Economic Value of Weather Forecasting Systems Information: A Risk Aversion Approach[*]

by

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ABSTRACT

Extreme meteorological events have increased over the last decades and it is widely accepted that it is due to climate change (IPCC, 2007; Beniston et al., 2007). Some of these extremes, like drought or frost episodes largely affect agricultural outputs and risk management becomes crucial. The goal of this paper it is to analyze farmers' decisions about risk management, taking into account climatological and meteorological information. We consider a situation in which the farmer, as part of crop management, has available a technology to protect the harvest from weather effects. This approach has been used by Murphy et al. (1985), Katz and Murphy (1990 and 1997) and others in the case that the farmer maximizes the expected returns. In our model we introduce the attitude towards risk. Thus we can evaluate how the optimal decision is affected by the absolute risk aversion coefficient of Arrow-Pratt, and compute the economic value of the information in this context, while proposing a measure to estimate the amount of money that the farmer is willing to pay for this information in terms of the certainty equivalent.

***Key words*:** information value, cost-loss ratio, decision models, risk aversion.
***Classification JEL* :** C6.

RESUMEN

El número y la intensidad de los fenómenos meteorológicos extremos han aumentado en las últimas décadas, y es ampliamente aceptado que se debe al cambio climático. Algunos de tales fenómenos, como sequías o heladas, afectan mucho a los outputs agrícolas, por lo que la gestión del riesgo es crucial. El objetivo de este artículo es analizar las decisiones de los agricultores acerca de la gestión del riesgo, teniendo en cuenta la información climatológica y la meteorológica. Se considera una situación en la que el agricultor tiene a su disposición una tecnología para proteger la cosecha de los efectos meteorológicos. Este enfoque ha sido utilizado por Murphy et al. (1985), Katz y Murphy (1990 y 1997) y otros, en el caso en que el agricultor maximiza el beneficio esperado. En nuestro modelo se introduce la actitud hacia el riesgo. Así podemos evaluar cómo la decisión óptima viene afectada por el coeficiente absoluto de aversión al riesgo de Arrow-Pratt, y calcular el valor económico de la información en este contexto. Asimismo, se propone una medida para estimar la cantidad de dinero que el agricultor está dispuesto a pagar por esta información en términos de equivalencia cierta.

1. INTRODUCTION

Meteorological information affects agricultural production since it is able to change producers' decisions. Many farmers use weather forecasts to manage their activities, taking into account some meteorological variables to make better decisions when choosing the planting and harvesting time, the application of pesticides, and so on (McNew and Mapp, 1990). Cost-Loss analytical models constitute a theoretical approach to decisions under risk which are affected by weather. (See Clemen, 1996; Keeney, 1982; Winkler and Murphy, 1985; Winkler et al., 1983).

The uncertainty comes from some meteorological variable which depending on the specific case produces uncertain consequences. The meteorological forecasts help in the decision making altering the conditional probability associated to these events and the economic value of these forecasts can be considered as the difference between the expected value when an imperfect forecast is available and when just basic information exists there. The basic information most commonly accepted is the climatological information. That is, to assume that the agent knows the historical relative frequencies for the meteorological events those affect his activity.

What is commonly known as the "Cost-Loss Ratio Situation" model is a particularization of prototype decision models, in which an agent must decide between two actions: (i) to protect the harvest from an adverse meteorological situation, with a cost *C*, or (II) not to protect it and expose himself to a loss *L* if the adverse event takes place $\left(0 < C < L < \infty\right)$. Although this analysis can be applied to any agent whose activity is exposed to uncertainty, most of the literature on this particular decision making problem is addressed to the farmer's protection decision. See Katz and Murphy (1997) for a complete revision of these studies centred on crop management.

In the traditional cost-loss model, in its static version (Thompson, 1952, 1962; Thompson and Brier, 1955; Murphy, 1977), and also dynamic (Murphy et al., 1985; Katz and Murphy, 1990), an essential condition is assumed: the agent presents neutrality to the risk, which means that he minimizes the expected expense. However, agents are sensitive to risk, at least where important decisions are concerned, and not taking into consideration this attitude, could lead to wrong conclusions in some cases (Wilks, 1997). Some examples of maximization of expected utility in actual applied models have evaluated the frost forecasting for pear orchard production (Baquet et al., 1976), the precipitation forecast for pasturing in Oregon (Wilks and Murphy, 1985) or perfect forecasts of sea surface temperature anomalies for selected rain-fed agricultural locations of Chile (Meza et al., 2003).

In Section 2 we propose a model in which the risk attitude has been considered, and that allows us to evaluate how the optimal decision depends on the absolute risk aversion. It is assumed that individual preferences are represented by a CARA (Constant Absolute Risk Aversion) utility function.

Expected utility framework has been adopted for the risk aversion treatment. A first advantage is certainly its analytical convenience, but there is also a normative advantage in decision making problems. Expected utility may provide a valuable guide to action (Mas-Collel, 1995). Although the expected utility theory has been under attack since Allais paradox in the early 50's, however there are firm reasons for not rejecting it (Palacios-Huerta and Serrano, 2006).

In Section 3 the introduction of additional meteorological information is analyzed and we obtain the economic value of this information as welfare difference motivated by the forecast system. We also compute the amount of money that the farmer is willing to pay for this information in terms of the certainty equivalence. This analysis is shown in Section 4, and finally, Section 5 concludes the paper.

2. CLIMATOLOGICAL INFORMATION

2.1. The model

In this section the role of risk aversion is analyzed by considering that the farmer simply decides between protecting and not protecting his harvest. We formulate the model in a general form.

Let K be the value of portion of loss that the farmer is able to avoid by protecting the harvest, with a cost γK, where $0 < \gamma < 1$. We assume that the avoided loss is proportional to the total value of the harvest L, so $K = \alpha L$. Thus, $\alpha = 1$ (and $K = L$), if the farmer protects all the harvest, whereas $\alpha = 0$ (and $K = 0$), if he protects nothing. (We use this notation in order to develop a framework which allows the possibility of considering the continuous choice of α as part of future research).

Hence, while the protect versus not to protect decision is analyzed, the chosen frame is the cost-loss traditional model, including two possible states (adverse weather $\theta = 1$ or non adverse weather $\theta = 0$) and two possible actions for the farmer (protect, $\alpha = 1$, or do not protect, $\alpha = 0$). The cost of protection is γL and the total loss if there is no harvest is *L*. The payoff matrix is in Table 1.

