**Quantifying the Value to the Farmer of Adopting Climate Change Resilient Technologies: Evidence from the Agricultural Sector in Uruguay.**

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**Abstract**. Technology adoption and innovation are some of the alternatives firms have to adapt to variability and climate change. In the agricultural sector, for example, farmers seek to generate climate resilient production systems by innovating in input-based or process-based technologies, which impacts on productivity and production costs. Of significant interest, are those technologies inducing a reduction in variability of productivity. However, typical feasibility analyses do not consider the economic benefits arising from the higher revenue stability. We evaluate adaptation technologies for two agricultural activities, summer crops and livestock production in Uruguay, using an expected utility approach, and monetarily quantify the value to the farmer of the induced average revenue increase, but also of the productivity variability reduction. We find there is a relatively high value a risk adverse farmer assigns to the lower volatility, amounting to 7%-39% of the total value assigned to the use of the corresponding adaptation technology.

Key words: *Adaptation, expected utility, crop production, irrigation, livestock production, natural rangelands*

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**Quantifying the Value to the Farmer of Adopting Climate Change Resilient Technologies: Evidence from the Agricultural Sector in Uruguay.**

1. Introduction

Climate conditions play a salient role in agricultural production due to its high dependence on weather variables. Farmers and policy makers seek to develop strategies for adaptation to climate change and variability. Their objective is the development, promotion, and adoption of production technologies and innovations that reduce the annual variability of physical productivity, resulting in more resilient production systems.

The income (annual) volatility, which is a result of the exposition of production systems to volatile factors such as climate, pests and prices, create an uncertain environment to the farmers that negatively affect their production and investment decisions. Behind this statement lies the perception that farmers dislike risk (i.e., are risk averse) as shown by early studies (Binswanger 1980). The introduction of production practices that turn production systems more resilient to variability and climate change, have a direct and positive impact on expectations and generate a preferable business environment. In some cases, the benefits of these technologies are not restricted to the reduction in the volatility of the productivity; they also induce an increase in its average value.

While it seems straightforward to evaluate and observe the monetary benefits associated to the higher average productivity, it is more difficult to document the benefits associated to their lower volatility. We argue that efforts focused on quantifying the latter, positively impact the adoption of these types of technologies, for example, by informing and supporting promotion and extension activities.

A vast literature on economic decisions under uncertainty can be applied to this context, in particular, the seminal work in agricultural and resource economics by Dillon (1971) and Just and Pope (1978), and more recently by Moschini and Hennessy (2001), Quiggin and Chambers (2006), and Bocquého et al. (2013). In general, these methodologies allow the evaluation of competing risky activities, by factoring into the farmer´s decision both the risk embedded and the potential average values of the productivity.

The key contribution of our study is to show how these methodologies can be applied in the context of technologies for adaptation to variability and climate change. We compare the risky profits of an activity with and without the adoption of the adaptation technology of interest. We apply the Expected Utility framework (von Neumann and Morgenstern, 1944) using a Constant Absolute Risk Aversion (CARA) utility function and rely on the concept of certainty equivalent to quantify the value to the farmer of producing with and without the technology. Finally, by comparing the results of both states, we conclude about the degree to which such adoption is more or less valued by the farmer, distinguishing the value due to the higher mean productivity from that one coming from its lower volatility.

We show an application to two agricultural production activities for which adoption of adaptation technologies are currently being promoted by the Uruguayan government and private organizations. The first application is the use of supplemented irrigation in summer crops. While Uruguay has an annual rainfall of about 1100 mm in average, allowing to grow rainfed crops, it has a significant inter-annual variability and an important uncertainty on rainfall levels during the summer. When supplemented irrigation is introduced, a significant increase in average yields and a reduction in their annual volatility is expected, with a direct impact on the economic profitability of the crop. As a result, the area of supplemented irrigation has been increasing since the mid-2000´s. For example, irrigated area of soybeans, corn, and sorghum doubled between 2017 and 2011. They account for only 2% of the total area of these crops, implying that there is a significant room for expansion. Most of this expansion comes from pressured irrigation, particularly pivots. For example, before 2006 there were only 12 pivots registered in the country, but they increased to 166 in 2011 (irrigating about 10,300 ha) and to 411 in 2017 (irrigating about 25,590 ha), according to official statistics (MGAP-DIEA 2018).

