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The economic value of forests in supplying local climate regulation*

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Several authors have argued that forest ecosystems serve as a hedge against extreme climatic events at a local scale. Consequently, the local climate regulation ecosystem services provided by forests can be economically valued by evaluating the reduction (increase) in the insurance premium that risk-averse individuals are willing to pay when forest cover is marginally increased (reduced). This type of insurance value associated to forest ecosystems services is estimated to be USD 0.0733 per hectare of forest for Chilean farmers. The empirical framework proposed in this paper is useful and relevant for the cost-benefit analysis of natural resource conservation investments.

Key words: ecosystem services, insurance value, local climate regulation.

1. Introduction

Extreme weather events, such as droughts, heat waves, excessive precipitations and large storms, as well as large natural disasters, such as floods, landslides and earthquakes, typically result in significant human casualties and economic damage (Loayza *et al.* 2009; Cavallo and Noy 2010).[1]

These events have large welfare costs for people who would willingly pay to avoid such disasters. For example, Barro (2009) has shown that society would willingly reduce its GDP by approximately 20% per year to eliminate large-scale economic costs such as those caused by natural disasters. On a local geographical scale, extreme climate events can also cause significant economic losses and human casualties with considerable human welfare costs. Moreover, because biodiversity and ecosystems provide local climate regulation (MEA 2005; IPCC *et al.* 2007; West *et al.* 2011), they reduce local climate variability and the probability of extreme weather events at the local level. Thus, through the provision of climate regulation ecosystem services, natural ecosystems play a role that is similar to that of financial insurance by helping in hedging the risk of agents whose outcomes depend on climate distribution (for example, farmers). The theory that natural ecosystems reduce variability in the provision

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[1] Among climatic extreme events, heat waves often claim the largest number of fatalities (Gabriel and Endlicher 2012) and natural disasters, including extreme climatic events, impose a disproportionate share of their effects on people in developing countries (Kahn 2005).

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of ecosystem services and are thus valuable to risk-averse individuals was first proposed by Baumgärtner (2007). This paper applies Baumgärtner's idea to estimate empirically the economic value (benefit)[2] of local climate regulation that is provided by natural ecosystems. To the best of our knowledge, this paper is the first attempt to present an empirical methodology for estimating the economic value of local climate regulation. This can be a useful contribution due to the increasing evidence that regulating services often add up to the biggest share of the total economic value provided by ecosystems (TEEB 2010).

The study of the economic value of ecosystem services that affect the variance and higher moments of the benefit distribution of economic agents is underdeveloped in both environmental and insurance economics, and this paper is a first step in filling this gap. In the following section, we develop a simple model of risk-averse farmers facing a climatic risk whose size is negatively related to the area covered by an ecosystem. In Section 3, as an illustration, we report empirical estimates of the insurance value of local climate regulation based on information drawn from a survey of climate insurance paid by Chilean farmers. Finally, Section 4 concludes.

1.1. The insurance value of ecosystem local climate regulation services

Through its effects on the exchange of energy, humidity, carbon and other elements (Oke 1982, 1987 and Heisler 1986; Bonan 2008), the size of an ecosystem provides natural insurance against climatic variability, particularly against extreme climatic events. Thus, an ecosystem provides insurance value beyond the conventional (more extensively studied) economic (use and non-use) values. The theoretical foundations for the estimating strategy we use here are provided by the theory of the insurance value of biodiversity proposed by Baumgärtner (2007), the theory of competitive supply by risk-averse farmers developed by Newbery and Stiglitz (1981) and by the theory of production economics in the presence of risk (Shankar 2012).

According to the expected utility paradigm, individuals who are facing a risk can be characterised as maximising $Eu(x+\tilde{y})$, that is the expected value of the utility, u, of his/her deterministic x and risky $\tilde{y}$ income. In this paper, we postulate that the riskiness of income $\tilde{y}$ decreases with the size of the ecosystem and we refer to this property as *the insurance value of the ecosystem*.

