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Water Policy 14 (2012) 539–560

The costs of drought: the 2007/2008 case of Barcelona

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Abstract

Water scarcity and drought are social and economic problems in large parts of the world that will intensify due to climate change. The existing literature on the costs of drought is scarce, fragmented and heterogeneous and there is a need for comprehensive cost estimations to help design an effective policy response. This is particularly the case in Europe, which is currently developing its drought strategy. The severe drought that affected Barcelona in 2007/2008 is used here as a case study to illustrate the costs of this type of extreme event. We assess direct losses of the affected economic sectors, indirect costs to the rest of the economy and non-market welfare losses caused by environmental damage and household water restrictions. Additionally, we also look at the cost of the measures implemented to address the drought and discuss the implications in terms of their cost-effectiveness. Our results indicate a total cost of this drought event of 1,605 million Euros (0.48% of the regional GDP) and highlight the need for more accurate cost estimations at the European level. The study also points to the need to promote water saving measures and to increase the structural adaptive capacity of systems subjected to water scarcity.

Keywords: Barcelona; Climate change; Costs; Drought; Non-market losses

1. Introduction

Water scarcity and drought are social and economic problems in large parts of the world. These phenomena are particularly severe in those regions where development has strongly relied on the permanent increase in the water supply on offer, leading to unsustainable water consumption. This will intensify under climate change. In Europe, a dryer and warmer climate is expected in the Mediterranean region and a shift of climatic regimes in Europe northwards is predicted (e.g. Huntingford *et al.*, 2003; IPCC, 2007). As a result there will be a considerable enhancement of inter-annual variability in the summer, associated with higher risks of heatwaves and droughts, already experienced in recent years. According to the Working Group on Water Scarcity and Drought of the European Union (EU, 2006)

doi: 10.2166/wp.2011.121

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there have been, over the last 20 years, four significant large-scale droughts that have covered more than 800,000 km^2 of EU territory (37%) affecting more than 100 million people.

As a response to this threat, the EU is currently working on the development of its drought common policy. Since the 2007 Communication of the Commission on water scarcity and droughts (EC, 2007), a set of policy options for action have been reviewed and a working plan has been established to move towards a water-efficient and water-saving economy. As part of this process, accurate economic analysis of the impact of droughts is required for a more efficient response (EC, 2007).

The economic assessment of natural hazard-induced losses such as droughts is a difficult and under-researched topic, fraught with uncertainty, intrinsic complexity and methodological challenges. The literature on the costs of drought is limited and heterogeneous (Markandya *et al*., 2010). Focusing on developed countries, among the sparse literature we find the study by Riebsame *et al*. (1991) who estimated that the economic damage caused by the 1988 drought in central and eastern USA amounted to US$39,400 million. In 1995, the Federal Emergency Management Agency (FEMA) estimated that the average annual drought-related economic losses were between US$6,000 and US$8,000 million (NOAA, 2002). Ross & Lott (2003) provide an overview of ten droughts in the USA between 1980 and 2003 whose economic impact range from over 1,000 up to 60,000 million 2002 US dollars. Hayes *et al*. (2004) have collected drought-loss estimates for the 2002 drought event which hit many US states. Albeit incomplete, and relying on different sources and methodologies, the total losses sum up to almost US$ 13,000 million. Finally, Howitt *et al*. (2009) have estimated that in the short-run, the losses due to the 2009 drought in Central Valley California may amount to US$2,200 million and some 80,000 jobs may have been lost. The Australian 2002 drought is believed to have lowered the GDP by 1.6%, with agriculture alone contributing around a 1.0% decline (Adams *et al*., 2002). The 2006/2007 drought in Australia reduced the GDP by almost 1%, but the farm GDP fell by around 20% (RBA, 2006).

In Europe, the only existing large-scale study is based on a survey conducted by the Directorate General Environment (DG ENV) in 2006/07. The economic impact of droughts for the past 30 years has been estimated to be up to 100,000 million Euros (EC, 2007). In the most recent years the annual costs climbed to over 6,200 million Euros, which would be around 0.05% of the GDP of the Euro area in 2006. But the DG ENV itself warns about the moderate level of reliability of these data and suggests a potential underestimation of the real costs, concluding that ‘further cost-analyses are urgently needed in order to specify more precisely the impacts of water scarcity at EU level’.

Most of the studies mentioned focus on specific aspects of the drought, such as the direct costs or indirect cost only, or focus on only one or two affected sectors, such as agriculture and hydropower. Comprehensive estimates are still lacking and there is need for more research to assist in the development of the design of its drought policy. The aim of this study is to contribute to this limited literature and we do so by analyzing the drought in the Metropolitan area of Barcelona between 2007 and 2008 affecting 5.5 million people. For this, we use a combination of methods to provide a comprehensive estimate of the costs. This analysis includes: the direct economic losses of the affected sectors, the indirect costs to the rest of the regional economy and the non-market welfare losses to society derived from the environmental damage and the restriction in household water use. Additionally, we also estimate the cost of the measures taken to address the drought and discuss the implications in terms of their cost-effectiveness.

