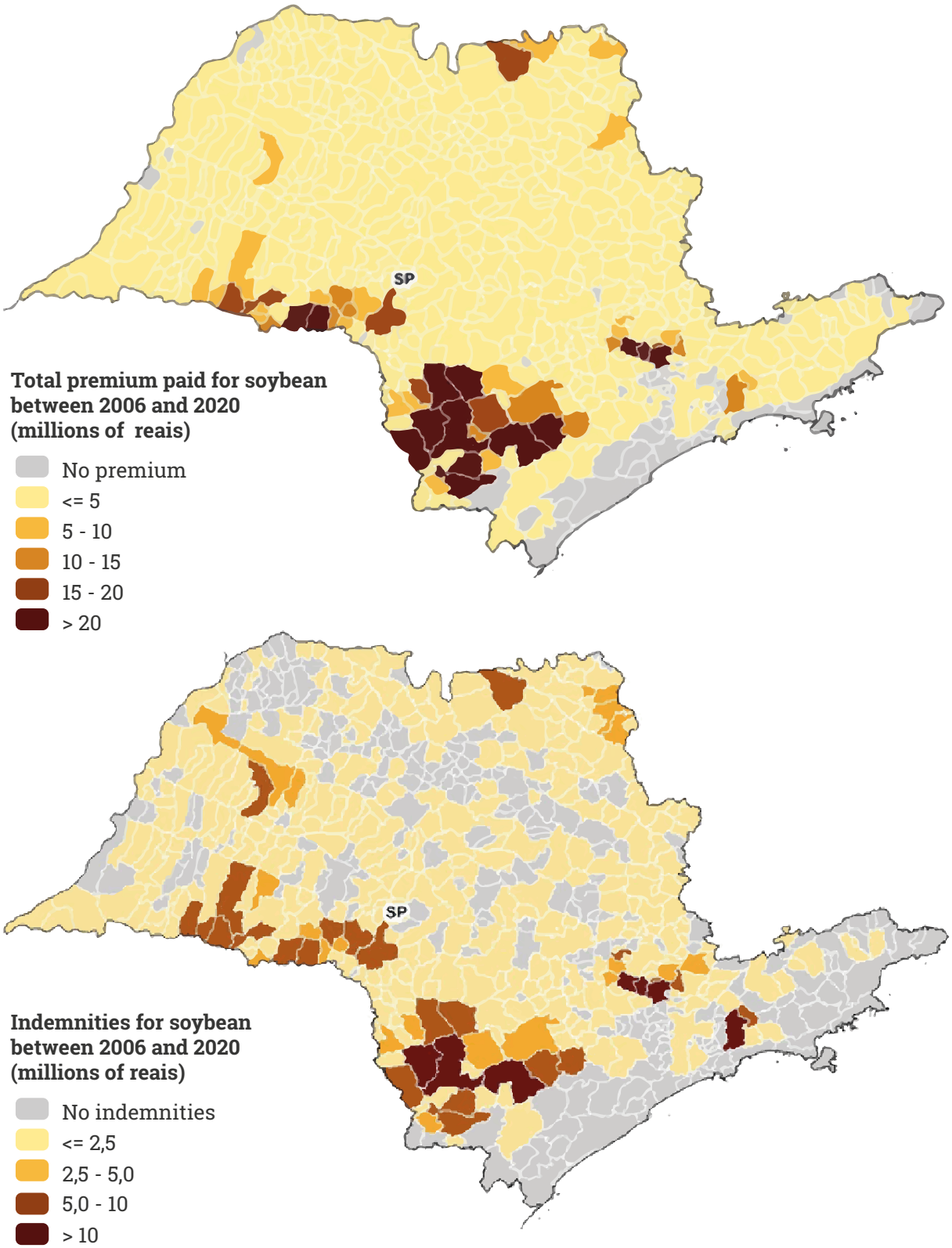
Figure 1 – Net premium, subsidy and indemnities (labels in yellow) in the PSR for soybeans in São Paulo state



