AN ECONOMIC MODELLING APPROACH FOR VULNERABILITY ASSESMENT IN IRRIGATION FARMS IN SPAIN

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1. Introduction and context of the research

In the last years, vulnerability assessment has emerged as a need for policy making instead of being a pure academic exercise (Hinkel, 2010). In the current context of changing climate, increasing water scarcity threatens economic activities in many arid or semi-arid regions of the World. Climate change (CC) science and policy debates have traditionally focused on CC mitigation and impact assessment (Krysanova et al., 2010). However, even if mitigation policies are successfully enforced some climate change is still expected. Then, adaptation is strongly necessary and, for that, improved knowledge on vulnerability and adaptive capacity is required.

Being agriculture the main water consuming economic sector in many countries, such as Spain, water policy is a matter of the highest relevance in rural areas where irrigation is the main productive activity. The use of water for irrigation establishes a fragile equilibrium between the maintenance of ecosystems and the economic development. This equilibrium is often vulnerable to change (Downing et al. 2006). Water management constitutes a difficult task for the Administration at every scale, as it impacts that fragile and vulnerable equilibrium and affects social, economic, environmental and institutional interactions.

In Spain, the most arid country in Europe, agriculture consumes around 70% of total renewable water resources. In the Guadiana basin (Figure 1) agricultural water consumption is even higher, and the remarkable difference between the upper and middle parts of the basin makes it difficult for the water authority to manage water resources in the basin as a unique water body (as required by the Water Framework Directive (WFD)).

In the Upper Guadiana agriculture consumes 95% of the renewable water resources, and groundwater pumping for irrigation led, during the 70's, 80's and 90's, to the aquifer overexploitation and the subsequent degradation of the RAMSAR listed wetlands of Las Tablas de Daimiel. This is the typical case of conflicting management of common pool resources and currently several water plans have been developed aiming at solving this conflict.

However, the situation in the Middle Guadiana basin differs largely from the Upper Guadiana basin. In the Middle Guadiana, irrigation agriculture is mainly based on surface water. The great development of hydraulic infrastructures in this area minimizes vulnerability to drought (Krysanova et al. 2010), water stress is expected to rise due to climate change and environmental policy constraints. The application of the WFD and climate related uncertainties pose important challenges to the Middle Guadiana water users as water allotments and consumption has been high in the last decades. The Guadiana basin could be, according to the preliminary assessments carried out in Spain, the most affected by climate change river basin in Spain with an 11% decrease of annual average total water inflow by 2030 (Iglesias et al., 2005), and therefore, compliance with the WFD and implementation of adaptation policies can be problematic issues.

- *The policy context*

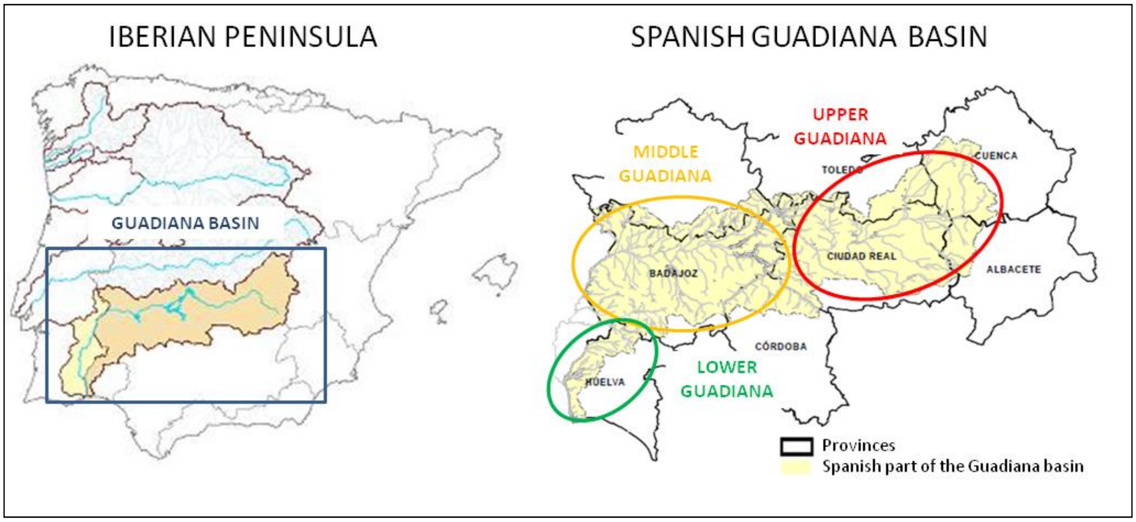
Several authors (Varela-Ortega, *in press*; Van Vliet et al., *under review*) report a high level of policy consciousness in the Guadiana basin. This is probably due to the very important role that policies have played in the last decades both in the upper and the middle Guadiana. Specifically, in the middle Guadiana, socio-economic development was driven by a policy in place during the 50's and 60's, the so called Plan Badajoz. This plan aimed at fostering socio-economic development and one of the main elements of the policy was the establishment of large irrigation areas and the building of dams.