Note that the introduction of risk decreases total utility if $Eu(x+\tilde{y})-u(x)<0$, which is only true if $u(x)$ is concave (i.e. the individual

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[2] In this phrase, and if one accepts that the concept of economic 'value' can only be defined in the context of an optimal economic allocation, the word 'value' could be considered more appropriate than the word 'benefit'. However, as it is increasingly argued in social as well as physical sciences, this is a rather restrictive way of defining economic value, because it could only be used properly in a very restrictive theoretical setting (one with no distortion whatsoever from a fully competitive environment) and which would obviously have little practical use in the real world. Therefore, by employing a comprehensive concept of economic 'value', one can use both terms — 'value' and 'benefit' — as synonymous, as we do in the remainder of the paper.

is risk-averse). The difference $Eu(x+\tilde{y})-u(x)$ is a measure of the degree of pain involved in adding risk in terms of the expected utility loss (Friedman and Savage 1948; Eeckhoudt and Schlesinger 2006).

However, a second measure of the cost of the risk is given by the risk premium $\pi(x,\tilde{y})$ that makes the agent indifferent between receiving the risk $\tilde{y}$ and receiving $E(\tilde{y})-\pi(x,\tilde{y})$ with certainty. By the properties of utility,

$$Eu(x+\tilde{y})=u(x+E(\tilde{y})-\pi(x,\tilde{y})) \tag{1}$$

Because the agent is indifferent between receiving the risk $\tilde{y}$ and receiving for sure the amount $\hat{y}=E(\tilde{y})-\pi(x,\tilde{y})$, this amount is called the certainty equivalent.

When risk $\tilde{y}$ is unfavourable, the insurance premium $\pi_I(x,\tilde{y})$ is the amount that makes the decision maker indifferent between facing the risk $\tilde{y}$ and paying the non random amount $\pi_I(x,\tilde{y})$. Because paying π_I is equivalent to receiving - π_I, Pratt (1964) shows that:

$$\pi_I(x,\tilde{y})=\pi(x,\tilde{y})-E(\tilde{y}) \tag{2}$$

We assume that the mean of the risky income $\tilde{y}$ is zero (i.e.$E(\tilde{y})=0$) and thus, according to (2) the risk premium and the insurance premium coincide.

Assuming that a farmer operates for only one period and that his/her production function is given by $\tilde{q}=f(\mathbf{z},\tilde{\varepsilon},\varphi)$, where output $\tilde{q}$ is a function of inputs z (an n-dimensional vector); the state of weather is described by the random variable $\tilde{\varepsilon}$; and the production technique is φ. For a given technique, we assume that the risk is additive, such that the following equations hold true:[3]

$$\tilde{q}=f(\mathbf{z})+k\,\tilde{\varepsilon}; E\,\tilde{\varepsilon}=0; Var\,\tilde{\varepsilon}=\sigma_\epsilon^2 \tag{3}$$

E is the expectation operator and the parameter k is the size of the additive risk. Thus, the output is random with a mean of $E\tilde{q}=f(\mathbf{z})=\bar{q}$ and a variance of $Var\,\tilde{q}=k^2\sigma_\epsilon^2$. Our main hypothesis in this paper is that the size of risk k decreases as the size of ecosystem s increases, such that $k'(s)<0$.[4]

This ability of the ecosystem to reduce climatic risk is what the literature calls the climate regulation ecosystem service provided by natural ecosystems (Oke 1982, 1987; Heisler 1986 and MEA 2005; Bonan 2008). The models explaining the effects of forest cover on local, regional and global climate are

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[3] The analysis of multiplicative risks is not conceptually different and the main conclusions remain. For production economics in the presence of both additive and multiplicative risks see Shankar (2012).

[4] To model risk we use a theoretical framework associated with the definition of a mean preserving spread (Rothschild and Stiglitz 1970), in which the mean is not affected by changes in the control variable. Under different theoretical frameworks, the mean may also be affected by other factors, but we are not interested in further exploring these frameworks since our focus here is on the second moment rather than the first moment of the weather distribution. See Baumgärtner and Strunz (2014) for more information on the extension to cases in which both the mean and the variance changes with a change in the control variable.

complex and many of their aspects are on the very frontier of current research (see for example Makarieva and Gorshkov 2007 and Makarieva *et al*. 2013). Nonetheless, there exist already clear evidence on the specific effect of forest cover on climate variation and climatic risk indicating that $k'(s)$ is in fact negative (which is indirectly corroborated by our estimations in Section 3 below). For example, Chambers (1998) has shown that the intensity and duration of droughts are increased by the reduction in forest cover. Costa and Pires (2010) have shown that deforestation changes precipitation patterns, increasing the duration of the dry season. Yoon (2001) also shows that forest masses in Costa Rica contribute to the formation of low clouds that maintain the productivity of one of the most diverse ecosystems of the planet. Bonan *et al*. (2004) Ge (2010) and Mishra *et al*. (2010) have shown that reductions of biomass due to deforestation and the change of pastures into crop areas in the USA have increased the maximum daily temperatures and reduced precipitations. Bonan (2008) shows that reductions in forest cover provoke lower temperatures in the winter and higher temperatures in the summer. Below we propose and apply an econometric procedure to empirically estimate the economic value of this ecosystem service.