Typical methodologies used to assess the feasibility of irrigation technology at the farm level, such as net present value and internal rate of return, only consider the benefits arising from the higher average, but they leave the reduction in their volatility unconsidered. Some studies are Tavakoli et al. (2010) for Iran, Yuan et al. (2003) for China, Marra and Woods (1990) for Maine in the United States, and Rosas et al. (2014) for Uruguay. To the best of our knowledge, exceptions are Pandey (1990) and Apland et al. (1980) who use a different methodological approach to deal with risk, and Gelós (2016) for Uruguay, who focuses on only one crop (corn) and does not analyze the sensitivity of the results to different production systems or locations.[[1]](#footnote-1)

The second application of this paper evaluates a process-based technology applied to livestock production on natural rangelands in Uruguay. It consists of managing livestock with a higher supply of natural grass per head and unit of land, which has proven to reduce livestock exposition to extreme climatic events, droughts in particular, yielding a more resilient production system. Early work by Mott (1960), Jones and Sandland (1974) and Petersen et al. (1965) characterized the behavior of livestock productivity as a function of the stocking rate, concluding that after a threshold (time-dependent), productivity starts to decrease. This technology, validated both at the experimental and commercial levels in Uruguay (Scarlato 2017 and Soca 2017), Argentina (Beeskow et al. 1995), and Brazil (Borges et al. 2016, Barbieri et al. 2014, Jochims 2013, Cruz et al. 2010), results in an increase in average livestock productivity and a reduction in its annual variability when compared to the alternative management strategy. The latter implies managing livestock with higher stocking rate and reducing it only when the observed corporal condition of the animal deteriorates (weight loss) due to lower grass supply, caused by adverse climate conditions (reduction in rainfall or droughts).

For exposition purposes, we refer to “reactive” farmers as those who react (by decreasing the stocking rate) to observed corporal condition deterioration, which may occur too late in cases of severe droughts, leading to high mortality rates. On the other hand, adopting farmers are referred to as “proactive.” While assessments of the value to the farmer of the reduced volatility in productivity are rarely available, research-based evidence of its positive impact on average physical productivity has been mounting over recent years (Soca et al. 2002, Soca et al. 2013a, Soca et al. 2013b, Becoña et al. 2014, Modernel et al. 2016, Claramunt et al. 2017).

Finally, the two technologies under study belong to a broader strategy of adaptation to variability and climate change in the agricultural sector stated in the Uruguayan climate change policy (ROU-PNCC 2017) and in the Uruguayan First Nationally Determined Contributions to the 2015 Paris Agreement (ROU-NDC 2017). In this sense, this study contributes to support private and public initiatives with empirical evidence of the economic convenience of the adoption of these adaptation technologies.

1. Methodology

Consider an individual with two alternative production technologies *j*. One technology which features a reduction of vulnerability of the production activity to climate variability, hereafter referred as “adaptation technology” (AT). The other, does not provide vulnerability reduction and will be referred hereafter as “no adaptation technology” (NAT).

Each technology implies a stream of uncertain profits with different mean and standard deviation. The expected utility of the profits of using alternative *j* is:



where  is the stochastic function of profits of alternative *j*, with *j =* {NAT, AT}. Profits are stochastic because prices  and the per hectare production  are unknown at the moment production decisions are made. Variable depends on a random climate variable (), that links climate conditions to production (see details in the next section). Prices belong to the interval  and are unknown at the planting decision moment. Prices and per-hectare production are correlated events and characterized by a joint density function .

Given that the daily percentage change of commodity prices can be approximated by a Normal distribution, we assume that the variable in levels has a Lognormal distribution (Hull 2009, p. 271),  . We approximate the marginal density of yields per hectare, , for both technologies, using non-parametric methods and historical data on irrigated crops and of a livestock simulation model (see details in the next section). The expectations operator (*E*) is taken with respect to both random variables. The variables *X* and *PX* are deterministic quantities and prices of inputs, as they are known variables.

Function *U*(.) is a concave twice continuously differentiable utility function which we approximate with a Constant Absolute Risk Aversion (CARA) function. This function has an uncertain terminal wealth , where, being  the random profits and *W0* the deterministic initial wealth. The CARA utility function takes the form:



where *r* is the absolute risk aversion coefficient (*ara*) that measures the individual’s degree of risk aversion.[[2]](#footnote-2) As risk aversion increases, the likelihood that individuals implement adaptation technologies also increases, as higher average profits with less dispersion bear a higher level of utility. In other words, the risk premium[[3]](#footnote-3) increases, as risk averse individuals are willing to pay a higher premium to avoid profit uncertainty. For the CARA utility function, the risk premium takes the form .[[4]](#footnote-4) We follow the methodology by Babcock et al. (1993), Babcock and Hennessy (1996), and Hennessy et al. (1997) to report results, expressing the risk premium for different values of *ara*, as a percentage of the standard deviation of the random profits.[[5]](#footnote-5)