The high storage capacity of the middle Guadiana basin, and the way the irrigation districts were developed have largely determined the current type of agriculture in this area. Agriculture is the main economic activity in the rural areas of the middle Guadiana, were horticulture, maize, fruits and rice are the most important products. Average water consumption is rather high, with a general water allotment of 7500 m^3/ha and a low water use technical efficiency (around 60% of gravity irrigation).

Given those characteristics, compliance with the Water Framework Directive is a difficult challenge for farmers, water managers and the river basin authority. Cost recovery, water pricing and the good ecological status of water bodies are three goals of the WFD whose achievement is problematic, in light of the current water delivery and management system and the RBA commitment by law to ensure the water demand satisfaction to all users.

At the same time the Common Agricultural Policy (CAP) has largely evolved to meet the environmental objectives demanded by the international agreements and today's society. Currently, many EU policies are gradually converging to common overall goals and this is the case of the CAP and the WFD which are both under the umbrella of the EU Sustainable Development Strategy (CEC, 2001, 2006, 2009). In this line, the last CAP reform, the 2009 CAP Health Check, introduced water management, climate change, biodiversity and renewable energies, as the new challenges to address through the agricultural policy.

Figure 1. The Guadiana basin and its parts



Source: Own elaboration from CHG (2007) and Albufeira Convention (www.cadc-albufeira.org)

2. Objectives

The hypothesis we hold in this paper is that the economic impact of water policy on agriculture varies largely among different farm types in the same area, and this is due to different vulnerability profiles. This fact must be considered for policy design and implementation as it is a matter of the highest relevance for downscaling of global policies to local contexts (Varela-Ortega, in press).

The objectives of this research are:

1. To assess the economic impact of two different water policy options, water quotas (currently in place) and water tariffs, intended to ensure the maintenance of environmental flows.
2. To evaluate which variables determine farm income and the differential economic impact among farms. This will allow building a classification tree of vulnerable farms.

3. Methodology

The methods used in this research are largely determined by the way the authors frame water scarcity impacts and vulnerability.

3.1 Conceptual framework for vulnerability

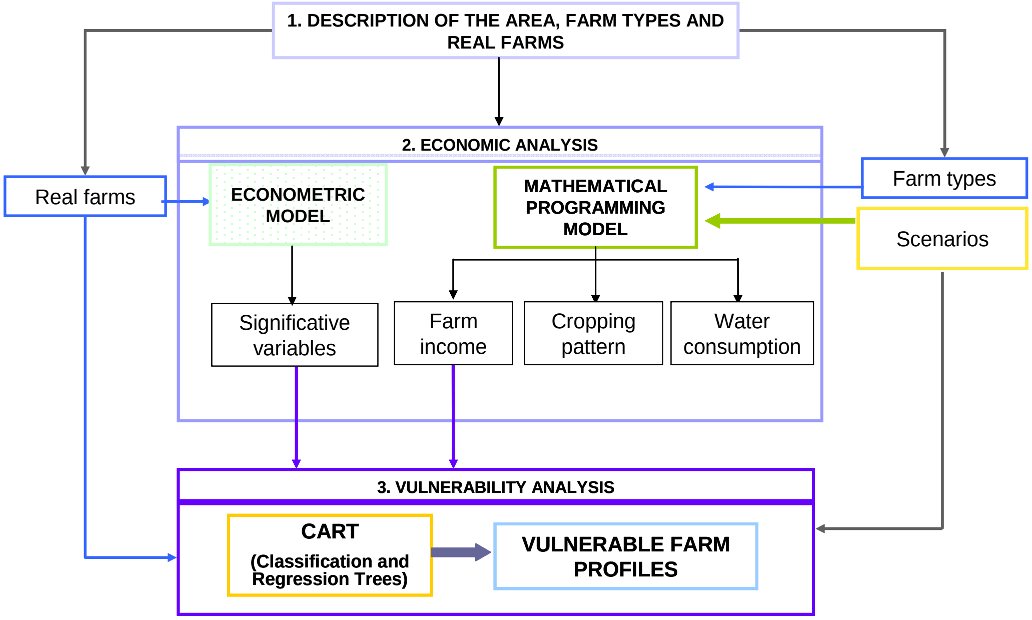
Discussions about the concept of vulnerability lead many times to endless debates as it is a concept used in many different disciplines, for many different purposes and under very different conditions. As highlighted by Hinkel (2010), most vulnerability definitions are vague with respect to the main elements that determine vulnerability and, consequently, with the methods for analysing it.