A farmer's net income is given by the following expression:

$$\tilde{x} = N + (p - c)\tilde{q} = N + (p - c)\bar{q} + (p - c)k(s)\varepsilon \tag{4}$$

where N is non-farm income, p is the exogenously determined price faced by farmers and c is the constant average cost (per unit of output). Thus net income $\tilde{x} = x + \tilde{y}$ is a random variable itself with

$$x = N + (p - c)\bar{q} \text{ and } \tilde{y} = (p - c)k(s)\varepsilon \tag{5}$$

Net income $\tilde{x}$ is used to purchase C units of consumption at a given price of p_c; thus, a farmer faces the following budget constraint: $p_c C \leq \tilde{x}$. Assuming that the utility function is a monotonic and concave function $U(C)$ and normalising consumption price p_c to 1, the budget constraint becomes $C = \tilde{x}$ and as a result of this, the expected utility can be written as:

$$EU(\tilde{x}) = EU(x + \tilde{y}) \tag{6}$$

We assume that (6) is a von Newmann-Morgenstern utility function that represents the risk preferences of a farmer who maximises the expected value of the utility that he/she obtains from the random variable $\tilde{x}$.

According to Pratt (1964), the risk premium in (1) is as follows:

$$\pi(x, \tilde{y}) \simeq -\frac{1}{2}\sigma_y^2 \frac{U''(x)}{U'(x)} = \frac{1}{2} A\sigma_y^2 \tag{7}$$

where $A = -\frac{U''(x)}{U'(x)}$ corresponds to the coefficient of absolute risk aversion. Using (7), the fact that the variance of net income σ_y^2 is given by

$(p-c)^2k^2(s)\sigma_\epsilon^2$, and remembering that the insurance premium and the risk premium coincide by Equation (2), we are able to show that the insurance premium is given by:

$$\pi(s)=\frac{1}{2}(p-c)^2k^2(s)A\sigma_\varepsilon^2 \tag{8}$$

Thus, the farmer's willingness to pay to avoid random climatic shocks (the insurance premium) increases with the coefficient of absolute risk aversion A, with the variance of climatic risk σ_ε^2, with the size of the risk $k(s)$ (which is a function of the ecosystem size s) and with the square of profits per unit of output $(p-c)$. Moreover, Equation (8) is the functional form that links the risk premium π (s) to the size of the natural ecosystem. Taking the derivative of (8) with respect to s, we obtain the following expression:

$$\frac{\partial\pi(s)}{\partial s}=(p-c)^2kk'(s)A\sigma_\varepsilon^2 \tag{9}$$

which is negative if the ecosystem provides local climate regulation ecosystem service (i.e. k' $(s) < 0$). Thus, for a risk-averse farmer, the risk premium is decreasing as a function of s.

2. Method

In spite of the well known difficulties to obtaining exact measures of marginal values of ecosystem services (MEA 2005; TEEB 2010; IPBES 2013), it is possible to obtain conceptually adequate and practical useful estimates of the marginal economic value (benefit) of the local climate regulation services in (9) by observing the actual behaviour of farmers facing real-life decisions with regard to avoiding the effects of climate shocks.[5]

The observed insurance premium that is paid by farmers for an insurance policy that protects them against extreme climatic events can be viewed as the maximum premium that he/she is willing to pay to avoid a lottery with risk size $k\tilde{\varepsilon}$. According to our previous results, the observed risk premium paid (π (s)) must be a decreasing function of the ecosystem size (s). Thus, the empirical relationship between the risk premium and the size of an ecosystem can theoretically be determined by running the following regression:

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[5] In the case of our empirical estimations, we assume that farmers made their decisions in a nonoptimal economic setting, as we expect that the existing amount of forest ecosystem may be suboptimal and that many externalities are not fully internalised. Thus, we estimate the economic 'value' of the local climate regulation ecosystem service in a nonoptimal setting, or its economic 'benefit' to farmers who are forced to make their decisions in the existing real-world setting.

$$\pi_i = g(\beta, s_i, X_i) + \epsilon_i \tag{10}$$

where π_i is the insurance premium paid by farmers in county i, β is a vector of parameters to estimate, s_i is area covered by forest in county i, X_i denotes other control variables and ϵ_i is the error term.