To compare the value (or utility) the farmer gets by choosing whether or not to adopt a technology resilient to climate variability, we rely on the concept of certainty equivalents (*CE*). The *CE* is the certain amount of monetary that leaves the farmer with the same utility level as facing a risky gamble. It is computed as . It negatively depends on the risk premium, i.e. the riskier the activity and/or the higher the risk aversion of the farmer, the lower the certainty equivalent. As adaptation technologies imply higher average and more stable profits, the *CE* for the farmer adopting is likely to be higher than that of the farmer choosing otherwise.

We compute the *CE* of the random profits obtained when applying (*CEat*) and not applying (*CEnat*) the adaptation technology, and represent the *total additional value* to the farmer of adoption as a percentage change. Remarkably, this additional value comes on the one hand by the higher average profits, and on the other, by the lower profit volatility. To make this decomposition, we first create a stream of profits with the mean of the profits obtained when applying the adaptation technology but with the volatility that would have been obtained otherwise. The *CE* of these profits is denoted as *CEat2* and, when compared to *CEnat*, yields the portion of the total value of using the adaptation technology attributed to the higher average, namely . The rest corresponds to the value attributed to the lower volatility.

1. Data simulation and sources

In this section, we describe the data used in both applications and their sources.

*Data simulation and sources for crop production*. For this application, we construct a series of representative scenarios of typical Uruguayan conditions. Firstly, scenarios differ by soil agricultural aptitude. We rely on the CONEAT index, a productivity index extensively used in Uruguay, such that index values greater (lower) than 160 imply high (medium) aptitude. Secondly, we distinguish by distance to the port, as closer farms have the incentive to produce export-oriented crops (e.g. soybean). Short (high) distance is less (more) than 150 kilometers from the Nueva Palmira Port.[[6]](#footnote-6) Thirdly, we distinguish between farms that have crop production as their main source of revenue from those with a completely integrated crop-livestock production system. Finally, scenarios differ by crop prices as they impact profitability, but due to space constrains, we only use medium-level prices.[[7]](#footnote-7)

Each scenario is characterized by a crop rotation or sequence typically observed in each set of conditions, complying with existing regulations on soil use and management implemented by the environmental and agricultural authorities. Supplementary material 1 shows the crop rotations by scenario.

To characterize the yield marginal density function of crop *j*,, we begin by detrending a time-series of annual observed non-irrigated yields (MGAP-DIEA). We then multiply the series by the average yields between 2011-2014, and following DiNardo and Tobias (2001), we fit a non-parametric density function[[8]](#footnote-8) to the detrended series. Then we draw 5000 random deviates by Monte Carlo simulations, which represent the uncertain yields farmers face. We conduct this exercise for soybean as first and second crop (S1, S2), corn as first and second crop (M1, M2), and wheat (W), which are the crops we use in the scenarios presented in this paper.[[9]](#footnote-9) Finally, we change the support of the density function (its mean and range) such that the descriptive statistics match those registered in the conditions we seek to represent. This transformation is calibrated with observed data of non-irrigated crops of commercial farms.[[10]](#footnote-10)

We do not observe long enough historical time-series of irrigated crops as we do for rain-fed systems, as supplemented irrigation expanded only recently. To solve this, we take the draws of rain-fed crop *j* and transform its support to match the observed statistics (mean, standard deviation, coefficient of variation, minimum and maximum) of the surveyed commercial farms for each desired scenario. Finally, we generate 5000 random draws by Monte Carlo simulations.

Using historical price time-series of each crop *j*, taken from Index Mundi and “Cámara Mercantil de Productos del País” (CMPP) in Uruguay, we compute their implicit volatility. We then generate random deviates from a Lognormal distribution with mean equal to the price of crop *j* in the corresponding scenario and variance equal to the computed implicit volatility. Prices of crop *j* are drawn to be correlated with yields, as captured by the joint density function , using the approach proposed by Johnson and Tenenbein (1981) to correlate bivariate distributions.

Crop *j* costs (inputs, farm hired labor, irrigation costs, post-harvest costs, cost of water, and irrigation equipment recovery in a 12 years lifetime) are obtained from observed data on commercial farms, for each scenario (see footnote #10).[[11]](#footnote-11)

We compute the random profit for each rotation and plug it in equation (2) to calculate the corresponding *CE*.