The remainder of this paper is as follows. In Section 2, the case study is presented. Section 3 describes in detail the methodology. Sections 4 and 5 present and discuss the results and Section 6 contains concluding remarks.

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2. Case study description

Catalonia, located in the North-east of Spain, is characterized by the irregularity of its rainfall pattern which is typical of the Mediterranean climate. This makes the region especially vulnerable to drought episodes. The hydrographical network of Catalonia (31,896 km^2) is composed of two sets of river basins: the inland basins and the inter-regional and international basins (including the Ebro river and the international river Garona). The former correspond to 28 hydrological units that occupy 52% of the Catalan territory. They are managed by the Catalan Water Agency (Agència Catalana de l'Aigua).

Catalonia has endured various episodes of moderate and severe drought, as evidenced in records that go back 90 years. Figure 1 shows the rainfall evolution in the region for the period 1916–2008 measured through the standardized precipitation index (SPI-12) proposed by McKee *et al.* (1993) and elaborated for Catalonia by Altava-Ortiz (2010)[1]. The last drought episode affecting Catalonia began in November 2004 and lasted until April 2008. The dry period was characterized by three peaks (summer 2005, winter 2007 and winter 2008) and two mild phases (end of 2005 and beginning of 2006). The measurement of the costs of the drought in this study covers only the period 2007/2008, the time during which water supply was threatened.

A comparison of the described event with previous ones recorded since 1916 shows that this episode can be considered the most severe, in terms of both duration and intensity, in the last 92 years. No previous drought registers from instrumental data are comparable, although there is evidence of comparable drought records during the 16th, 17th, 18th and 19th centuries from documentary sources such as rogation ceremonies records[2] (Martín-Vide & Barriendos, 1995; Barrera-Escoda, 2008).

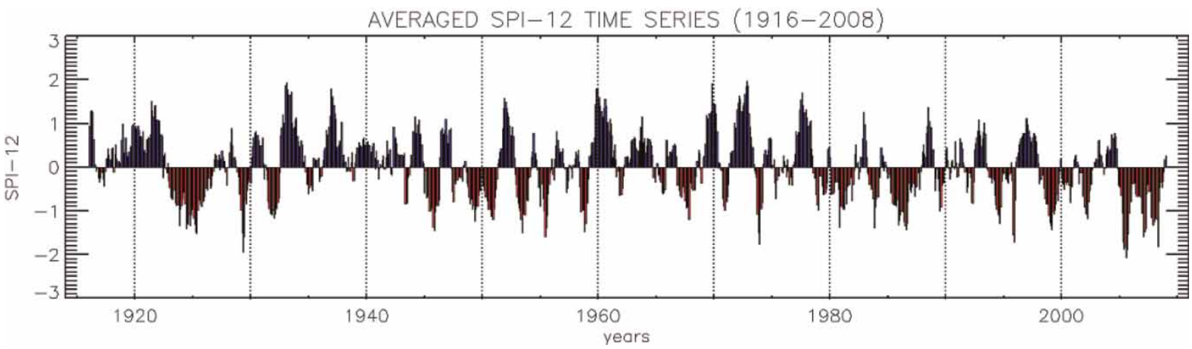

Fig. 1. Rainfall evolution in Catalonia 1916–2008. *Source:* Altava-Ortiz (2010).
SPI: standard precipitation index. A SPI between –0.99 and 0.99 corresponds to a normal water regime, below –0.99 is considered drought and below –2.00 is extreme drought (McKee *et al*., 1993).

[1] The SPI is a drought index based on standardized precipitation. In this case monthly values for the period February 1915 to December 2008 were aggregated in periods of 12 months (first value in the graph then corresponds to February 1916).

[2] According to Martín-Vide & Barriendos (1995) ecclesiastical sources offer a variety of interesting weather information. The Catholic Church generated and preserved over the centuries a remarkable variety of important documents regarding weather and water phenomena. Of special interest here are the 'pro pluvial' rogation ceremonies that each town organized to pray for rain during dry periods.