To use a flexible functional form in (10), we employ a Box-Cox transformation (Box and Cox 1964), which allows the optimal functional form to be derived from the data rather than merely imposing such a form a priori. In this context, regression (10) is expressed as

$$\frac{\pi_i^\lambda - 1}{\lambda} = \alpha + \beta\left(\frac{X_i^\lambda - 1}{\lambda}\right) + \gamma\left(\frac{s_i^\lambda - 1}{\lambda}\right) + \epsilon_i \tag{11}$$

where λ, α, β, and γ are parameters to be estimated; π_i is total insurance premium per hectare that is paid in county (municipality) i of a total of 146 municipalities in Chile's agricultural zone; X_i is the mean size of the insurance policy in municipality i (the total insured value divided by the number of insurance policies that are paid in municipality i); the latter is included to account for the insurance subsidy that is given by the government to the farmers, which decreases with the size of an insurance policy and renders this insurance more expensive for larger policies. Thus, β is expected to be significant and positive. Because in our empirical work we are studying the local climate regulation ecosystem services provided by forests, the variable s_i corresponds to the area covered by forest ecosystems (both native and exotic) as a proportion of the total area of municipality i. Therefore, the crucial empirical test of the hypothesis of the insurance value of the local climate regulation ecosystem service of forests implies that the estimated value of γ obtained from the econometric estimation of (11) should be significant and negative.

Because the transformation in (11) embeds several popular functional forms, the Box-Cox method has received a significant amount of attention as a means of seeking the most empirically appropriate functional form in each case. In particular, if $\lambda = 1$ then expression (11) collapses to a linear regression model, such that the following equation holds true:

$$\pi_i = \alpha + \beta X_i + \gamma s_i + \epsilon_i \tag{12}$$

The expression in (11) collapses to a log-linear regression when $\lambda = 0$ as follows:

$$\ln(\pi_i) = \alpha + \beta \ln(X_i) + \gamma \ln(s_i) + \epsilon_i \tag{13}$$

To empirically run the regressions from (11) to (13), we obtained data on climate insurance (premiums paid, crop areas covered and average amount insured for 2006) from a database that is maintained by the Agricultural

Table 1 Estimation of the climate regulation model

	Equation		
	Linear	Natural log	Box–Cox transformation
Mean size of the insurance policy	0.0007*** (4.39)	0.57*** (7.79)	0.43*** (48.3)
Area of the ecosystem	−1.00 *** (−5.61)	−0.25***(−6.33)	−0.28*** (−35.3)
Constant	0.76*** (11.02)	−4.03*** (−11.10)	−3.61
Lambda			0.04 (0.58)
R^2	0.29	0.46	
Observations	146	146	146

OLS regressions. The dependent variable is RISK PREMIUM. *t*-statistic values are in parenthesis. ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively.

Insurance Commission (COMSA) in Chile.[6] This insurance covers losses that are caused by a lack or excess of rain, damaging winds, snow, hail and ice, and the insurance applies to operations in some valleys of Chile's regions I and III and regions V to X for a broad range of crops.[7] Data on forest coverage are employed from the Forestry National Corporation (CONAF),[8] and data on municipality areas are obtained from the National Institute of Statistics (INE).[9] Two municipalities (Limache and Ancud) are eliminated after controlling for outliers. The information used to calculate the variables π_i, X_i, and s_i is reported in Appendix along with summary statistics and data description.

The results for the three econometric specifications – the linear form, the logarithmic form, and the more general lambda-model of a Box-Cox regression – are reported in columns 2, 3 and 4 of Table 1, corresponding to Equations 12, 13 and 11, respectively. In addition, Table 2 reports the results of the likelihood-ratio tests for three standard functional specifications: multiplicative inverse ($\lambda = -1$), natural logarithmic ($\lambda = 0$), and linear ($\lambda = 1$).