*Data simulation and sources for Livestock production.* In this application, the farmer productivity is the random variable , which is obtained from simulations of the Model of Extensive Livestock Operation (MEGANE) developed by the Agricultural Plan Institute of Uruguay (Dieguez, 2012). MEGANE is a biophysical deterministic dynamic model that relates livestock weight with natural grass growth. It has been extensively used for extension and policy analysis; some examples are MGAP-FAO (2013a), MGAP-FAO (2013b), and Dieguez (2012).

Remarkably, the model embeds relationships calibrated with experimental data, and allows users to vary farm management decisions by changing model parameters. As a result of the simulation, it generates a set of output variables, namely height of pasture, pregnancy rate, weight of calves and discarded cows at selling time, and number of sheep, that we use to compute the random profits for both proactive and reactive farmers.[[12]](#footnote-12) Supplementary material 4 presents a detailed description of the model.

A key input variable of the model is a climatic coefficient (*coefclima*,) that establishes the link between climate and grass growth, influencing the development of livestock categories. The coefficient is centered around 1, and higher (smaller) values imply a more (less) favorable climate for grass growth. The values of  were obtained from the average dry matter growth rate (DMGR in kgDM/day/ha) of the eco-zone Basaltic Cuesta[[13]](#footnote-13) from March 2000 to February 2016, provided by the Regional Laboratory of Remote Sensing of the University of Buenos Aires (LART). The observed values of are computed as the deviation of the *DMGR* of station *i* in period *t* relative to its historical average:



We run the model on simulated values of the climatic coefficient , calibrated using their observed counterparts, . Monthly random deviates of were drawn by Monte Carlo simulations following Dieguez and Terra (2014). Briefly, we first take a draw from a Normal distribution with mean zero and standard deviation *DE*, to represent the first month. We obtain the following months as:



where *a*t is the historical autocorrelation of the observed variable of the involved months *t* and (*t*+1), *b*t is such that , and *N*(0,*DE*). As it is a lineal combination of Normal distributions,  is also Normal, with mean one and standard deviation DE, and therefore, the Normal distribution and the historical correlation between and are approximately maintained. We set *DE* = 1.75 and generate climatic coefficients for 30 years. We then use quantile matching to obtain the simulated climatic coefficient based on the observed series of climatic coefficient of the desired eco-zone, [[14]](#footnote-14) and normalize it to be centered around 1. See supplementary material 5 for details.

Other key inputs to MEGANE include farm area, number of cows and sheep, initial livestock weight, and initial grass height, while the rest of the variables are endogenous to the model.

For this application, we assume a farmer devoted to the commercial breeding of cows and sheep on natural rangelands. Although there may be other production activities, we restrict the revenues to the sale of weaned calves, discarded cows, and sheep meat and wool.

A reactive (proactive) strategy of rangeland management implies in this paper an average stocking rate of 1.10 (0.8) livestock units per hectare (LU/ha), cows with initial live weight of 320kg (350kg), initial grass height of 5cm (7cm), and a sheep/cow ratio of 4:1 (1:1). These initial values are extracted from MGAP-FAO (2013b) and are summarized in Table S.6 in supplementary material 5. The proactive farmer owns a total of 700ha with 500ha dedicated to cow breeding. The categories are calves, “cows in service” (“cows of more than one offspring,” “heifers of first offspring,” “heifers of one and two years,” and weaned heifers), and sheep. The weaned heifers and “heifers of one and two years” are the replacement for “cows in service”. To simplify the presentation, our simulation focuses on “cows of more than one offspring” and calves. Incorporating profits of the remaining categories does not affect our final conclusions.

The production cycle starts with the summer breeding of the “cows in service.” The model computes an average pregnancy rate based on the average weight of the herd and grass height. The pregnant cows continue their gestation period towards the next season (fall) gaining or losing weight, while the failed cows are discarded from the herd and send to finishing to be sold in summer.[[15]](#footnote-15) In spring, cows have their offspring, switching category to “cows with calves” and therefore their weight equation gain also changes. Cow weight is adjusted down by the weight of the new born calf. The male/female ratio of births is set to 1:1.

In the summer, the reproductive cycle ends, and the following management decisions are made. (a) 20% of the cows in service are discarded after their fifth offspring. (b) Cows in service increase by one category: “heifers of first offspring” change to “cows with more than one offspring,” and “heifers of two years” enter to the “cows in service” category.[[16]](#footnote-16) (c) At the end of the summer, the calves are weaned, the males and females that are not for reposition are sold, and so are the discarded cows. (d) Sheep production (wool and standing lambs) is sold.[[17]](#footnote-17) (e) As it is the beginning of the next productive cycle, the summer breeding of cows takes place and the process is repeated. For a further description of the annual management scheme, see supplementary material 6.