Table 1. Payoff Matrix

	STATE OF NATURE	
ACTION	Adverse weather ($\theta = 1$)	Non adverse weather ($\theta = 0$)
Protect ($\alpha = 1$)	$-\gamma L$	$-\gamma L$
Not protect ($\alpha = 0$)	$-L$	0

In order to evaluate the risk influence over farmers decisions, and therefore to obtain the information value, we are going to analyze the decision considering the risk aversion, which provides one of the central concepts in economic analysis ((Mas-Collel et al. (1995)).

We assume that individual preferences can be represented by the expected utility with the utility function $U(\cdot)$, the CARA function (Constant Absolute Risk Aversion), being:

$$U(x) = -\exp\{-\rho x\}, \qquad (1)$$

where: x is monetary gains and $\rho > 0$ is the Arrow-Pratt coefficient of absolute risk aversion, which is constant for this function.

The Arrow-Pratt absolute risk aversion coefficient can be interpreted as the percentage change in marginal utility caused by each monetary unit of a gain or loss. (Raskin and Cochran, 1986). If the coefficient does not change across the monetary level, the decision-maker exhibits constant absolute risk aversion (CARA), which implies that the level of the argument of the utility function does not affect his or her decisions under uncertainty. Since ρ is not a non-dimensional measure of risk aversion, its value is dependent on the currency in which the monetary units are expressed (Gómez-Limón et al, 2003), and makes the comparison among different economic agents difficult. However, it remains a good measure for decision making problems involving a sole economic agent. This is suitable for the farmer's decision problem while the risk aversion remaining independent on the harvest value.

The optimal decision in this case is obtained maximizing the expected utility, which increases with the decrease of the expected expense. (That is the reason for writing the payoffs as negative monetary costs).

2.2. Solution and theoretical results

Climatological information consists of a single probability of adverse weather

$$P_\theta = \Pr\{\theta = 1\},$$

usually deriving from historical weather records. From a Bayesian perspective, the parameter P_θ can be viewed as the "prior probability" of adverse weather.

As we study the case of a risk averse farmer whose utility function is given by (1), all the elements relevant for the decision problem, including the payoff values of the farmer in accordance with the utility function, are collected in Table 2.

Table 2 Payoff values of the agent in accordance with the utility function.

	P_θ	$1-P_\theta$
	STATE OF NATURE	
ACTION	Adverse weather ($\theta = 1$)	Non adverse weather ($\theta = 0$)
Protect ($\alpha = 1$)	$-\exp\{\rho\gamma L\}$	$-\exp\{\rho\gamma L\}$
Not protect ($\alpha = 0$)	$-\exp\{\rho L\}$	-1

The optimal action to be chosen by the farmer in order to maximize the expected utility is given in the following proposition.

Proposition 1 *For the decision problem with risk, defined in Table 2, the optimal decision of the farmer considering the maximization of the expected utility criterion is*

- *Protect ($\alpha = 1$), if $A < P_\theta$. In this case the expected utility is* $EU(1) = -\exp\{\rho\gamma L\}$.
- *Do not protect (α=0), if $A > P_\theta$. In this case the expected utility is* $EU(0) = -P_\theta \exp\{\rho L\} + P_\theta - 1$.
- *Indifference between both actions if* $A = P_\theta$,

where $A = \dfrac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}}$.

Proof If protective action is taken ($\alpha = 1$), then the expected utility of the farmer is:

$$EU(1) = P_\theta U[-\gamma L] + (1-P_\theta)U[-\gamma L] = U[-\gamma L] = -\exp\{\rho\gamma L\}.$$

If protective action is not taken ($\alpha = 0$), then the expected utility of the farmer is:

$$EU(0) = P_\theta U[-L] + (1-P_\theta)U[0] = -P_\theta \exp\{\rho L\} + (1-P_\theta)[-\exp\{0\}] =$$
$$= -P_\theta \exp\{\rho L\} + P_\theta - 1.$$

Therefore, to take protective action is strictly better if

$$EU(1) > EU(0) \Leftrightarrow -\exp\{\rho\gamma L\} > -P_\theta \exp\{\rho L\} + P_\theta - 1 \Leftrightarrow \frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}} < P_\theta,$$

and in that case, the expected utility of the farmer is $EU(1) = -\exp\{\rho\gamma L\}$.

Similarly, not to protect (α = 0) is strictly better when $EU(1) < EU(0)$, and there is indifference between the two actions when $EU(1) = EU(0)$. ■

A being the probability threshold from which a farmer with constant absolute risk aversion and climatological information will protect the harvest from adverse weather, the optimal decision policy appears in Figure 1.

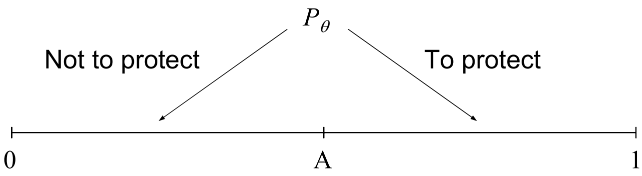

Figure 1. Optimal policy with climatological information and risk aversion

In the case of a risk neutral agent, it is optimal to protect the harvest whenever the cost per unit of loss to be avoided by protection is below the probability of suffering this loss (Murphy et. al., 1985), that is if $\gamma < P_\theta$. In Proposition 2 it is proved that $\gamma > \frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}}$ and therefore, it could happen that P_θ were in an interval, between A and γ. In that case, a risk adverse agent (with constant absolute risk aversion) will prefer to protect the harvest, although it would not be optimal for him to protect it in the event that he were risk neutral, thus minimizing the expected cost. Consequently, the risk adverse individual is more cautious and would take protection action in situations in which he would not take it if he were risk neutral.

Proposition 2 *The probability threshold values A and* γ*, (representing the threshold from which a risk-averse and a risk-neutral farmer respectively will protect his harvest from adverse weather when climatological information is available) verify that A <* γ*.*

Proof As

$$A = \frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}} = \frac{-\sum_{i=1}^{\infty}\frac{(\rho\gamma L)^i}{i!}}{-\sum_{i=1}^{\infty}\frac{(\rho L)^i}{i!}} = \frac{\gamma\sum_{i=1}^{\infty}\frac{\rho^i L^i \gamma^{i-1}}{i!}}{\sum_{i=1}^{\infty}\frac{(\rho L)^i}{i!}},$$ we have that

$$A<\gamma \Leftrightarrow \frac{\sum_{i=1}^{\infty}\frac{\rho^i L^i \gamma^{i-1}}{i!}}{\sum_{i=1}^{\infty}\frac{(\rho L)^i}{i!}}<1 \Leftrightarrow \sum_{i=1}^{\infty}\frac{\rho^i L^i \gamma^{i-1}}{i!}<\sum_{i=1}^{\infty}\frac{(\rho L)^i}{i!} \Leftrightarrow \sum_{i=2}^{\infty}\frac{\rho^i L^i \gamma^{i-1}}{i!}<\sum_{i=2}^{\infty}\frac{(\rho L)^i}{i!},$$ which is satisfied, because as $\gamma<1$, we have that $\frac{\rho^i L^i \gamma^{i-1}}{i!}<\frac{\rho^i L^i}{i!}, \forall i=2,3,4.....$

So, as always $\gamma<1$, it is satisfied that $\gamma>\frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}}$, as we wanted to prove. ■

In Proposition 3 we prove three interesting properties of the probability threshold *A* from which a farmer with constant risk absolute aversion will protect the harvest from adverse weather.