As shown in Table 1, the econometric estimations render the correct positive sign for the mean size of the insurance policy and the correct negative sign for the area covered by forests in the three models estimated. Moreover, all the estimated coefficients are highly significant at the 1% level. However, in the Box-Cox transformation model (column 4), the lambda transformation does not significantly add to the regression. This last result is confirmed by Table 2, which shows that both the linear and multiplicative inverse specifications are strongly rejected; however, the natural logarithmic

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[6] www.comsa.gob.cl.

[7] Further details can be found at www.seguroagricola.com.

[8] www.conaf.cl.

[9] www.ine.cl.

Table 2 Likelihood ratio tests for three standard functional form specifications

Test Ho	Restricted Log likelihood	LR statistic chi^2	*P*-value Prob>chi^2
Lambda = −1	−104.7	174.0	0.00
Lambda = 0	−17.9	0.3	0.56
Lambda = 1	−88.7	141.9	0.00

specification cannot be rejected at the 5% cut-off point. Thus, the data render the natural logarithmic specification (column 3 in Table 1) as the best empirical model. With this model as a benchmark, Figure 1 is drawn free of the effect of 'mean policy' X_i and depicts the relationship between the log of π_i and the log of s_i and thus the log of the insurance premium paid for the climate insurance and the log of area covered by forest ecosystem, respectively.

3. Estimation of the insurance value of local climate regulation ecosystem service

The insurance value of local climate regulation ecosystem service $V(s)$ provided by the forest of area s is the functional form that links the risk premium π to the area s of the ecosystem as follows:

$$V(s) = -\frac{\partial \pi(s)}{\partial s} \tag{14}$$

The insurance value of the ecosystem size $V(s)$ evaluated at the mean value of the premium $\bar{\pi}$ and the ecosystem size $\bar{s}$ for the general form of the Box-Cox transformation in (11) is expressed as follows:

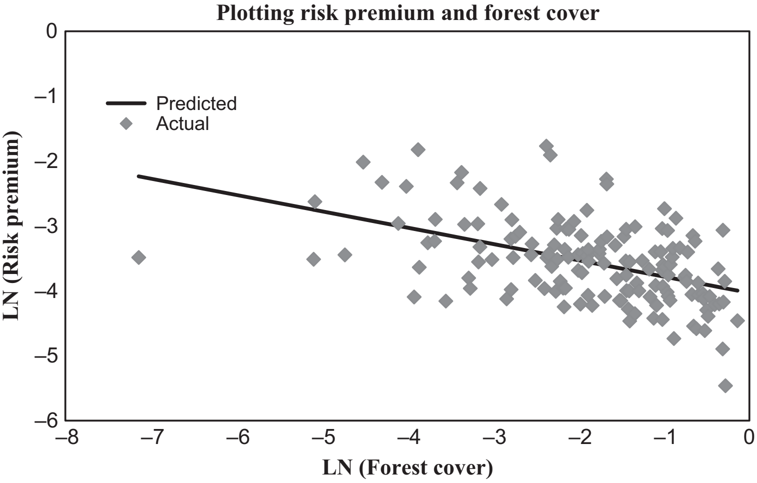

Figure 1 Scatter plot of area of forest ecosystems (in logs) and predicted and actual insurance premiums (in logs).

Table 3 Marginal and total value of local climate regulation service provided by forests in protected areas in Chile (UF, CH$ and USD)

	UF	CH$ 2010	USD 2010*
Marginal annual value per ha	0.0016	34.33	0.0733
Total annual value	4,256	91,315,191	194,972

*USD (2009) 1 = CH$ 468.37 (Central Bank of Chile).

$$V(s) = -\frac{\partial \pi(s)}{\partial s} = -\gamma \left(\frac{\bar{s}}{\bar{\pi}}\right)^{\lambda - 1} \tag{15}$$

Thus, using the results of the regression of the natural logarithmic model in column 3 of Table 2, we obtain $\lambda = 0$ and $\gamma = -0.25$; using our database, we obtain $\bar{s} = 28{,}701$ and $\bar{\pi} = 86.52$. Thus, the insurance value of local climate regulation is 0.25(86.52/28,702) = UF 0.0008, indicating that an additional hectare of forest ecosystem reduces the insurance premium amount paid by farmers by UF 0.0008 per year.[10] Moreover, because the average percentage of public subsidies for agricultural insurance policies in Chile is about 50% of the gross premiums paid, it is possible to estimate the total (a farmer's costs in addition to subsidy costs) absolute value of a marginal hectare of forest ecosystem in UF as 0.0016 per year. As an example, the total surface of the forests that are included in protected areas between the V and X regions of Chile (the regions in which most of the agricultural insurance is actually applied) is 2,659,924 hectares. Thus, the total value of the 'local climate regulation' service provided by the ecosystem forest in these protected areas is estimated to be USD 194,972 per year. Table 3 translates these marginal and total values to Chilean pesos (CH$) and North American dollars (USD) for 2010.