Cows are supplemented if necessary. Throughout the process, when the average live weight of cows is below 225kg, we simulate feed supplementation of animals until they reach the threshold.[[18]](#footnote-18) We supplement with feed sorghum, assuming a conversion efficiency of 7kg (8kg) of dry matter per kg of live weight for “heifers of first offspring” (“cows with more than one offspring”). We compute feed costs at market prices.

We generate random prices with a Lognormal distribution, , for each product the farmer sells. We set the means at the February price levels (the selling month according to the simulation) and compute their implicit volatility from observed historical prices. Female and male calves and feeder cow prices are from Plaza Rural from 2001 to 2015, lamb prices from the National Meat Institute (INAC) from 2011 to 2015, and wool prices from the National Wool Institute (SUL) from 2004 to 2015. Following the Johnson and Tenenbein (1981) methodology, we impose correlation among prices setting the observed historical correlation as the target correlation.

Finally, we compute per-hectare profits of proactive and reactive farmer in US dollars, by aggregating revenues of the various sources and subtracting costs of supplementation.[[19]](#footnote-19) We plug profits in equation (2), and add them to the assumed farmer´s per-hectare initial wealth (*W0*), which was set to the value of the animals kept on average per hectare during the production period.

1. Results and discussion

This section presents the results and discussion of both applications.

*Crop production*. We simulate three scenarios, all of them facing medium level prices. *Scenario 1*consists of a crop-only production activity, located close to the port, and with high soil aptitude.[[20]](#footnote-20) The rotation with supplemented irrigation comprises two years and is {CC-S1}{CC-M1} while the rain-fed system is of three years {CC-S1}{T-S2}{CC-M1}.[[21]](#footnote-21) The probability distributions of irrigated and rain-fed profits, are presented in figure 1-left panel. Irrigation profits have a higher mean and a lower dispersion than the rain-fed system (the coefficient of variation is 0.36 versus 0.52), i.e. more compacted around their mean. Random profits are then plugged into the CARA utility function[[22]](#footnote-22) to compute the *CE*.

For a farmer with a moderate level of risk aversion (consistent with a willingness to pay of 28% of the standard deviation of his benefits to avoid the risk and keep the same utility level), we find that supplemented irrigation reports an additional value of 59% compared to the rain-fed situation (table 1). The certainty equivalent, , for the rain-fed case is lower than the irrigation case, because the average profits are lower, but also because the risk premium (*RP*) is higher (due to the penalty arising from the higher volatility). Remarkably, if we decompose the 59%, 65% of it corresponds to the higher average profits of the irrigation system and 35% to the higher stability of profits. The latter seems to be a significant portion, considering that this value is typically not quantified, but solely appreciated qualitatively.

As expected, when risk aversion increases (moving to the right of table 1), the value given to a lower volatility is higher. This is because individuals dislike risk to a higher extent and thus are willing to pay a higher risk premium. In addition, the relative value attributed to the higher average benefits is reduced. Risk neutral individuals (*RP*= 0% of the standard deviation of the profits), do not value the change in volatility under irrigation, and as expected, only value the higher average profits.

We analyse other two scenarios that represent typical schemes found in Uruguayan crop production. Their results are qualitatively similar to *scenario1*, which is indicative that the relatively high value producers assign to the lower volatility when using irrigation is independent from the production system, the soil aptitude, and the distance to the port.

*Scenario**2*, which describes a livestock and cattle production system, in high soil aptitude and close to the port, uses a rotation with irrigation that lasts two years {CC-S1}{W-M2}. The rain-fed rotation takes three years, {CC-S1}{W-S2}{CC-M1}. In this case, the use of irrigation reports to the producer a *CE* 75% higher, where one fifth of it can be associated to the lower volatility of profits.

*Scenario**3* is also a livestock and cattle production system, in high soil aptitude, but far from the port. It features the same rotation with and without irrigation, which lasts three years, {CC-S1}{W-S2}{CC-M1}. The value attributed to the use of irrigation is consistent with previous scenarios. Importantly, the fact that both rotations are the same suggests that the results are not driven by differences in rotations.

If we compare scenarios 2 and 3, we show the result of leaving everything else equal but changing the distance to the port. When we increase the distance (*scenario 3*), the additional total value attributed to irrigation is around 7% - 8% lower than when the farm is close to the port, for all levels of risk aversion. Interestingly, the proportion of that value associated to the lower volatility is higher when the farm is far from the port (27%) than when it is close (20%). This shades light on how important it is for farmers the use of irrigation when moving away from the port. This is relevant because these type of farmers usually face a significant restriction in producing export-oriented crops due to freight costs.