Source: Rural Insurance Atlas. Prepared by Agroicone

The maps below (Figure 2) show the geographic distribution of both premiums and indemnities of insurance policies with some PSR subsidy for the soybean crop in the state in 2006-2020. It is noteworthy that rural insurance is contracted almost across the entire state for soybeans, which is especially concentrated on the border with the Paraná State in the immediate regions around Itapeva (further south of the state), Assis and Ourinhos (further to the west). It is also noteworthy that for many municipalities that took out some insurance for soybeans, there were no incidents and, therefore, no indemnities were paid.

Figure 2 - Spatial distribution of premiums and indemnities for soybeans in São Paulo state



Source: Rural Insurance Atlas. Prepared by Agroicone

4. Database & methodology

4.1. Database

The data used in this exercise refer to microdata from the Census Survey of Agricultural Production Units in São Paulo State (LUPA) for 2016/2017, coordinated by the Agricultural Economics Institute (IEA).

For the purposes of this analysis, a cut was made for soybean production, totaling 16,956 Agricultural Production Units (UPAs). Soybeans were chosen because they account for the largest volume of rural insurance premiums paid in São Paulo State.

To perform the analysis, four BPATs were defined: no-tillage, improved seeds, irrigation[4], and crop diversification. In addition, institutional variables, producer and property characteristics were used to estimate producers' propensity to take out insurance and their propensity to adopt some of the aforementioned practices. It is also worth mentioning the inclusion of a categorical variable representing the Rural Development Offices (EDR), the geographical division of municipalities according to productive characteristics defined by the IEA. The variables used are shown in Table 2.

[4] It is known that irrigation may not necessarily be considered a sustainable practice or technology from an environmental standpoint, but it increases the activity's resilience and productivity and was included in the Sectoral Plan for Adaptation to Climate Change and Low Carbon Emission in Agriculture 2020-2030 (MAPA, 2021). It will therefore be considered as a BPAT for the purposes of this study.

Table 2 - Description and descriptive statistics of the variables used (soybean in São Paulo State, 2016/17)

Category	Vaariable	Description	Average
Good agricultural practices and technologies (BPATs): Dependent variables	No-tillage	If the rural producer adopts the no-tillage system	79.66%
	Irrigation	If the producer adopts an irrigated system	4.28%
	Improved seeds	If the producer uses improved seeds	82.14%
	Diversified crops	If the rural producer produces at least 3 crops a year[5]	49.26%
Risk management tool: Dependent variable	Rural insurance	If the producer contracted rural insurance in the last 12 months	32.80%
Financial instrument	Rural credit	If the producer contracted rural credit in the last 12 months	48.74%
Access to information	Accesses the internet	If the producer accesses the internet to gather agricultural information	25.52%
	Is cooperated or associated	If the producer belongs to a cooperative and/or rural producers' association	46.34%
	Technical Assistance	If the producer receives public and/or private technical assistance	82.23%
Agricultural management	Agricultural management	If the producer regularly makes agricultural bookkeeping (rural accounting)	59.38%
	Soil analysis	If the producer frequently collects soil samples for chemical and physical analysis	86.79%
	Resides at the UPA	If the producer resides on the property	22.91%
	No. of owners of the UPA	How many owners does the UPA have	1.55
Education levels	No education or incomplete elementary school	If the producer is illiterate or has not completed elementary school	28.66%
	Elementary school	If the producer has only completed elementary school	21.33%
	High School	If the producer has only completed high school	28.18%
	Concluded Higher Education	If the producer completed higher education	21.83%

[5] Since most of soybean planting is made in rotation with another crop throughout the crop year, it was decided to consider that practice of planting at least three crops in the same UPA during the crop year as crop diversification.