Proposition 3 $A=\frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}}$ *satisfies the following properties:*

(i) $\frac{\partial A}{\partial \gamma}>0,$

(ii) $\frac{\partial A}{\partial \rho}\le 0,$

(iii) $\lim_{\rho\to 0} A=\gamma.$

Proof (i) $\frac{\partial A}{\partial \gamma}=\frac{-\exp\{\rho\gamma L\}\rho L}{1-\exp\{\rho L\}}>0.$

(ii) $$\frac{\partial A}{\partial \rho}\le 0 \Leftrightarrow \frac{\partial A}{\partial \rho}=\frac{-\left[\exp\{\rho\gamma L\}\gamma L\right]\left[1-\exp\{\rho L\}\right]+\left[1-\exp\{\rho\gamma L\}\right]\exp\{\rho L\}L}{\left[1-\exp\{\rho L\}\right]^2}\le 0 \Leftrightarrow$$

$$\Leftrightarrow -\left[\exp\{\rho\gamma L\}\gamma L\right]\left[1-\exp\{\rho L\}\right]+\left[1-\exp\{\rho\gamma L\}\right]\exp\{\rho L\}L\le 0,$$

because $\left[1-\exp\{\rho L\}\right]^2>0$,

so $\frac{\partial A}{\partial \rho}\le 0 \Leftrightarrow \left[1-\exp\{\rho\gamma L\}\right]\exp\{\rho L\}\le \exp\{\rho\gamma L\}\left[1-\exp\{\rho L\}\right]\gamma \Leftrightarrow$

$$\Leftrightarrow \frac{\left[1-\exp\{\rho L\}\right]\exp\{\rho\gamma L\}\gamma}{\left[1-\exp\{\rho\gamma L\}\right]\exp\{\rho L\}} \leq 1.$$

Denoting $M = \frac{\left[1-\exp\{\rho L\}\right]\exp\{\rho\gamma L\}\gamma}{\left[1-\exp\{\rho\gamma L\}\right]\exp\{\rho L\}}$, we have that $\frac{\partial A}{\partial \rho} \leq 0 \Leftrightarrow M \leq 1$.

We can see that $M \leq 1 \quad \forall \gamma \in (0,1)$, because:

- M is an increasing function of $\gamma \in (0,1)$:

In fact:

$$M = \frac{\exp\{\rho\gamma L\}\gamma}{A\exp\{\rho L\}}, \quad \text{where } A = \frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}}$$

So, *A* depends on γ.

We know that *A*>0, and that $\frac{\partial A}{\partial \gamma} = \frac{-\exp\{\rho\gamma L\}\rho L}{1-\exp\{\rho L\}} > 0$.

So we have:

$$\frac{\partial M}{\partial \gamma} = \frac{\left[\exp\{\rho\gamma L\}\rho\gamma L + \exp\{\rho\gamma L\}\right]A\exp\{\rho L\} - \left[\frac{\partial A}{\partial \gamma}\exp\{\rho L\}\right]\exp\{\rho\gamma L\}\gamma}{\left[A\exp\{\rho L\}\right]^2} =$$

$$= \frac{\left[\exp\{\rho\gamma L\}\rho\gamma L + \exp\{\rho\gamma L\}\right] - \frac{1}{A}\frac{\partial A}{\partial \gamma}\exp\{\rho\gamma L\}\gamma}{A\exp\{\rho L\}} =$$

$$= \frac{\exp\{\rho\gamma L\}}{A\exp\{\rho L\}}\left[1 + \rho\gamma L - \frac{\gamma}{A}\frac{\partial A}{\partial \gamma}\right].$$

But as $\rho > 0$, $0 < \gamma < 1$ and $L > 0$ we have that

$\exp\{\rho\gamma L\} > 0$, $A > 0$ and $\exp\{\rho L\} > 0$.

We will see that $\left[1 + \rho\gamma L - \frac{\gamma}{A}\frac{\partial A}{\partial \gamma}\right]$ is also positive:

$$\left[1 + \rho\gamma L - \frac{\gamma}{A}\frac{\partial A}{\partial \gamma}\right] = 1 + \rho\gamma L + \gamma\frac{\left[1-\exp\{\rho L\}\right]}{\left[1-\exp\{\rho\gamma L\}\right]}\frac{\exp\{\rho\gamma L\}\rho L}{\left[1-\exp\{\rho L\}\right]} =$$

$$= 1 + \rho\gamma L + \frac{\rho\gamma L\exp\{\rho\gamma L\}}{1-\exp\{\rho\gamma L\}} = \frac{1-\exp\{\rho\gamma L\} + \rho\gamma L - \rho\gamma L\exp\{\rho\gamma L\} + \rho\gamma L\exp\{\rho\gamma L\}}{1-\exp\{\rho\gamma L\}} =$$

$$= \frac{-\left[\sum_{i=1}^{\infty}\frac{(\rho\gamma L)^i}{i!}\right]+\rho\gamma L}{-\left[\sum_{i=1}^{\infty}\frac{(\rho\gamma L)^i}{i!}\right]} = \frac{\left[\sum_{i=2}^{\infty}\frac{(\rho\gamma L)^i}{i!}\right]}{\left[\sum_{i=1}^{\infty}\frac{(\rho\gamma L)^i}{i!}\right]} > 0.$$

- In addition, we can see that if $\gamma = 1 \Rightarrow M = 1$.

M being an increasing function of γ, and *M* = 1 when $\gamma = 1$, we have that $M \le 1$.

So, $M \le 1 \Rightarrow \frac{\partial A}{\partial \rho} \le 0$, as we wanted to prove.