Several authors have presented wide revisions of the conceptualization of vulnerability and the evolution of vulnerability assessments (see Turner et al., 2003; Kasperson et al., 2005; Ionescu et al., 2005; Füssel and Klein, 2006), but it is not the purpose of this paper to do another review. According to Füssel (2006), the main approaches to vulnerability research are the risk-hazard approach, the political economy approach, the pressurerelease model, the integrated approaches and the resilience approach. Following Füssel's classification, this research would be framed in the political economy approach in which, according to Adger and Kelly (1999), vulnerability is the state of individuals or systems, in terms of their capability to respond and adapt to external stresses affecting their livelihoods and wellbeing.

3.2 Methodological framework

The methodology developed for this research is based on the integration of different types of modelling tools. Figure 2 summarizes the methodological framework of the study, which is based in four main sequential steps: (1) development of a knowledge base of the sub-basin, the irrigated agriculture in the region, the types of farms, etc.; (2) economic analysis which includes two parts: 2a) an econometric analysis to understand the elements, apart from crop prices and yields, which influence farm profitability, and 2b) an agro-economic mathematical programming model of constrained optimization to simulate farmers behaviour and assess the impact of different water policy options on farm income, water consumption and cropping patterns; and finally (3) the analysis of vulnerability and the factors involved in farmers' vulnerability through the elaboration of a classification tree.

Figure 2. Methodological framework



- *Development of a knowledge base*

The basic unit of analysis in this study is the farm. Farmer activity and behaviour with respect to production techniques, irrigation and other cropping activities, are determined by the type of irrigation community he belongs to, the agricultural characteristics of the area, water policies (determined in this case at the basin, national or EU levels) and agricultural policies (mainly determined at the EU level). This fact shaped the development of a knowledge base, which included: a review of EU, national and regional legislation, review of regional and local statistics, extensive fieldwork and the development of a farm typology.

The fieldwork, carried out in 2008 and 2009, comprised 4 irrigation communities and 107 farms. Through interviews and surveys we got a knowledge base about the functioning and structure of the irrigation communities, and information on 46 variables (see econometric model) of the farms.

As shown in table 1, the irrigated agriculture of the Middle Guadiana basin was depicted by the selection of two irrigation communities, which represent two opposite types of water management and technologies, and five farm types which represent the farm typology in the Middle Guadiana basin. The two irrigation communities (IC) are "Tomas Directas del Guadiana" (TD), a modern IC with pressurized irrigation systems in which farms take water directly from the natural water courses, and "Montijo" (MON), a non modernized IC with small traditional farms in which water comes from the Montijo canal.

Table 1. Farm types selected for the economic analysis.

Farm Type	IC	Municipality	Size (ha)	Crops
F1 – TD	Tomas Directas	Badajoz	90	maize (30 ha), tomato(40 ha), olive trees (20 ha)
F2 – TD		Guareña	20	rice (20 ha)
F3 – TD		Mérida	45	peach tree (30 ha), plum tree (15 ha)
F4 – MON	Montijo	Montijo	50	wheat (10 ha), maize (20 ha), tomato (12ha), peach (8 ha)
F5 – MON		Puebla de Alcocer	10	maize (4 ha), tomato (6 ha)

- *Econometric model*

Statistic and econometric assessments can be useful for vulnerability studies. They provide knowledge on the main elements shaping the economic activity of farmers, such as the most relevant and profiting crops, whether they have other economic activities as an alternative to farming, which policy elements affect them, and what are the key market and labour elements involved in farmers welfare (Stephen and Downing, 2001).