Category	Variable	Description	Average
UPA characteristics	No. of workers	Total workforce on the property, both family and non-family	1.33
	Planted area	Soybean planted area in hectares	48.90 ha
	% of family income from the property	Agriculture's share in family income	70.04%
UPA characteristics / instrumental variable[6]	Distance to the seat of the municipality	Distance in kilometers between the UPA farmhouse and the seat of the municipality	14.12 km

Source: results of the research based on LUPA 2016/2017 microdata

4.2. Methodology: Bivariate Recursive Probit

To assess the relationship between contracting rural insurance and adopting BPATs, a Bivariate Recursive Probit model was used. The model was initially introduced by Heckman (1978) and by Maddala (1986), and it enables two simultaneous and jointly-determined events to be correlated by residuals (i.e. unobservable factors that are common between both events) and at the same time enables one of the events to settle endogenously on the second. In other words, as they are both risk management instruments, contracting rural insurance and adopting good practices and technologies, are decisions to be made simultaneously, in which unobservable factors affect the dynamics of choices independently of each other, and at the same time the decision to take out insurance directly affects the decision to adopt best practices and technologies. The model can be described as:

$$y^*_{1i} = \beta_{1i}\, x_{1i} + \delta_{1i}\, z_i + \mu_{1i} \mid y_{1i} = 1 \text{ se } y^*_{1i} > 0{,}0 \text{ or}$$

$$y^*_{2i} = \beta_{2i}\, x_{2i} + \gamma y_{1i} + \mu_{2i} \mid y_{2i} = 1 \text{ se } y^*_{2i} > 0{,}0 \text{ or}$$

[6] In order to control possible endogeneity, the variable distance to the municipality seat was included.

Where y^*_{1i} and y^*_{2i} are dependent latent variables that represent the decision to take out insurance (y_{1i}) and the decision to adopt best practices and technologies (y_{2i}).

The determinants of both events are represented by x_{1i} x_{2i}, which in this case are exactly the same. The terms β_{1i} and β_{2i} are the coefficients of the regressors vector (previously shown in Table 2), while z_i represents an instrumental variable for controlling potential endogeny (MONFARDINI; RADICE, 2008). In this specific case, the distance from the UPA to the seat of the municipality was used. Since this is a simultaneous equations system, there is a possibility of bias due to endogeny. To this end, it was defined as an instrument, that is, a variable that directly affects the propensity to take out insurance, but that does not directly affect the propensity to adopt BPATs. This instrument, the distance to the seat of the municipality, tests the transaction costs hypothesis. The greater the distance, the lower the propensity to take out insurance is expected due to a higher transaction cost.

As previously stated, the residuals are allowed to correlate with each other. Therefore:

$$\mu_{1i} = \rho_i + \varepsilon_{1i}$$

$$\mu_{2i} = \rho_i + \varepsilon_{2i}$$

Which means that there is a there is a common component ρ_i between the residuals of both equations that captures the unobservable, however common relationship between them.

5. Results

The results obtained by the regressions are shown in Table 3. The results refer to the marginal effect on the unitary (or state) variation of an explanatory variable on the occurrence propensity in the analyzed event. For example, the marginal effect of contracting rural credit (in detriment to not contracting) is 35.54 percentage points (p.p.) of the probability of the rural producer contracting insurance. Similarly, for every 10 km further away from the property to the seat of the municipality, there is a 0.83 p.p. decrease in the propensity of the producer contracting rural insurance at the UPA. The results will be discussed more broadly by category of variables.

Table 3 - Results of the regressions in marginal effects (E.M.)