(iii) $\lim_{\rho\to 0} A = \lim_{\rho\to 0}\frac{1-\exp\{\rho\gamma L\}}{1-\exp\{\rho L\}} = \lim_{\rho\to 0}\frac{-\gamma L\exp\{\rho\gamma L\}}{-L\exp\{\rho L\}} = \lim_{\rho\to 0}\frac{\gamma\exp\{\rho\gamma L\}}{\exp\{\rho L\}} = \gamma.$ ■

In accordance with (i) in Proposition 3, the greater the cost to protect the harvest, the smaller the caution of the farmer. In (ii) we see that the greater the risk aversion, the smaller the probability threshold from which the agent protects the harvest. If the producer is highly adverse to the risk (ρ is very high), he will maximize his expected utility by protecting the harvest from adverse weather (making sure it will not suffer the loss if the weather is adverse) although the associated probability of that adverse situation (P_θ), is small. In (iii) we see that the behaviour of a farmer whose risk aversion tends to zero is similar to that of a risk neutral agent.

Example 1 In Table 3 it can be seen how propositions 2 and 3 apply for $L = 1$ and for parameters γ and ρ taking different values. The entries of the matrix correspond to the values of the threshold value *A*.

If for example $P_\theta = 0.45$ and $\gamma = 0,5,$ the risk neutral farmer does not protect. The risk averse farmer (with CARA function) does not protect if $\rho = 0,01$ or 0.1 but protects if $\rho = 0.5, \quad 0.8, \quad 1 \text{ or } 5,$ according to the values given in Table 3.

Table 3 Probability threshold from which the agent protects the harvest for different values of γ and ρ when L=1.

	$\rho = 0.01$	$\rho = 0.1$	$\rho = 0.5$	$\rho = 0.8$	$\rho = 1$	$\rho = 5$
$\gamma = 0.1$	0.099	0.099	0.079	0.068	0.061	0.004

$\gamma = 0.3$	0.299	0.290	0.249	0.221	0.204	0.024
$\gamma = 0.5$	0.499	0.488	0.438	0.401	0.378	0.076
$\gamma = 0.7$	0.699	0.689	0.646	0.613	0.590	0.218
$\gamma = 0.8$	0.799	0.792	0.758	0.731	0.713	0.364

Figure 2 display the "protect" and "do not protect" regions for a range of ρ, γ, and P_θ values.

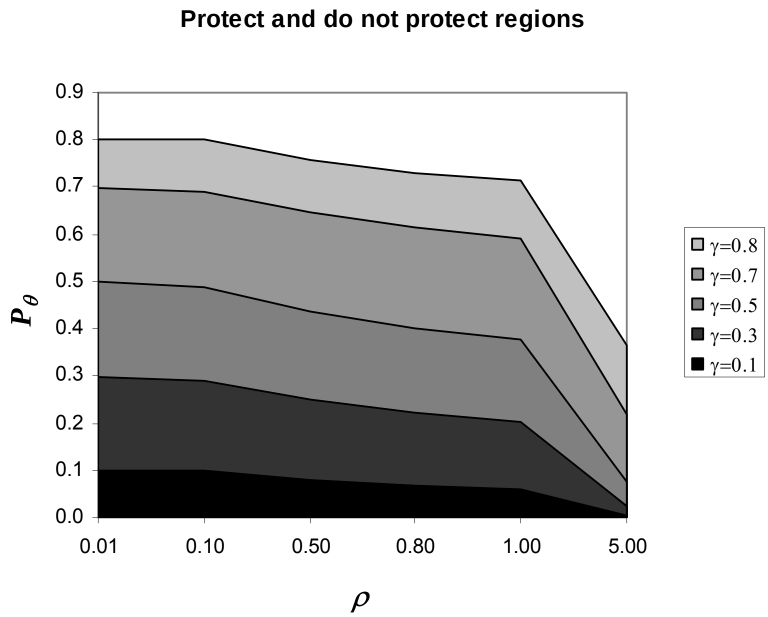

Figure 2. Protect and do not protect regions

3. FORECASTING INFORMATION

As in Murphy et. al. (1985), we consider the incorporation of additional information to the model. It is introduced as an imperfect weather forecasting from a meteorological office. The goal is to obtain the optimal decision rule in this context and also to quantify the economic value of such a forecasting system, considering the information value as the benefits of changing the farmer's behavior when he has this additional information available.

Let the random variable Z which indicates a forecast of adverse weather $(Z=1)$, or of non adverse weather $(Z=0)$ be introduced. The conditional probabilities of adverse weather are denoted by $P_1 = \Pr\{\theta = 1/Z=1\}$ and $P_0 = \Pr\{\theta = 1/Z=0\}$. In addition, as in Murphy et al. (1985) it is assumed that $\Pr\{Z=1\} = \Pr\{\theta=1\} = \mathrm{P}_\theta$, that is, the forecasting system produces adverse weather signals with the same probability that adverse weather events take place. Without loss of generality, $0 \le P_0 \le P_\theta \le P_1 \le 1$, is also assumed. In these conditions it is easily obtained that $P_0 = \dfrac{(1-P_1)P_\theta}{(1-P_\theta)}$. *

For the case of a risk averse farmer whose utility function is given by (1), all the elements relevant for the decision problem with imperfect information, in the context we have just defined are collected in Table 4.

The quality of information is defined in terms of the following index: $q = Corr(\theta, Z) = \dfrac{(P_1 - P_\theta)}{(1-P_\theta)}$.

The value of information is defined as

$$V = \text{Value of information} = EU(\text{with forecasting}) - EU(\text{without forecasting}),$$

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* $P_\theta = \Pr\{\theta=1\} = \Pr\{\theta = 1/Z=1\}\Pr\{Z=1\} + \Pr\{\theta=1/Z=0\}\Pr\{Z=0\} = P_1 P_\theta + P_0(1-P_\theta) \Rightarrow P_0 = \dfrac{(1-P_1)P_\theta}{1-P_\theta}.$

where *EU is* the value of the expected utility corresponding to the optimal decision in both cases (with and without forecasting). Specifically, *EU*(without forecasting) is the corresponding value obtained in Proposition 1.

$$EU(\text{with forecasting}) = EU(Z=1)\Pr\{Z=1\} + EU(Z=0)\Pr\{Z=0\}$$

it is the ex-ante(before a concrete forecast revealed) expected utility with forecasting.
It is interesting to obtain the value of information as a function of the quality of information *q*.

Table 4 . Payoff Matrix with imperfect information

	If $Z=1$		If $Z=0$	
	P_1	$1-P_1$	P_0	$1-P_0$
	STATE OF NATURE		STATE OF NATURE	
ACTION	$\theta=1$	$\theta=0$	$\theta=1$	$\theta=0$
$\alpha=1$	$-\exp\{\rho\gamma L\}$	$-\exp\{\rho\gamma L\}$	$-\exp\{\rho\gamma L\}$	$-\exp\{\rho\gamma L\}$
$\alpha=0$	$-\exp\{\rho L\}$	-1	$-\exp\{\rho L\}$	-1

In order to obtain the optimal decision rule of the farmer and also the value of the information we need to distinguish between two cases, as the expected utility of the optimal decision without forecasting enters in the calculation of the value of information.