*Livestock production*. We discuss the results of the value assigned to the proactive and reactive management strategy of livestock on natural rangelands. We first study the case including only the production of cows, and then include both cows and sheep production.

In the production of cows, the mean profits of the proactive producer is 44% higher than the reactive, while the coefficient of variation is 25% lower (figure 1- middle panel). Table 2 shows, that the *CE* of the proactive producer is about 80% higher than that of the reactive, which arises from both the higher average profit and its lower volatility. For moderate risk aversion levels (*RP* = 12% of standard deviation of profits), 90% of the total additional value is due to higher average profits, and the remaining 10% is due to their lower volatility. As risk aversion increases, the higher is the value attributed by the farmer to the lower volatility (reaching 14% for more risk averse individuals), as they are willing to pay a higher risk premium to avoid the risk. A risk neutral producer (*RP* ~ 0%) assigns value only to the higher average profits. These results show the degree to which a proactive management of natural rangelands values the lower volatility of profits relative to the reactive strategy.

Interesting insights arise when we consider simultaneously the profits of sheep and cow production. Sheep production has a good performance in dry years, being more resilient than cows. In extreme climatic conditions, dryer years or even droughts, sheep tend to put up better with climate translating into better economic results compared to cow production under similar circumstances. In fact, evidence shows that farmers incorporate sheep as a strategy to gain resilience in their production system (Picasso et al 2014).

When we add the profits from sheep production to our simulations, both reactive and proactive farmers increase their average profits by about 15% and 100% respectively. Mean profits of the proactive are still 4% higher, but most importantly, the lower volatility of sheep profits of the reactive offset the variability of cow production profits, reaching a similar coefficient of variation than the proactive. Also, note that sheep profits of the reactive account for a higher share of total profits than in the proactive case. These findings are consistent with the existent evidence about the strategies adopted by farmers to cope with unfavourable climate conditions in this region (Figure 1- right panel).

Translated into the *CE*, we find that the *total additional value* of the proactive strategy is only 4.21% higher than that of the reactive. Recall that when we considered only the production of cows, this value was ~80% higher. Now, despite using a higher stocking rate, the reactive is capable of obtaining profits that are as stable and as high (on average) as the proactive.[[23]](#footnote-23) These results provide evidence that explains the rationality of farmers in the Basaltic Cuesta region,[[24]](#footnote-24) who keep a high stocking rate but also produce sheep.

1. Conclusions

Climate change and variability have critical effects on agricultural production due to its high dependence on weather conditions. Adopting production practices and technologies that generate resilience in production systems has become key as an adaptation strategy.

In this study, we are interested in analyzing the set of technologies that generate an increase in average yields, but most importantly, a reduction in their annual volatility. Assuming risk averse farmers, the adoption of practices that generate profit stability creates a good business environment and a positive impact on expectations, fostering production expansion and investment in agribusiness.

To the best of our knowledge, the economic literature has focused on evaluating the benefits that arise from higher average productivity, but attention to the benefits associated to the lower volatility has been scant. In this paper, we monetarily quantify both, and present two different applications of adaptation technologies in the agricultural sector of Uruguay. The first application is the adoption of supplemented irrigation on summer crops while the other involves livestock production on natural rangelands. We differentiate in each application, two types of producers according to the technology they adopt.

We apply an expected utility approach, and compute the certainty equivalent (*CE*) as it simultaneously factors the value to the farmer from obtaining higher average profits on the one side, and more stable profits on the other. We use the *CE* to compare the stochastic profit flows of a farmer that applies the mentioned AT with that of a farmer that does otherwise (NAT).

In the crop production application, we formulate a set of scenarios by the production focus of the farm, soil aptitude, and distance to the port, using a set of medium level prices. Our results show that for crop-only farms, in high soil aptitude, and located close to the port, the value risk averse producers assign to their production is 59% higher than that of the producers who, everything else equal, do not apply supplemented irrigation. A 65% of this value comes from obtaining higher average profits, while the remaining 35% is derived from their lower volatility. These results are robust to different scenarios, which indicate that the value attributed to the lower volatility is considerably high, and thus, should not be omitted when deciding on the adoption of adaptation technologies.