Category	Variable	Rural insurance E.M[7]	No-tillage E.M.	Irrigation E.M.	Crop diversification E.M.	Improved seeds E.M.
Risk management instrument	Rural insurance	-	5.44**	3.95**	-26.86***	-2.70
Financial instrument	Rural credit	35.54***	1.96*	-0.38	11.92***	5.03***
Access to information	Internet	7.13***	1.33*	2.23***	8.19***	4.23***
	Associated	2.33***	-3.25***	1.52***	3.49***	0.80
	Technical Assistance	6.26***	3.92***	-0.37	6.91***	9.70***
Agricultural management	Economic management	9.42***	-0.59	0.92**	6.98***	2.78***
	Soil analysis	14.30***	4.85***	-0.02	0.71	17.46***
	Resident	-1.56**	-0.4	-1.11***	20.70***	-0.57
	No. of owners	0.05	0.09	-0.40***	1.60***	-0.16
Access to information	Internet	7.13***	1.33*	2.23***	8.19***	4.23***
	Associated	2.33***	-3.25***	1.52***	3.49***	0.80
	Technical Assistance	6.26***	3.92***	-0.37	6.91***	9.70***
Education levels	Elementary School	4.85***	0.92	-0.15	-3.42***	-3.57***
	High School	3.82***	0.25	1.47***	-4.87***	-5.10***
	Higher Education	3.12***	-2.51***	0.99**	0.94	-5.10***
UPA characteristics	No. of workers	0.17	0.11	-0.00	2.83***	0.62***
	Planted area (100 ha)	0.86***	0.50	1.24***	7.80***	0.69**
	% of family income (10%)	0.79***	0.06	-0.00	0.46***	0.4***
	Distance to municipal seat (10 km)	-0.83***	-	-	-	-

Note: the asterisks represent the levels of statistical significance of the coefficients resulting from the econometric model, as follows: *10%; **5%; ***1%.

Source: research results based on LUPA 2016/2017 microdata

[7] It is noteworthy that for each BPAT regression there is a result for insurance. However, they showed few differences in terms of coefficient magnitude and statistical significance. Therefore, only the insurance result referring to no-tillage regression was used.

Financial Instrument

Rural credit was the variable that had the greatest impact on propensity to take out rural insurance. Producers in UPAs that take out rural credit have 35.54 p.p. more chance of taking out rural insurance than those who do not take out credit. This can happen in two expected ways: the first is that producers who take out credit have a greater degree of funding, with easier access to risk management instruments; rural credit can affect the propensity to take out insurance for the purpose of reducing credit operation risk.

Furthermore, access to rural credit has the expected impact on the propensity to adopt BPATs, since access to credit secures the necessary financial resources for adapting the productive activity and adopting BPATs.

Access to Information

Access to technical assistance, as well as being a member of associations and/or cooperatives are the main means of accessing information in rural areas. Collective environments for sharing information are part of knowledge transmission, both formally and from practice. Such factors directly impact the propensity to take out rural insurance as well to adopt BPATs.

Furthermore, access to the internet enables free access to information at an almost zero marginal cost. This factor, linked to technical assistance and membership in associations, guarantee producers broad access to essential agronomic information for guidance and risk management strategies on the property.

Agricultural Management

Managing agricultural activities, both in financial aspects and in terms of soil quality, was also incorporated into the model. For greater perception and understanding of risk exposure, rural producers must monitor their main financial and productivity indicators, as well as product and input prices. Such economic management is essential in risk mitigation strategies, positively impacting both the propensity to take out rural insurance and in adopting BPATs.

In addition, knowledge of the soil's physical and chemical properties enables greater ability for managing inputs and defining the practices to be adopted, as well as the choice of cultivars, planting period and soil requirements, thus positively impacting risk mitigation strategies.

Furthermore, the variables "resident in the UPA" and "number of UPA owners" presented meaningful results for adopting the crop diversification BPAT. This fact is probably the result of the need for greater need for labor and the predominance of this BPAT as a risk mitigation strategy, especially in small rural properties. It is worth remembering that the arithmetic average of the soybean planted area per UPA in São Paulo is 48 hectares (Table 2).

Education Levels

Formal education is a key factor in risk management and mitigation. However, there is a decreasing increment as the education level rises for the insurance results. On the other hand, the results of this variable for adopting BPATs present certain unexpected inconsistencies, with the increase in education reducing the propensity to adopt BPATs. It is important to point out that this "inconsistency" was also identified by Fortini (FORTINI, 2018). One of the possible arguments is that more educated producers would have greater opportunity to engage in productive activities beyond the agricultural activity, thus reducing the concern with adopting best practices.