3.1 Case in which $0 < A \le P_\theta$.

As has been proved in Proposition 1, where $A \le P_\theta$, if we consider a situation without forecasting (that is only climatological information is used), the optimal decision of the farmer is to protect and then $EU(\text{without forecasting}) = -\exp\{\rho\gamma L\}$.

In the following proposition the optimal action to be chosen by the farmer in order to maximize the expected utility in the case of incomplete information, as well as the value of information for this case are obtained.

Proposition 4 *For the decision problem with risk and incomplete information, defined in Table 4, assuming that* $0 < A \leq P_\theta$, *the optimal decison of the farmer considering the maximization of the expected utility criterion is:*

- *If* $A < P_0$, *to protect, whatever the signal is, and then the expected utility is* $-\exp\{\rho\gamma L\}$.
- *If If* $A > P_0$, *to protect if Z = 1 (the expected utility being* $-\exp\{\rho\gamma L\}$) *and not protect if Z = 0 (the expected utility being* $-P_0 \exp\{\rho L\} + P_0 - 1$).
- *Indifference between both actions if* $A = P_0$.

The value of information is

$$V(q) = \begin{cases} 0, & \text{if } q \leq q_A^* \\ (1-P_\theta)\left[\exp\{\rho\gamma L\} - 1\right] + P_\theta(1-P_\theta)\left[1 - \exp\{\rho L\}\right] - & \\ \qquad - q(1-P_\theta)P_\theta\left[1 - \exp\{\rho L\}\right], & \text{if } q > q_A^* \end{cases}$$

where $q_A^* = 1 - \dfrac{A}{P_\theta}$.

Proof Since the variable Z has two possible values, we have the following possibilities:

If $Z = 1$, as $P_1 \geq P_\theta$, then $A \leq P_1$, so the optimal decision is to protect and the expected utility is equal to: $-\exp\{\rho\gamma L\}$.

If $Z = 0$, as $P_0 \leq P_\theta$, there are two more possibilities:

(i) $A < P_0$. In that case, the optimal decision is to protect and the expected utility is also equal to $-\exp\{\rho\gamma L\}$.

(ii) $A > P_0$, where not to protect is optimal, with an expected utility of: $-P_0 \exp\{\rho L\} - (1 - P_0)$.

If $A = P_0$, the agent is indifferent between the two possible actions.

So, if $A < P_0$, the optimal decision is to protect if the information is $Z = 1$ and also to protect if the information is $Z = 0$, with the same expected utility that the farmer achieves without the forecasting system. So, in this case, meteorological information has no value because it does not affect the decision making.

If $A > P_0$, the optimal decision is different depending on the received information.

If $Z = 1$, the optimal decision is to protect and the expected utility is $-\exp\{\rho\gamma L\}$. If $Z = 0$, the optimal decision is not to protect and ex-ante expected utility is:

$$EU(\text{with forecasting}) = EU(Z=1)\Pr\{Z=1\} + EU(Z=0)\Pr\{Z=0\} =$$
$$= -P_\theta \exp\{\rho\gamma L\} + (1-P_\theta)\left[-P_0 \exp\{\rho L\} - (1-P_0)\right].$$

Accordingly, with $0 < A \le P_\theta$, and constant absolute risk aversion, meteorological information has positive economic value if and only if $A > P_0$. In this case, the economic value of the information, $V(q)$, is:

$$V(q) = \begin{cases} 0, & if \quad A \le P_0 \\ (1-P_\theta)\exp\{\rho\gamma L\} - (1-P_\theta)\left[1 - P_0\left[1-\exp\{\rho L\}\right]\right], & if \quad A > P_0 \end{cases}$$

Considering the information quality index $q = \dfrac{(P_1 - P_\theta)}{(1-P_\theta)}$, and the probabilities relation $P_0 = \dfrac{(1-P_1)P_\theta}{(1-P_\theta)}$, the information has economic value if and only if:

$$A > P_0 \Leftrightarrow A > \frac{(1-\left[q(1-P_\theta)+P_\theta\right])P_\theta}{(1-P_\theta)} \Leftrightarrow q > 1 - \frac{A}{P_\theta}.$$

Denoting: $q_A^* = 1 - \dfrac{A}{P_\theta}$, the economic value is positive if and only if $q > q_A^*$.

The economic value of the meteorological information can be expressed as a function of the quality index:

$$V(q) = \begin{cases} 0, & \text{if } q \le q_A^* \\ (1-P_\theta)\left[\exp\{\rho\gamma L\} - 1\right] + P_\theta(1-P_\theta)\left[1-\exp\{\rho L\}\right] - & \\ \qquad - q(1-P_\theta)P_\theta\left[1-\exp\{\rho L\}\right], & \text{if } q > q_A^* \end{cases}$$

There is a threshold, q_A^*, below which the forecast system does not improve the farmer's expected utility. This threshold increases with the absolute risk aversion coefficient of Arrow-Pratt ρ. So, with a more risk averse agent the information quality needed to influence his decision making is higher.

In fact, $\frac{\partial q_A^*}{\partial \rho} = \frac{\partial q_A^*}{\partial A}\frac{\partial A}{\partial \rho} = -\frac{1}{P_\theta}\frac{\partial A}{\partial \rho}$, where $\frac{\partial A}{\partial \rho} \leq 0$, as has been shown in Proposition 3, so necessarily: $\frac{\partial q_A^*}{\partial \rho} \geq 0$. The larger is the risk aversion, the higher is the quality threshold q_A^*. This result can appear as paradoxical, but it is meaningful that a highly risk averse farmer will not change the decision of protecting his harvest (obtaining a certain result), unless the information quality is very high.

In the $q > q_A^*$ interval, it is satisfied that

$$V'(q) = -\left(1 - P_\theta\right) P_\theta \left[1 - \exp\left\{\rho L\right\}\right] > 0,$$

so we have that $V(q)$ is strictly increasing throughout that interval.

To see how the information value depends on the absolute risk aversion coefficient ρ, when $q > q_A^*$, we have:

$$\frac{\partial V(q)}{\partial \rho} = \gamma L(1-P_\theta)\exp\left\{\rho\gamma L\right\} - P_\theta(1-P_\theta)L\exp\left\{\rho L\right\} + qP_\theta(1-P_\theta)L\exp\left\{\rho L\right\} > 0 \Leftrightarrow$$

$\Leftrightarrow \exp\left\{\rho L\left(\gamma - 1\right)\right\} > \frac{(1-q)P_\theta}{\gamma}$. That is, the value increases with ρ when $q > 1 - \frac{\gamma}{P_\theta}\frac{\exp\left\{\rho\gamma L\right\}}{\exp\left\{\rho L\right\}}$, and decreases below this level of quality. This is due to the fact that the threshold q_A^* increases with the risk aversion coefficient ρ, causing the information value changes to be zero when the risk aversion becomes higher nearby q_A^*. However, as we have seen, if the information quality is over that critical region (which happens if it exceeds the level $q = 1 - \frac{\gamma}{P_\theta}\frac{\exp\left\{\rho\gamma L\right\}}{\exp\left\{\rho L\right\}}$) is more valuable when the risk aversion is high.