In the livestock production application, we first analyse a scenario of cow production only and find that, regardless of the risk aversion level, the total additional value a proactive producer gets from following a resilient management strategy is approximately 81.2% higher than what the reactive gets. When we decompose this value, 14% corresponds to less volatile profits, while the other 86% to higher means, which suggests the importance lower volatility acquires for risk adverse producers. We then incorporate the sheep production profits and conclusions change substantially. The key factor here is that sheep production is less sensible to climatic variations, especially in natural rangeland conditions, making its economic results relatively more stable. We find that their incorporation is a highly effective strategy for the reactive producer to increase average profits and gain stability. The total additional value for the proactive is only 4% higher than the reactive (substantially lower than the 81% found in the cow production only). These results provide an empirical explanation for a generalized production practice in Uruguayan natural rangelands, which consists of keeping a high stocking rate of cows and sheep, at the cost of cow productivity deterioration.

Our study contributes to the literature of economic methodologies that evaluate practices that aim at reducing income volatility. Furthermore, the particular applications of this paper provide consistent evidence to support public and private efforts promoting the adoption of technologies for adaptation to variability and climate change in Uruguay.

**Figure 1. Probability functions of the profits of both applications.**



**Table 1. Value attributed to the use of irrigation with respect to rain-fed systems, for the CARA utility function, by risk aversion levels and productive activities.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Value** | **Risk premiums as a % of the standard deviation of the profits** | | | |
| ***Scenario 1:* crop only - high soil aptitude – close to the port** | | | | |
|  | **0%** | **19%** | **28%** | **37%** |
| Total additional value | 0.53 | 0.57 | 0.59 | 0.60 |
| Value for higher mean | ~0.53 | 0.43 | 0.38 | 0.36 |
| Value for less volatility | ~0 | 0.13 | 0.20 | 0.24 |
|  | ~100% | 77% | 65% | 61% |
|  | ~0% | 23% | 35% | 39% |
| ***Scenario 2:* livestock & crop – high soil aptitude - close to the port** | | | | |
|  | **0%** | **17%** | **25%** | **33%** |
| Total additional value | 0.69 | 0.73 | 0.75 | 0.75 |
| Value for higher mean | ~0.71 | 0.62 | 0.60 | 0.53 |
| Value for less volatility | ~0 | 0.11 | 0.15 | 0.22 |
|  | ~100% | 85% | 80% | 70% |
|  | ~0% | 15% | 20% | 30% |
| ***Scenario 3:* livestock & crop - high soil aptitude - far from the port** | | | | |
|  | **0%** | **18%** | **27%** | **35%** |
| Total additional value | 0.62 | 0.66 | 0.67 | 0.69 |
| Value for higher mean | ~0.60 | 0.51 | 0.48 | 0.45 |
| Value for less volatility | ~0 | 0.15 | 0.18 | 0.25 |
|  | ~100% | 77% | 73% | 64% |
|  | ~0% | 23% | 27% | 36% |

Note: Risk premiums as % deviation of standard deviation of profits in columns 2 through 5 are equivalent to relative risk aversion coefficients of 0, 2, 3, and 4.

**Table 2. Value attributed to the proactive versus the reactive strategy for the CARA utility function, by risk aversion levels and productive activities.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Value** | **RP as a % of the standard deviation of profits** | | | |
| **Cows’ production** | | | |  |
|  |  |  | **1** |  |
| Total additional value | 0.8035 | 0.8062 | 0.8098 | 0.8122 |
| Value for higher mean | ~0.8035 | 0.7499 | 0.7260 | 0.6956 |
| Value for less volatility | ~0 | 0.0990 | 0.1230 | 0.1560 |
|  | ~100% | 93% | 90% | 86% |
|  | ~0% | 7% | 10% | 14% |
| **Cows’ production & sheep** | | | | |
|  |  |  | **1** |  |
| Total additional value | 0.0421 | 0.0421 | 0.0421 | 0.0421 |
| Value for higher mean | ⁓0.0421 | 0.0364 | 0.034 | 0.0314 |
| Value for less volatility | ⁓0 | 0.0057 | 0.0081 | 0.0107 |
|  | ~100% | 86% | 81% | 75% |
|  | ~0% | 14% | 19% | 25% |

Note: Risk premiums as % deviation of standard deviation of profits in columns 2 through 5 are equivalent to relative risk aversion coefficients of 0, 2, 3, and 4.