The aim of the econometric estimation here is to verify the hypothesis that farm income depends on structural, social, agricultural and technological factors, it means we will perform a significance test of structural, social, agricultural and technological variables. The estimated model is:

$$Y_i = \alpha + \beta^e \cdot X_i^e + \beta^s \cdot X_i^s + \beta^a \cdot X_i^a + \beta^t \cdot X_i^t + \varepsilon_i$$

Where: X_i^e : Structural variables vector for the observation *i*

X_i^s : Social variables vector for the observation *i*

X^a : Agricultural variables vector for the observation *i*

X_i^t : Technological variables vector for the observation *i*

The database used for the model estimation includes 107 farm surveys carried out in 3 irrigation communities: Tomas Directas del Guadiana (TD), Montijo (MON) and Mérida-Canal de Montijo (ME). This database includes 46 variables which were selected according to fieldwork, to stakeholder meetings carried out in the context of the SCENES project, and from literature. From Varela-Ortega (1984) we selected variables in relation to land productivity and transaction costs, such as farm size, irrigated land, labour, etc., and from econometric based vulnerability studies (Glewwe and Hall, 1998; Adger, 1999; Jalan and Ravallion, 1999; Haughton 2005) we selected social variables such as household size, educational level, age, hired labour, etc. Other studies from Apata et al. (2009), Rodriguez and Smith (1994), Ghazouani and Goaied (2001), focus on the adaptive capacity of farmers to shocks, and consider agricultural and technical variables including crop types and crop production techniques, besides the already mentioned structural and social variables (farm size, farmer type, age, education, sex, access to loans, etc.)

Then, the 46 variables selected were clustered in structural, social, agricultural and irrigation, technological and financial variables.

- *Mathematical programming economic model*

The mathematical programming model (MPM), written and solved in GAMS (General Algebraic Modelling System), builds upon previous work by Varela et al. (1998, 2006) and Esteve (2007). It is an optimization non-linear economic model that simulates farmer's behaviour, in which we maximize farmer's utility subject to technical, structural, economic and policy constraints.

Farmer's utility is defined by the farm's gross margin (Z) and a risk component, in which φ is the farmer's risk aversion coefficient and $\sigma(Z)$ is the standard deviation of farm's gross margin due to climate variability (affecting yields) and market variability (affecting prices).

Objective function: $MaxU = Z - \varphi \times \sigma(Z)$

The maximization of farmer's utility is constrained by policy, technical and agronomic conditions: land use (total farm area and total irrigation surface), labour use, water consumption and agricultural policy constraints (maximum and minimum set-aside).

Constraints: $g(x) \in S_1$,

$x \in S_2$

The technical coefficients and parameters are based on fieldwork, statistics and previous works. The model calibration and validation was done by means of the farmer risk aversion coefficient (Hazell y Norton, 1986) and data on the actual cropping patterns in the area, and land and labour parameters.

- *Vulnerability analysis*

The vulnerability analysis aims at assessing the vulnerability of different farms and improving understanding about the structural, agricultural, technical,social and institutional elements contributing to farmers' vulnerability.

The study of vulnerability we present in this paper focuses on the vulnerability of farmers to income losses driven by water scarcity and by the policies implemented to address that water scarcity that constraint water use.

According to Brooks et al. (2005), when different systems experience similar hazards, in this case the same water conservation policy, the difference in the outcome responds only to the differences in vulnerability across the systems. It means that under a similar water policy, the different impact on farm income is just a consequence of the different vulnerability. Then, vulnerability is considered here as the degree to which a given farm experiences economic negative impacts in a situation of water scarcity and restrictive water policies. Therefore, the main indicator of vulnerability in this study is farm income. The diverse impacts on farm income of the policy scenarios simulated show the different vulnerability of farmers.

The assessment of vulnerability and its determinants is based in the results of the MPM and the econometric model. Brooks et al. (2005) use a statistical approach to identify key indicators of vulnerability, looking at correlation between those indicators and the outcome of vulnerability, in that case mortality. A similar approach is followed here by linking significant variables which determine farm income (obtained throught the econometric analysis) with the income losses estimated by the MPM.

First, the economic model gives us the magnitude of the impact of restrictive water policies on farm income. For this purpose a set of 60 real farms (out of 107 real farms in the database) were classified into five groups according to the five different representative farm types. Then, assuming each group has a similar behaviour towards risk, we simulated the effect of water policies on each real farm. Second, the econometric model provided the selection of variables which are significant on the determination of farm income.