Example 2 Let us consider the following values for the parameters: $\gamma = 0.3$, $L = 1$, $P \ = 0.4$ and ρ taking the values 0.1, 0.5 or 0.9.

For $\rho = 0.1$ it is obtained that $A = 0.289$ and $q_A^* = 0.034$.

For $\rho = 0.5$, the corresponding values are $A = 0.249$ and $q_A^* = 0.168$.

For $\rho = 0.9$, $A = 0.212$ and $q_A^* = 0.292$ are obtained.

In Figure 3 the critical region can be observed due to changes on the quality threshold from which individual decisions with an imperfect forecast are different to those in the case of simple climatological information; and how over this region, the information value increases with the risk aversion coefficient.

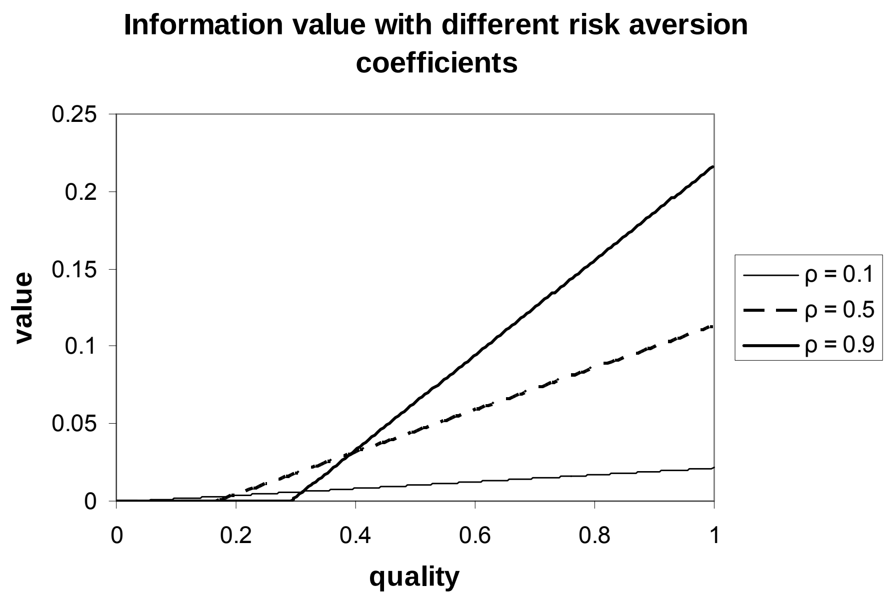

Figure 3. Quality-value curve for different values of ρ, where $\gamma = 0.3$, $L = 1$, and $P_\theta = 0.4$

3.2 Case in which $A > P_\theta$.

As has been proved in Proposition 1, when $A > P_\theta$, the optimal decision in a situation without forecasting (using just climatological information) is do not protect and then $EU(\text{without forecasting}) = -P_\theta \exp\{\rho L\} + P_\theta - 1$.

Proposition 5 *For the decision problem with risk and incomplete information, defined in Table 4, assuming that $P_\theta < A$, the optimal decison of the farmer considering the maximization of the expected utility criterion is:*

- *If $A > P_1$,* do not *protect, whatever the signal is.*
- *If $A < P_1$, to protect if Z = 1 (the expected utility being $-\exp\{\rho\gamma L\}$) and do not protect if Z = 0 (the expected utility being $-P_0\exp\{\rho L\} + P_0 - 1$).*
- *Indifference between both actions if $A = P_1$.*

The value of information is

$$V(q) = \begin{cases} 0, & \text{if } q \le q_B^* \\ P_\theta\left[\exp\{\rho L\} - \exp\{\rho\gamma L\}\right] + P_\theta(1-P_\theta)\left[1-\exp\{\rho L\}\right] - \\ \qquad - q(1-P_\theta)P_\theta\left[1-\exp\{\rho L\}\right], & \text{if } q > q_B^* \end{cases}$$

where $\quad q_B^* = \dfrac{A - P_\theta}{1-P_\theta}.$

Proof If the signal received is $Z = 0$, as $A > P_\theta \ge P_0$, the optimal decision is not to protect and the corresponding expected utility is $-P_0\exp\{\rho L\} + P_0 - 1$.

If the signal is $Z = 1$, as $P_\theta \le P_1$, there are two possibilities:

(i) $A < P_1$, in which case the optimal decision is to protect and the expected utility is $-\exp\{\rho\gamma L\}$.

(ii) $A > P_1$, in which case the optimal decision is not to protect and the expected utility is $-P_1\exp\{\rho L\} - (1 - P_1)$.

If $A = P_1$ the agent is indifferent between the two possible actions.

Therefore, if $A > P_1$, it is optimal not to protect, whatever the signal is, and the meteorological information has no value. If $A < P_1$, it is optimal to protect if the signal is

$Z=1,$ (the expected utility being $-\exp\{\rho\gamma L\}$) and not to protect if Z = 0 (the expected utility being $-P_0\exp\{\rho L\}+P_0-1$).

Assuming $A<P_1$,

$$EU(\text{with forecasting}) = EU(Z=1)\Pr\{Z=1\}+EU(Z=0)\Pr\{Z=0\}=$$
$$=-P_\theta\exp\{\rho\gamma L\}+(1-P_\theta)\left[-P_0\exp\{\rho L\}-(1-P_0)\right]=$$
$$=-P_\theta\exp\{\rho\gamma L\}+q(1-P_\theta)P_\theta\left[\exp\{\rho L\}-1\right]-(1-P_\theta)\left[P_\theta\exp\{\rho L\}+1-P_\theta\right].$$

The value of the meteorological information is zero if

$$A\geq P_1\Leftrightarrow A\geq P_\theta+q\left(1-P_\theta\right)\Leftrightarrow q\left(1-P_\theta\right)\leq A-P_\theta\Leftrightarrow q\leq\frac{A-P_\theta}{1-P_\theta}.$$

As by definition

$$V(q)=EU(\text{with forecasting})-EU\left(\text{without forecasting}\right),$$

substituting the expressions for the expected utilities the final expression for the value of information is obtained. ■

In this case we have:

$$\frac{\partial q_B^*}{\partial\rho}=\frac{\partial q_B^*}{\partial A}\frac{\partial A}{\partial\rho}=\frac{1}{1-P_\theta}\frac{\partial A}{\partial\rho}\leq 0,\text{ because }\frac{1}{1-P_\theta}>0\text{ and }\frac{\partial A}{\partial\rho}\leq 0.$$

Therefore, the larger is the risk aversion, the smaller is the quality threshold q_B^*. This result is reasonable, taking into account that when $A>P_\theta$, the optimal decision with simple climatological information is not to protect. Then, the larger is the risk aversion of the farmer, the smaller are the conditions for a change to protection.