4. Conclusions

Despite the growing evidence of the influence of ecosystems and biodiversity on local, regional and global climate in the last decade, few insurance and environmental economics studies have investigated the role of ecosystems as insurance against extreme weather events. Moreover, there is no formal framework for estimating the economic value of the 'local climate regulation' ecosystem service as described by the specialised literature (Oke 1982, 1987; Heisler 1986 and MEA 2005; Bonan 2008). To our knowledge, this article is the first attempt to develop a formal economic framework to empirically estimating the insurance value of the local climate regulation provided by natural areas (forest cover specifically).

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[10] A UF (Unidad de Fomento) is an inflation-corrected constant unit of value that is used in Chile, and its (nominal) value was CH$21,454.86 on December 30, 2010. The exchange rate for the same date was US$468.37 per Chilean peso (source: Central Bank of Chile).

Empirical estimates of the marginal and total economic value (benefit) of climate variability regulation services are undoubtedly important for conservation as well as restoration policy evaluation and implementation. Using a survey of the insurance premiums paid by farmers in Chilean agriculture, we estimated the marginal value of one hectare of a forest ecosystem as a provider of local climate regulation in approximately US$ 0.0733. Although this marginal value may appear rather small, when it is applied to value the local climate regulation service provided by the natural forest ecosystems included in the National System of Protected Areas of Chile, the total annual flow is of US$ 194,951, an amount that seems to be consistent with ecosystems where climate effects are expected to be larger on a global scale rather than on a local scale. Thus, the theoretically consistent and expected quantitative estimations obtained in this study are interesting and useful because these results provide empirical evidence of the local climate regulation services provided by forest ecosystems. These findings are undoubtedly useful from a policy perspective because the economic valuation of these ecosystem services provides a benchmark that is necessary to assessing prospective social investments for protecting and/or restoring natural areas. Moreover, the results of this study clearly show that the economic value of local climate regulation ecosystem services, albeit small, differs from zero and may be significant for large ecosystem areas. Finally, this study also attempts to contribute to satisfying the urgent need to advance our understanding of the role of biodiversity and ecosystems in determining climate, especially local climate conditions (IPCC *et al.* 2007; The Royal Society 2008), for which objective empirical evidence is crucial.

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Appendix A

Table A1: Summary statistics

Original data by municipality	Mean	Max	Min	SD	*N*
Total insurance premium	277,800479	2315,7	3,5	412,086233	146
Total insurance subsidies	191,279486	1628,725	3,25	284,242883	146
Total insured area	163,33219	1525,95	1	250,479874	146
Number of insurance policies	38,6232877	365	1	61,7693307	146
Total insured value	6057,06055	51295,65	40,6	9440,47593	146
Native forest ecosystem area	19988,2432	281997,4	0	39895,1829	146
Exotic forest ecosystem area	8714,27884	93141,1	0	13795,859	146
Total municipality area	85846,9178	450350	6050	75850,6189	146
Total insurance subsidies	Sum of State subsidies given to farmers within a municipality to crop insurance premiums.				
Total insured area	Number of hectares covered by insurance policies.				
Number of insurance policies	Number of insurance policies contracted within the municipality area.				
Total insured value	Equals the production expected returns multiplied for two-thirds the insured area multiplied for the crop price.				
Native forest ecosystem area	Number of municipality hectares covered by native forests.				
Exotic forest ecosystem area	Number of municipality hectares covered by exotic forests.				
Total Municipality Area	Number of hectares existing within the municipality area.				

π_i: Total insurance premium per hectare paid in municipality i.

π_i = (Total insurance premium–Total insurance subsidy)/Total insured area.

X_i: Mean size of the insurance policy in municipality i.

X_i = Total insured value/Number of insurance policies.

s_i: Area covered by forest ecosystem as a proportion of the total area of municipality i.

s_i = (Native forest ecosystem area + exotic forest ecosystem area)/Total municipality area.