Once each farm is assigned to a vulnerability level, CART (Classification and Regression Trees, Steinberg and Colla, 1997) produces a classification tree of vulnerable farms where the independent significant variables (from the econometric model) are the splitters of the sample. Those variables will be outcome indicators as they will serve as prediction variables (they can be used to predict vulnerability). These prediction variables comprise the structural, social, agronomic and technological elements included in the econometric assessment.

The use of CART for vulnerability analysis is based on the work by Yohannes and Webb (1999) where the authors explain the way CART can be used to identify indicators of different outcomes, such as food insecurity and vulnerability to famine, based on work carried out at IFPRI (International Food Policy Research Institute) about famines in Ethiopia in 1998.

Following Stephen and Downing (2001) some of the reasons why the use of CART can be appropriate for vulnerability assessment are: (1) vulnerability variables are diverse and classification trees are used to identify the key indicators, (2) this method provides high accuracy at the farm level, although it identifies key indicators and not key vulnerable farms, and (3) it enables a quick analysis with large databases and including both categorical or continuous variables.

4. Results and discussion

4.1 Results from the econometric model

After several preliminary estimations several variables were taken out from the model due to over specification of the model and multicollinearity. Then, the model estimated was:

$$\begin{aligned} Grossm\arg\_\,s_i &= \alpha + \beta_{1i}\cdot dummy\_ic + \beta_{2i}\cdot dummy\_fem + \beta_{3i}\cdot dummy\_atp + \beta_{4i}\cdot rent \\ &+ \beta_{5i}\cdot size + \beta_{6i}\cdot perm + \beta_{7i}\cdot annual\_in + \beta_{8i}\cdot press + \beta_{9i}\cdot temp\_lab\_j + \beta_{10i}\cdot dummy\_insur \\ &+ \beta_{11i}\cdot dummy\_credit + \beta_{12i}\cdot dummy\_corp + \beta_{13i}\cdot overconsumption + \beta_{14i}\cdot age + \varepsilon_i \end{aligned}$$

Where:

- *Grossmarg_s*: gross margin per hectare (dependent variable in the model)
- *Dummy_ic*: indicates the irrigation community the farm belongs to. (1=Tomas Directas IC; 0=Montijo IC)
- *Dummy_fem*: indicates farmer's gender (1=female; 0=male)
- *Dummt_atp*: indicates the type of farmer (1=full time farmer; 0=part time farmer)
- *Rent*: percentage of rented land in the farm
- *Size*: farm size (in hectares)
- *Perm, Annual_in*: percentage of farm land under permanent crops and annual intensive crops respectively
- *Press:* percentage of irrigated land with pressurized irrigation systems
- *Temp_lab_j*: temporary labour hired in the farm (working days)
- *Dummy_insur*: indicates farmer is insured (1= farmer has insurance; 0=no insurance)
- *Dummy_credit*: indicates farmer has access to loans for investments in equipments and on-farm infrastructures and for input purchase (1=access to credit; 0=no access to credit)
- *Dummy_corp*: farm is constituted as a corporation
- *Overconsumption*: percentage of consumption above the legal water allotments.
- *Age*: farmer's age

Due to heteroscedasticity of the perturbations (Breusch-Pagan test), we used the ordinary least squares estimator together with the robust variance estimator of White (1980) which provides a robust estimation of the standard errors of each β:

$$\hat{V}_{robust}(\hat{\beta}) = (X'X)^{-1}\left(\frac{N}{N-k}\sum_i \hat{u}_i^2 x_i x_i'\right)(X'X)^{-1}$$

Table 2: Results for the significant variables

Variable	Definition	Coef	Std. Err.	T	P>t
Dummy_ccrr	Irrigation community	-1674.85***	521.856	-3.21	0.002
Dummy_fem	Gender (female)	-1409.62*	816.083	-1.73	0.088
Dummy_atp	Full time farmer	-2103.87***	690.029	-3.05	0.003
Rent	% land rent	14.92***	3.71549	4.02	0.000
Size	Farm size (ha)	-12.81**	6.11687	-2.1	0.039
Perm	% Permanent crops	17.88*	9.4569	1.89	0.062
Press	% Surf. Press irrigation	9.997*	5.5195	1.81	0.074
temp_lab_j	Temp. labour hired (days)	0.559***	0.1193	4.68	0.000
dummy_soc	Firm constitution	1070.97*	540.013	1.98	0.051
overconsumpt	Over consumption(m^3/ha)	0.226*	0.11728	1.93	0.057
Age	Farmer age	36.16*	21.602	1.67	0.098
Constant		3025.595	1537.26	1.97	0.052

*90% significance level; ** 95% significance level; ***99% significance level

The results of the model estimation show that the most significant variables are: the irrigation community, the type of farmer, the percentage of rented land and the temporary labour hired.