In the $q>q_B^*$ interval, it is satisfied that

$$V'(q)=-\left(1-P_\theta\right)P_\theta\left[1-\exp\{\rho L\}\right]>0,$$

so we have that, as in the previous case, $V(q)$ is strictly increasing throughout that interval.

In the $q > q_B^*$ interval, we have

$$\frac{dV'(q)}{d\rho} = (1 - P_\theta)P_\theta L \exp\{\rho L\} > 0.$$

Therefore in this case, if $\rho_1 > \rho_2$, for $q > q_B^*$, the value of the inforamtion $V(q)$ corresponding to ρ_1 is always larger than the value of the information $V(q)$ corresponding to ρ_2.

Example 3 Let us consider the following values for the parameters: $\gamma = 0.3$, $L = 1$, $P = 0.2$ and ρ taking the values 0.1, 0.5 or 0.9.

For $\rho = 0.1$ it is obtained that $A = 0.289$ and $q_B^* = 0.111$.

For $\rho = 0.5$, $A = 0.249$ and $q_B^* = 0.061$.

For $\rho = 0.9$, $A = 0.212$ and $q_B^* = 0.015$ are obtained.

In Figure 4 the quality-value curves for the different values of ρ are plotted.

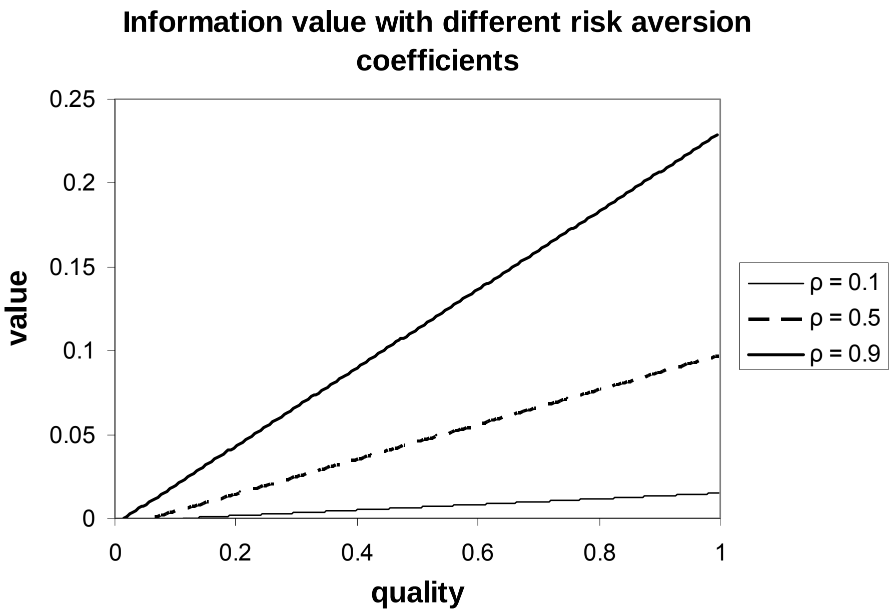

Figure 4. Quality-value curve for different values of ρ, where $\gamma = 0.3$, $L = 1$, and $P_\theta = 0.2$

The economic value, as defined in the literature, is measured in welfare or utility units. A consequence of the expected utility form, as a Von Neumann-Morgenstern (v.N-M) expected utility function is that differences of utilities have meaning and the ranking of utility differences is preserved by all linear transformations of the v.N-M expected utility function (Mas-Collel et al., 1995). However, a linear transformation of the utility function would represent the same preferences but would provide different values for V(q). In order to be able to compare between different agents we have also analysed the information value in terms of the monetary gains.

4. MONETARY GAINS

In order to achieve a monetary value unchanging with linear utility transformations to compute the amount of money that farmers will pay for the forecast service, we have considered the certainty equivalence approach. The certainty equivalent (*CE*) can be defined as the amount of money for which the farmer is indifferent between the gamble and the certain amount *CE* (Mas-Collel et al., 1995), that is the amount of money producing the same utility without uncertainty as the expected utility when the risk exists (See Figure 5).

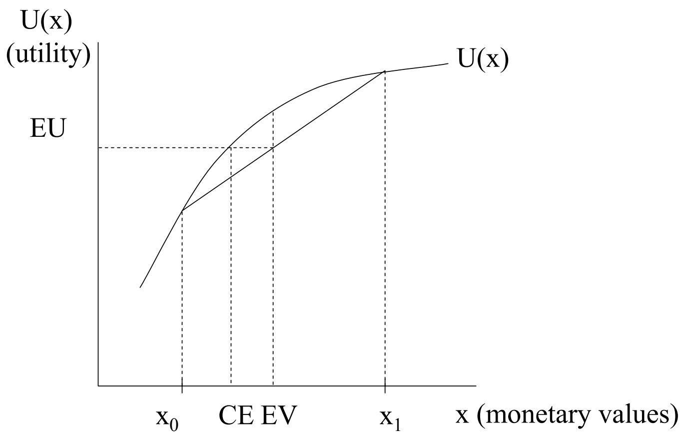

Figure 5. Expected value (EV), expected utility (EU) and certain equivalent (CE)

We define the monetary gains (*MG*) for a farmer, as the difference in certain equivalent due to the introduction of forecasting information, that is: *MG* = *CE*(with forecasting)-*CE*(without forecasting). Proposition 6 shows the monetary gains of the information.

Proposition 6: *The monetary gain of a forecast defined as the difference between CE(*with forecasting*) and CE(*without forecasting*) can be computed as:*

(i) *If* $0 \le A \le P_\theta$, *the monetary gain is:*

$$MG(q) = \frac{\ln\left[P_\theta \exp\{\rho\gamma L\} + (1-P_\theta) - P_\theta(1-\exp\{\rho L\})[1-q(1-P_\theta)+P_\theta]\right]}{-\rho} + \gamma L$$

(ii) *If* $A > P_\theta$, *the monetary gain is:*

$$MG(q) = \frac{\ln\left[\frac{P_\theta \exp\{\rho\gamma L\} + (1-P_\theta) - P_\theta(1-\exp\{\rho L\})[1-q(1-P_\theta)-P_\theta]}{1-P_\theta(1-\exp\{\rho L\})}\right]}{-\rho}$$

Proof.