UPA Characteristics

Some general characteristics of the UPA were included for control purposes, such as the soybean planted area and the number of workers in the UPA. Also noteworthy is the distance from the UPA to the seat of the municipality, which was included in the model as an instrumental variable. For every 10 km additional distance, there is a 0.83 p.p. decrease in the propensity to take out rural insurance. This is due to transaction costs: the greater the distance to the seat of the municipality, the greater the difficulties for rural producers to access the insurance market.

Rural Insurance

The main interest in this exercise is to assess the relationship between rural insurance and adopting good practices and technologies (second row in Table 3). Two of the four BPATs evaluated, are complementary to rural insurance, that is, producers who take out insurance are more likely to adopt BPATs. They are no-tillage (5.44 p.p.) and irrigation (3.95 p.p.). On the other hand, rural insurance showed a strong substitutability relationship with crop diversification (26.86 p.p.) and did not show a statistically significant relationship with adopting improved seeds.

No-tillage, a widespread conservation practice in Brazil, especially in cultivating grain, presents an important increase in terms of productivity and resilience. This complementary relationship has an important role, not only in spreading this practice, but also in reducing adverse selection of rural insurance.

The complementary relationship between rural insurance and irrigation was unexpected. It was thought that, since irrigation provides risk mitigation against drought, it would be related in a substitute way to rural insurance. The results indicate exactly the opposite, suggesting that rural producers protect themselves from risk of drought by adopting irrigation while at the same time mitigating residual risks by contracting rural insurance (for other climatic risks, such as hail, frost, etc.). This result has important implications for reducing adverse selection in the insurance market.

Finally, the high substitutability between rural insurance and crop diversification suggests an intensification of adverse selection in this regard. Crop diversification is known for being the most common risk mitigation strategy, especially in small rural properties, in addition to increasing the quality of the soil, and allows for smaller variations in rural producers' profitability. This result can be explained by the insurance market's difficulty in building products that simultaneously consider a set of activities, as well as producers' lower payment capacity (especially the small ones, who mostly adopt crop diversification) for committing to a risk management strategy such as rural insurance.

5.1. Rural Insurance and BPATs: Discussing results and possibilities for Brazil

The results point to a complementarity and substitutability relationship, depending on the BPAT. No-tillage and irrigation are complementary to rural insurance. In contrast, crop diversification is a substitute for rural insurance. These results have direct implications for the insurance system's financial health, as they directly influence the degree of adverse selection in insurance companies' portfolios.

Since UPAs that have contracted rural insurance are more likely to adopt certain BPATs (in this case, no-tillage and irrigation), this virtuous effect, in addition to increasing UPAs' resilience, reduces adverse selection in the composition of insurance companies' portfolios. On the other hand, the substitutability effect between insurance and BPAT (in this case, with crop diversification) accentuates adverse selection, since UPAs that take out rural insurance are less likely to produce at least three crops a year, one of which being soybeans.

Despite the relationship between rural insurance and BPATs, the Brazilian insurance system has several limitations when it comes to incorporating BPATs into insurance policy pricing. In interviews made with insurers, their interest in differentiating producers in order to attract the most resilient and reduce adverse selection could be seen. However, differentiation comes up against a critical point of the insurance system, which is information asymmetry and, consequently, elevated moral hazard.

By incorporating rural producers' concern with the natural resilience of their production into insurance pricing, a window of opportunity opened for intensifying the complementarity relationship between insurance and BPATs, and even reduce or reverse substitutability. By granting staggered discounts on policy premiums (or subsidies), differentiated coverage rates or different "triggers" for deploying insurance between producers who do or do not adopt certain BPATs, there would be a reduction in adverse selection. For example, only 32% of São Paulo State soybean growers take out insurance, while around 80% adopt no-tillage . Adjusting the basis risk in order to differentiate policies for those that adopt no-tillage[8] has the potential to increase the demand for rural insurance and, consequently, adoption of good agricultural practices and technologies.