The fact that farms belonging to Tomas Directas IC have a lower gross margin per hectare is surprising as this irrigation community has more modern irrigation techniques and technical efficiency in irrigation is higher. The reasons for this are: the lower water allotments per hectare and the larger average size of farms. First, water distribution in Montijo IC is made by open canals and control of consumption is difficult; as a result water consumption in average is much higher in this irrigation community and this affects productivity. Second, as the model estimation shows, the bigger is the farm the lower is the margin per hectare (see explanation below).

Land area rented is significant with a positive coefficient. This means that the larger is the portion of the area rented (with respect to the land owned by the farmer) the higher the gross margin per hectare. This result makes sense as farmers that must pay the land rent should reach higher land productivities.

One of the most interesting results from this model is that farm size is significant (95% level) with a negative coefficient. This is surprising as, apparently, the bigger the farm is the bigger are the opportunities for technical improvements and economies of scale. This fact has been widely discussed in economic literature. Sadoulet and De Janvry (1995) explain that in highly technified farming systems labour productivity can decrease as farm size increases. Many times, farm size increase leads to lower efficiency and a reversion of economies of scale. This is largely due to an increase in transaction costs driven by the higher employment of hired labour. De Janvry also discussed, in 1988, in relation to structural agricultural policies, that land productivity can decrease because of three factors: (i) limited access to capital because of land property, (ii) family labour in small farms is more productive, and (iii) there are costs of control associated to hired labour.

4.2 Results from the mathematical programming economic model

The scenarios simulated with the MPM correspond to two different policy instruments, water quotas and water tariffs, intended to achieve water savings of 10 and 30 per cent for maintaining environmental flows. The following table show the quotas of each scenario and the tariffs that achieve similar water savings for each IC.

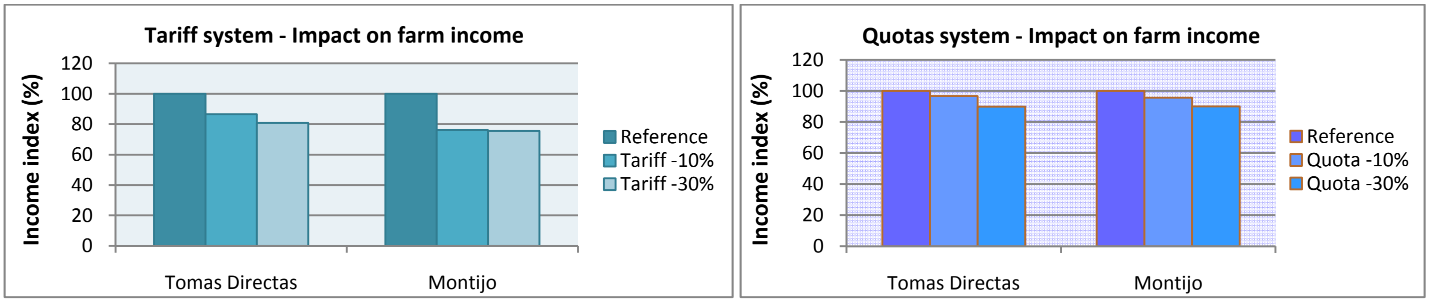
Table 3: Water policy scenarios

	IC Tomas Directas		IC Montijo	
	Quota (m^3/ha)	Tariff (€/m^3)	Quota (m^3/ha)	Tariff (€/m^3)
Reference	6600	0	7500	0
10% decrease	5940	0.035	6750	0.057
30% decrease	4620	0.055	5250	0.058

Results at irrigation community level

Figure 3 show that the water quotas system produces, as expected, a softer impact on farm income than the tariff system. If we look at the two ICs, we prove that the quotas system affect both of them in a similar way. However, this does not happen when we look at the tariff system. The tariff system is much more harmful for old irrigation systems than for modern systems already adapted to water scarcity conditions. Especially, looking at the 10% water saving scenario, there is a significant difference between the modern pressurized irrigation based Tomas Directas IC and the non-modern gravity based Montijo IC. The relevance of the link between water pricing policies and irrigation technology has been also stressed by Varela-Ortega et al. (1998), Johansson et al. (2002), and Blanco et al. (2011) among others.