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1. Pandey (1990), through a stochastic dominance approach and using the output of a crop simulation model, identifies risk-efficient irrigation schedules for winter wheat in central India and quantitatively estimates the benefits to the farmers due to risk reduction. Apland et al. (1980) use data of the Corn Belt from 1968 to 1975 to analyze the impact of risk aversion on the demand for supplemented irrigation. Gelós (2016) employs an expected utility approach and certainty equivalents to evaluate the most feasible supplemented irrigation technology of corn in Uruguay under different output price, interest rate, and risk aversion scenarios. [↑](#footnote-ref-1)
2. We set this parameter to be consistent with a coefficient of relative risk aversion (*rra*) equal to {0,2,3,4}, relying on the Arrow-Pratt measure of relative risk aversion: *rra* = *ara*×. [↑](#footnote-ref-2)
3. The risk premium (RP) is the amount of money the individual is willing to pay to avoid a risky gamble (uncertain production of crops or livestock in the case of this paper) that leaves him with the same level of utility: . [↑](#footnote-ref-3)
4. This expression is derived from substituting by the function in (2), and solving for *RP*. [↑](#footnote-ref-4)
5. This means that an individual is willing to pay an amount of money equal to x% of the standard deviation of his or her profits to avoid the implicit risk of the activity. [↑](#footnote-ref-5)
6. This is the port from which most grain export take place, and is located in the south-west of Uruguay. [↑](#footnote-ref-6)
7. Medium prices are those expected in 2016 for 2017. Low prices are equivalent to the minimum registered around the years 2015-2016, and high prices are those observed in the 2016 harvest season. Results for the other price scenarios are available from the authors upon request. [↑](#footnote-ref-7)
8. Non-parametric methods provided a better fit, especially in the tails of the distribution, than parametric methods such as *Beta* or *Gamma* distributions. [↑](#footnote-ref-8)
9. We also generated results for sorghum as first and second crop, which we use in other scenarios not presented here. [↑](#footnote-ref-9)
10. Table S.3 reports the descriptive statistics for various crops in one scenario. Calibrating data covers more than 350,000 ha during 10 years of rain-fed agricultural systems and more than 20,000 ha of crops during 8 years with irrigation. Furthermore, characteristics of farms surveyed match the scenarios of interest. [↑](#footnote-ref-10)
11. The data of the costs used is available from the authors upon request. [↑](#footnote-ref-11)
12. MEGANE is sensible to variations of only the quantity of sheep, not considering neither changes in weight nor their various categories. [↑](#footnote-ref-12)
13. This eco-zone is located in the north-central region of Uruguay, where most cow-calf operations are located. See supplementary material 3 for a further description of this eco-zone. [↑](#footnote-ref-13)
14. Quantile matching implies that for each simulated month in the normal space we obtain the corresponding observation in the same percentile but in the distribution of the observed series of climatic coefficients. [↑](#footnote-ref-14)
15. We assume failed cows do not go for a second service in the fall. [↑](#footnote-ref-15)
16. The heifers of first offspring are part of a breeding scheme of the producer but in this analysis, we do not simulate it explicitly. We do keep account of number and weight of weaned heifers and heifers of one and two years. [↑](#footnote-ref-16)
17. Weaning rate equals 70%, lamb weight 15kg/head of meat, and sheep produce 4kg/head of wool (Kremer 2010). [↑](#footnote-ref-17)
18. In MEGANE the survival weight is 220kg which is associated with a corporal condition leaning toward animal death. We assume the producer decides to incur in the cost of supplementation as the last alternative to avoid the death of the animal. [↑](#footnote-ref-18)
19. Adoption of the mentioned technology does not necessarily imply additional input costs; one reason is that it is a process-based technology, which basically requires technical assistance. Not only they are usually provided by the regular technical assistance the farmer receives, but also existing extension services provided by the government can provide it. In case the farmer must afford it, it will only affect average profit values but not their volatility, not affecting our main conclusions. [↑](#footnote-ref-19)
20. We present other two scenarios but with less detail. Additional scenarios are available from the authors upon request. [↑](#footnote-ref-20)
21. Each bracket corresponds to the year, and within it, the first is the summer crop and the second is the winter crop. CC: Cover Crop; S1 and S2: Soybean as 1st and 2nd crop; M1 and M2: Corn as 1st and 2nd crop; W: Wheat; SG1: Sorghum as 1st crop. [↑](#footnote-ref-21)
22. Constant Relative Risk Aversion (CRRA) results were similar and are available from the authors upon request. [↑](#footnote-ref-22)
23. Although we find that the decomposition of the total additional value is consistent with previous results, the absolute value where those proportions are applied to is practically insignificant. [↑](#footnote-ref-23)
24. This practice is also observed in other areas such as the East Hills, although not analyzed here. [↑](#footnote-ref-24)