The major challenge, therefore, is to seek insurance products that are capable of advancing such differentiation in order to increase insurers' capability to better price each producer's risk, taking into account actions that foster greater natural resilience in the activity.

In recent years, much has been discussed about the capacity of parametric insurance and information services for integrated risk management (such as geo-referencing, climate risk, soil quality, water availability) in reducing adverse selection.

Parametric insurance stands out for its ability to drastically reduce moral hazard and transaction costs, as there is no need for auditing claims. However, the major difficulty in parametric insurance is to build an index that adequately reflects losses. Since producers adopt concomitant risk management strategies, more resilient producers can receive indemnities without necessarily having reached the threshold for activating claims.

[8] It is important to emphasize that the ability of a BPAT to reduce risk exposure of an agricultural activity depends on the quality in which it is implemented. The model proposed here is not capable of making such a distinction.

By calibrating the insurance index by BPAT adoption degree, it would be possible to reduce adverse selection. More resilient producers would have the highest indemnity "trigger". On the other hand, policy prices would be lower (KRAMER; CEBALLOS, 2018).

Parametric insurance is, therefore, a window of opportunity for Brazil in terms of strengthening the complementary relationships between BPATs and rural insurance. The big challenge is to define how to scale the best policy conditions depending on the BPAT adoption degree.

An attempt to make this approach viable is currently under development under the Agricultural Climate Risk Zoning (ZARC). It would be the Zarc by stewardship level (Zarc NM)[9]. Since the 1990s, Zarc has been one of the main information bases for climate risk management in Brazil. So far, risk levels estimated by Zarc only consider the type of crop, the municipality, the cultivar group, the type of soil and the planting date. In the new version, Zarc NM uses an objective and measurable indicator scale, which make it possible to identify aspects of the production system that are decisive for a crop's water risk. Thus, based on this indicator scale, it is possible to classify production areas into stewardship levels, each with a risk assessment that is consistent with its parameters. In this approach, production systems with bad indicators are placed in a lower stewardship level and vice versa. This way, the effects of the stewardship level would be explicit in the risk values quantified by Zarc by stewardship level. Embrapa's evaluations considering four stewardship levels demonstrate that it is feasible to reduce the risk of water deficit from 40% to 20% under certain conditions, and gains of up to 30 days in the planting window when comparing the lowest and the highest stewardship level.

In other words, the ZARC stewardship levels constitute a methodology that is highly applicable in the context of rural insurance with regard to differentiating risk levels linked to BPATs.

[9] For brief information about ZARC NM, access: https://www.gov.br/agricultura/pt-br/assuntos/noticias/zarc-vai-ampliar-estudos-e-aprimorar-analises-sobre-riscos-climaticos-no-agro/CARTILHAPAP2021.22PSREZARC.pdf

In short, aggregating insurance products such as parametric differentiating ZARC risk levels based on stewardship levels has great potential to reduce adverse selection, while it fosters the adoption of BPATs. However, despite naturally having a lower exposure to moral hazard, a parametric insurance that incorporates BPATs would still be subject to opportunistic behavior, since information on stewardship levels is self-declarable and has a high audit cost. Third-party assessments, as well as sample audits, can reduce moral hazard in this regard. In the same sense, remote sensor data have been increasingly used for remote verification of information in the field.

It is noteworthy that this rationale applies to any type of insurance. When producers are classified at a lower risk level, they could receive different policy conditions, as long as the claim compliance criterion is different from that of producers who do not adopt any BPAT. The parallel made with parametric insurance is due to the fact that this type of insurance has very desirable characteristics such as low moral hazard, facilitating the payment of indemnities and, at the same time, a high capacity to use available information for building indices and possibly correlating this with the risk classification instrument by stewardship levels proposed in ZARC.