*(i).*Considering the case in which the economic value of information has a positive value we shown in proposition 4 that:

$EU(\text{with forecasting}) = -P_\theta \exp\{\rho\gamma L\} + (1-P_\theta)\left[-P_0 \exp\{\rho L\} - (1-P_0)\right].$

Therefore, the monetary gain producing the same utility as the expected utility under uncertainty, should satisfy: U[CE(with forecasting)]= -exp{-ρ[CE(with forecasting)]}=

$= -P_\theta \exp\{\rho\gamma L\} + (1-P_\theta)\left[-P_0 \exp\{\rho L\} - (1-P_0)\right].$

So, CE(with forecasting)= $\dfrac{\ln\left[P_\theta \exp\{\rho\gamma L\} - (1-P_\theta)[-P_0 \exp\{\rho L\} - (1-P_0)]\right]}{-\rho}$

Also for this case, we have that: $EU(\text{without forecasting}) = -\exp\{\rho\gamma L\}$.

And thus, the CE without forecasting should satisfy: U[CE(without forecasting)]= -exp{-ρ[CE(without forecasting)]}= $EU(\text{without forecasting}) = -\exp\{\rho\gamma L\}$.

So, CE(without forecasting)]=-γL

As we have characterized the monetary gain of the information (MG) as:

$MG(q)$= CE(with forecasting)-CE(without forecasting)=

$$= \frac{\ln\left[P_\theta \exp\{\rho\gamma L\} - (1-P_\theta)[-P_0 \exp\{\rho L\} - (1-P_0)]\right]}{-\rho} - (-\gamma L) =$$

$$= \frac{\ln\left[P_\theta \exp\{\rho\gamma L\} + (1-P_\theta) - (1-P_\theta)[P_0(1-\exp\{\rho L\})]\right]}{-\rho} + \gamma L =$$

And considering $P_0 = \dfrac{P_\theta[1-(q(1-P_\theta)+P_\theta)]}{1-P_\theta}$, we have:

$$MG(q)=\frac{\ln\left[P_\theta \exp\{\rho\gamma L\}+(1-P_\theta)-P_\theta(1-\exp\{\rho L\})[1-q(1-P_\theta)+P_\theta]\right]}{-\rho}+\gamma L$$

(ii) Considering the case in which the economic value of information is positive, we have shown in Proposition 5 that:

EU(with forecasting)=

$= \quad -P_\theta \exp\{\rho\gamma L\}+q(1-P_\theta)P_\theta\left[\exp\{\rho L\}-1\right]-(1-P_\theta)\left[P_\theta \exp\{\rho L\}+1-P_\theta\right]=$ *U*[*CE*(with forecasting)].

So, $CE(\text{with forecasting})=\frac{\ln\left[P_\theta \exp\{\rho\gamma L\}+(1-P_\theta)-P_\theta(1-\exp\{\rho L\})[1-q(1-P_\theta)-P_\theta]\right]}{-\rho}$.

And, $EU\left(\text{without forecasting}\right)=-P_\theta \exp\left\{\rho L\right\}+P_\theta-1$.

U[*CE*(without forecasting)]= $EU\left(\text{without forecasting}\right)=-P_\theta \exp\left\{\rho L\right\}+P_\theta-1$.

So, $CE(\text{without forecasting})=\frac{\ln\left[1-P_\theta(1-\exp\{\rho L\})\right]}{-\rho}$

MG(q)= *CE*(with forecasting)-*CE*(without forecasting)=

$$=\frac{\ln\left[\frac{P_\theta \exp\{\rho\gamma L\}+(1-P_\theta)-P_\theta(1-\exp\{\rho L\})[1-q(1-P_\theta)-P_\theta]}{1-P_\theta(1-\exp\{\rho L\})}\right]}{-\rho}$$ ■

Figure 6 shows a comparison between the monetary and the economic value in the case $0<A\le P_\theta$.

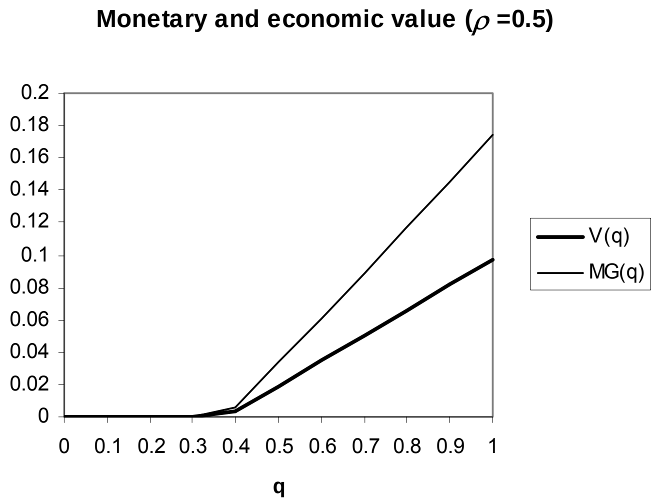

Figure 6. Monetary and economic value if $0<A\le P_\theta$. where $\gamma=0.3$, $L=1$, and $P_\theta = 0.4$

5. CONCLUSIONS

Many National Meteorological and Hydrological Services (NMHS) programs face limited budgets, and economic analysis, can be a helpful tool for justifying programs. (Lazo et al., 2007). Economic assessment of the value of such services often carries significant weight for policy decision making and budget setting. In this paper, the optimal decision of a farmer whose preferences are represented by a CARA utility function is obtained, in the context of cost-loss decision models under risk. The introduction of risk aversion changes the behavior of the farmer. In this context, we have computed measures of how much better off a decision maker is with or without a forecasting system, achieving the value of meteorological information. A positive relation between the information value and risk aversion has been underlined, so considering neutral agents in the type of decisions analyzed underestimates the value of meteorological information.

However, the information has zero economic value below a quality threshold, which is higher in the case of risk aversion, at least in certain important cases. So, evaluating the relevance of a higher quality information system, we conclude that a forecast system whose quality is very low, does not offer an added value for the decision making with respect to the simple statistical or historical information (that is climatological information). Accordingly, an improvement in the information quality highly increases its worth in all cases, if it improves the level in which the farmers take it into account when making their decisions. We have also computed the amount of money that the farmer saves due to improved information and it is also increasing with the quality of the forecasting service. As mentioned, showing net positive economic benefits of the information provided is critical for justifying the budgets for some important meteorological services oriented to increasing the information quality.

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