Figure 3: Economic impact of water tariffs and quotas on the two ICs



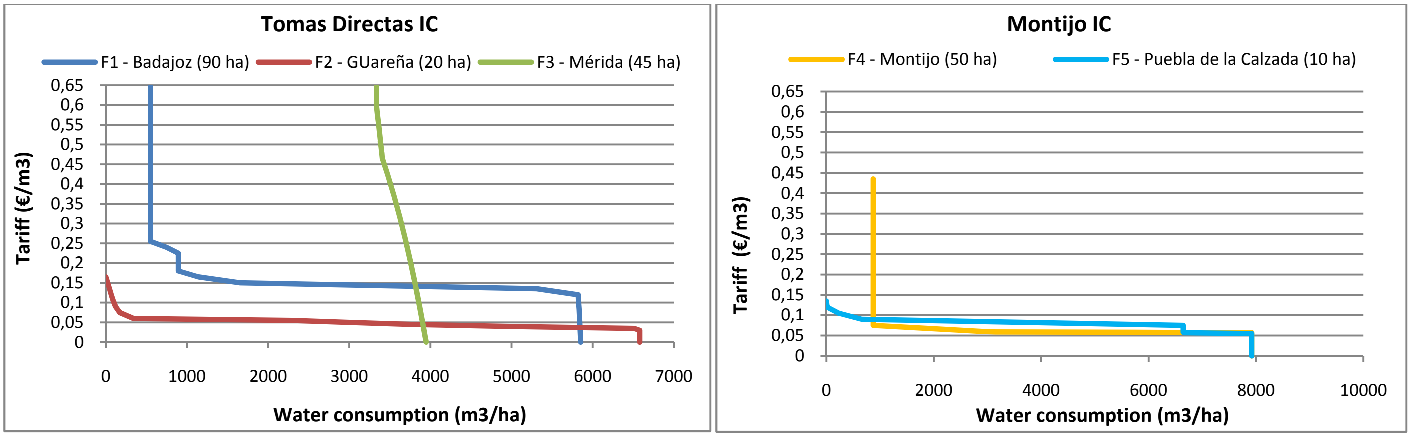
Both water policy instruments analyzed produces similar impacts on cropping patterns. The most remarkable outcome is the phasing of rice cultivation, which would entail structural and social problems. Rice is a very water demanding crop, highly adapted to specific medium-bad quality soils in the region, and which profits from important economies of scale. There is a great controversy around this crop as it is usually the main source of non-compliance with the current water allotment in the basin. Then, is it necessary to carry out a deeper analysis on the social consequences of the phasing of this crop.

Results at farm level

Regarding the impact of the two water policy instruments at farm level, the smallest farms of both ICs (F2 and F5) experience the most severe income losses. For these two farms, the impact of the tariff system is even higher than in the case of the quotas, and it is striking that for a reduction of 10% of water consumption farm F2 loses 30% of income and farm F5 loses 42%. Other authors (Varela et al., 1998; Berbel and Gomez-Limon, 2000; Chohin-Kuper et al., 2003; etc.) have also evidenced that in this type of farms income loss is more than proportional than the reduction in water consumption

The analysis of water demand curves is very meaningfull as it provides an idea about farmer's capacity to adapt and sensitivity to increases in water price. In figure 4 we show the lower part of the water demand curves for the two ICs under study.

Figure 4: Water demand curves



Water demand responses to water prices are different across farm types due to their different structural and technical characteristics. Farms in Montijo IC show a high elasticity at low prices. A similar behaviour is observed in farm F2 from Tomas Directas IC. This is explained by the lack of modern irrigation in those farms that makes not possible to adapt by switching to more efficient irrigation techniques. Modern farms better adapted to water scarcity (F1 and F3 in Tomas Directas IC) have a higher adaptive capacity and changing crop mixes and switching to efficient techniques they can still irrigate their crops. Blanco et al. (2011), Gomez-Limon and Riesgo (2004) and Varela et al. (1998) show similar results.

4.3 Results from the vulnerability analysis

Economic vulnerability is not only defined by income level but mainly by income losses produced by external shocks. In this case we analyze the vulnerability of farms facing a 30% decrease in water allotments. For this purpose we selected a set of 60 farms from the real farm database and simulated with the MPM the mentioned quota policy for each farm. Looking at the income losses experienced by each farm, farms were classified on four groups of similar income losses, considered as four levels of vulnerability:

- Low vulnerability: 0-10% income loss (13% of farms)
- Medium vulnerability: 10-20% income loss (48% of farms)
- High vulnerability 20-25% income loss (23% of farms)
- Very high vulnerability: >25% income loss (15% of farms)

The results of the classification tree produced by CART (see appendix 1), summarized in table 4, show that the main variables that determine vulnerability are structural variables: farm size and crop type.