Another window of opportunity that deserves mention is the efforts of the Central Bank of Brazil (BACEN) in the BC# Sustainability agenda. One of the strategies of this initiative is in building a sustainable rural credit bureau (or green rural credit bureau). Based on information available from rural credit operations, a sustainability rating will be created for credit takers. Producers who took out investment credit in recent years for the purpose of technological transition towards low-carbon agriculture, for example, could be differentiated. This producer differentiation also has potential for being used in the context of rural insurance. In an open finance environment, rural producers, as owners of their information, could negotiate better insurance policy conditions, since they adopt the BPATs, which are translated into the sustainable rural credit bureau indicator. The same rationale could be incorporated by the rural insurance market into open insurance, by collecting producers' information, which are owned by the rural producers themselves.

5.2. Potential biases

Some points of attention deserve to be highlighted. The first is the inability to generalize the results to other crops, as decision-making among available risk management strategies can vary depending on the crop. Therefore, a deeper reflection on these aspects for other crops is suggested.

The second point that deserves to be highlighted is the inability to consider risk factors that are specific to the property, such as, for example, water supply, soil type, etc. The alternative chosen here (using a categorical variable for each Rural Development Office) controls only part of the risk exposure. LUPA does not offer such information at this level of detail and does not allow exogenous information insertion into the database. One point to be taken into consideration for future work is precisely to establish a partnership between organizations in order to merge LUPA's bases with geo-referenced information to better characterize the UPAs.

Finally, the fact that LUPA's research does not specify the type of insurance contracted by producers may be a source of bias. For example, it is quite possible that the impact of a named drought insurance would have a surrogate relationship with irrigation. However, as it is not possible to distinguish among insurance products, it is possible that insurance for other types of risks may be producing the complementarity effect between insurance and irrigation.

Despite these limitations, it can be considered that the strategy adopted here is the best available, in addition to being unprecedented in Brazil, with regard to a greater understanding of the relationship between rural insurance and adopting good practices and technologies when viewed under the risk management instrument standpoint.

6. Final considerations

This exercise aimed to explore in an unprecedented way the relationship between rural insurance and good agricultural practices and technologies (BPAT) adoption by producers in the context of risk management in agricultural activities. Since BPATs have the potential to increase agricultural activities' resilience, they can be seen as a "natural insurance" and, therefore, can be related in a substitutive or complementary way to other risk management instruments, including rural insurance.

To make the analysis, LUPA microdata for soybean farmers in São Paulo State for the 2016/2017 period were used and estimated in a recursive bivariate Probit type model. The results point to a complementarity relationship between rural insurance and no-tillage and irrigation, while there is a substitutability relationship between rural insurance and crop diversification.

Despite the results, this complementarity or substitutability relationship is little explored in practice by the rural insurance market, since there is limitation by insurers in differentiating producers who invest in agricultural activities' natural resilience. Providing better policy conditions to producers adopting BPATs would enable reducing adverse selection while encouraging the adoption of good practices.

Given this situation, parametric insurance products coupled with information services for risk management, such as "ZARC NM", have great potential to take advantage of the complementarities between BPATs and rural insurance, as well as to reduce or reverse possible substitutability. By scaling policy premiums and indemnity triggers depending on the BPAT adoption degree, these policies would be less exposed to moral hazard and, at the same time, would reduce adverse selection and foster BPAT adoption. This rationale can be extended to any and all insurance products, as long as differentiating premiums is accompanied by a differentiation in the claim criteria for indemnity payment.

In short, for advancing rural insurance in Brazil, creating viable mechanisms is suggested for an adequate definition/measurement of the risk profile of each agricultural production unit (or rural property).

Furthermore, this study collaborates with the literature on the determining factors for contracting risk management instruments and, at the same time, on the determining factors for adopting good practices and technologies in the field. This effort is essential for guiding and improving public policies both for risk management and for fostering technologies and good agricultural practices in the countryside.

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