Table 4: Summary of results of the classification tree

VULNERABILITY	CHARACTERISTICS
Low	Farms with more than 25% of the area under permanent crops
Medium	Farms with less than 25% permanent crops, bigger than 9 hectares and more than 60% annual intensive crops or Farms with less than 25% permanent crops, annual intensive crops between 30 and 60% of the area, and between 9 and 40 hectares
High	Farms with less than 25% permanent crops, more than 30% annual intensive crops and smaller than 9 hectares or Farms with less than 25% permanent crops, annual intensive crops between 30 and 60% the area, and bigger than 40 hectares
Very high	Farms with less than 25% permanent crops and less than 30% annual intensive crops

High percentage area under of permanent crops in the farm is relevant here because in this area the combination of modern irrigation technology, water availability and soil and climate conditions make permanent crops (fruit trees mainly) very profitable (Osann et al., *in press*). This fact, together with the lower water requirements of these crops, is the reason why farms with more than 25% of permanent crop area present low vulnerability to water shortages.

Annual intensive crops are also relevant because, although they are more water demanding, they are also much more profitable than the extensive crops. Annual intensive crops in highly technified farms present a better capacity to adapt to water shortages.

Finally, farm size is a key variable as well. In accordance to the results of the econometric model estimation, the tree shows that above a certain farm size (40 hectares in this case) economies of scale are reverted, as shown in other studies (De Janvry 1988, Varela-Ortega et al., 2007). This can be partly due to increased transaction costs related to hired labour and limited access to capital.

5. Conclusions

Vulnerability assessment is crucial for water policy development and for integrated water resources management, especially in water scarce countries. The WFD pushes governments to select the most adequate policy option to achieve the good ecological status of water bodies. For this, it is very relevant to know the impacts of the different policy options, what are the costs of their implementation and how vulnerable are the different types of farms.

In this research we have developed an integrated modelling framework for the assessment of farmers' vulnerability and adaptation to water policies. The main challenge here was to integrate different methods, in line with other works based on model coupling (Jakeman and Letcher, 2003; Haughton, 2005; Benhin, 2008; Van Ittersum et al., 2008). The purpose of this model integration was to complement the quantitative economic analysis with qualitative aspects.

Real farms together with representative farm types, whose specific characteristics determine their vulnerability, constituted the base for economic analysis. This economic analysis, especially the MPM results, provides knowledge on how farmers behave and how they respond and adapt to water availability constraints.

Model integration links the results from the economic analysis, both from the econometric model and from the MPM, with the current vulnerability of farming systems through the use of CART. This software links the results from both models and provides a set of relevant vulnerability indicators from a classification tree.

The approach adopted in this research contributes to vulnerability analysis as it is a step further in traditional vulnerability assessments based on simple indicators or composed indicators such as the ones developed by Sullivan (2003) or Rygel et al. (2006), for water poverty and social vulnerability respectively. In this study we succeed to link factors and variables building vulnerable profiles and relating them to policy impacts and farmers' adaptive capacity through the use of models.

Water conservation policies affect negatively farmers' income. However, each instrument analyzed here produces different outcomes. Water tariffs and water quotas can achieve similar water savings, but the tariff system, while promoting greater economic efficiency in water use, produces higher income losses. Water pricing enhance water use efficiency so that farms that can use modern irrigation technologies (modern irrigation communities with pressurized water distribution) and whose production is based on high added value crops (such as tomato and maize) are better adapted to face a water tariff policy.

In this study, we carried out an economic vulnerability assessment in three steps, each one corresponding to a different tool. First, focusing on farm income, we analyzed the main factors, in a farm or in a farmer, influencing gross margin per hectare, apart from yields and prices. Second, we looked at the impacts of water conservation policies, especially at income loss. Finally, through the use of CART, we explored how the factors identified in step 1 relate to farm's income loss, producing a classification tree. This classification tree pointed out that farm vulnerability depends mainly on the types of crops and on farm size, evidencing that at small size level there are positive economies of scale but from a certain size level this economies of scale turn to negative.

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Appendix 1. CART Classification tree.