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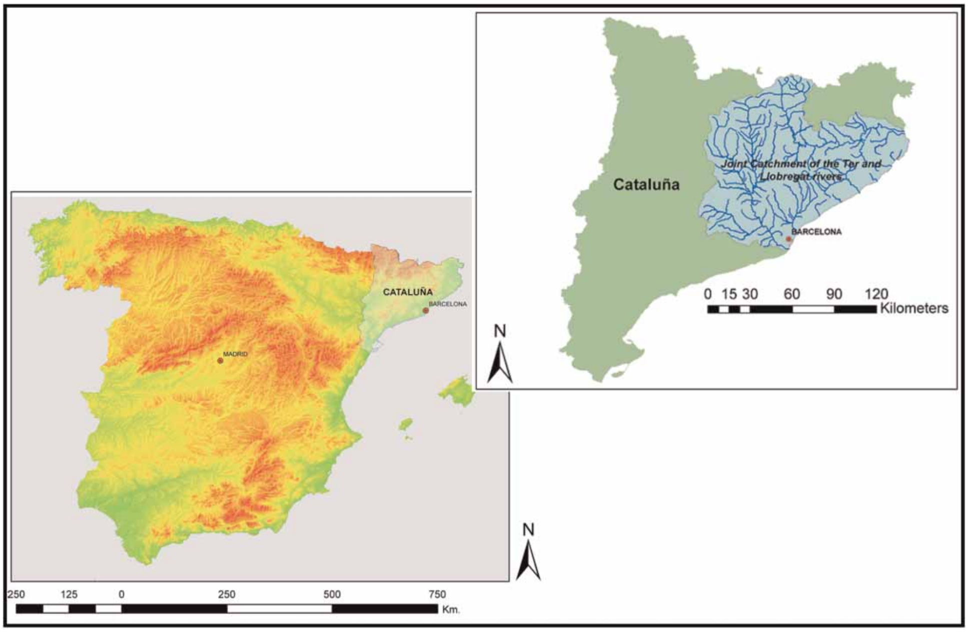

Fig. 2. Location of the Ter-Llobregat system. *Source:* CEDEX Spatial Data Base BBDD (Ministry of Environment and Rural and Marine Affairs of Spain, 2009).

The focus of this study is the drought affecting the so-called Ter-Llobregat system within the Catalonia Inland Basins, from which the metropolitan area of Barcelona is fed and where most of the population is concentrated (approximately 5.5 million people). The total surface of the system is 11.775 km^2, representing 37% of the total Catalan territory (Figure 2). In this particular area, the drought event is also considered to have been the most severe (in terms of extension, magnitude and duration) of the last century.

Figure 3 shows the rainfall evolution for the period 1916–2008 specifically for the Ter-Llobregat system, where the relative severity of this last episode within this time period is even more extreme than for the whole of Catalonia.

Drought events are expected to increase due to climate change in the region (Agència Catalana de l'Aigua & Fundación Nueva Cultura del Agua, 2009). It has been estimated that the temperature in Catalonia increased 0.15 °C per decade over the last 30 years. Calbó *et al*. (2009) project an increase in temperature from 2.9 to 4.4 °C – for the B2 and A2 SRES respectively[3] – in the period 2071–2100

[3] The Special Report on Emissions Scenarios (SRES) was a report prepared by the Intergovernmental Panel on Climate Change for the Third Assessment Report in 2001, on future emission scenarios to be used for driving global circulation models to develop climate change scenarios. The A2 family of scenarios is characterized by a continuously increasing population, regionally oriented economic development and slower and more fragmented technological changes and improvements per capita income. The B2 scenarios are characterized by a continuously increasing population (but at a slower rate than in A2), emphasis on local rather than global solutions to economic, social and environmental stability and intermediate levels of economic development.

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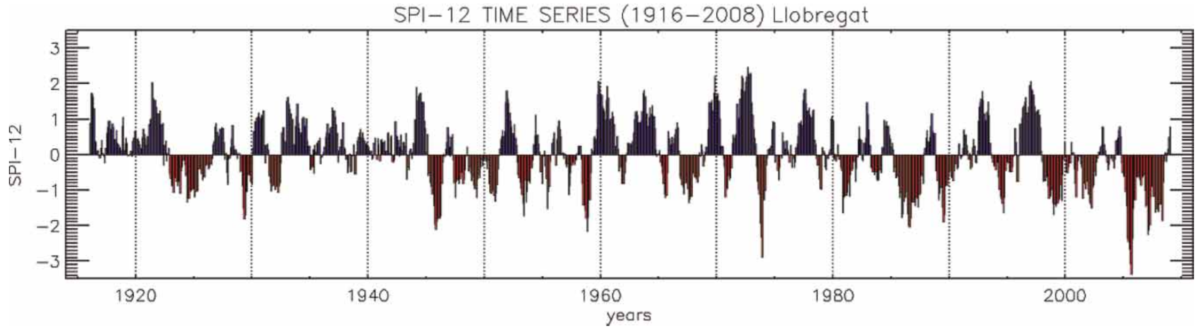

Fig. 3 Rainfall evolution in the Ter-Llobregat System, 1916–2008. *Source:* Altava-Ortiz (2010). See note on SPI in Fig. 1 caption.

in relation to the period 1961–1990[4]. Although there is no statistical proof of the reduction in the average annual precipitation in the last 50 years, it is predicted (with a medium degree of certainty) that with climate change average rainfall will decrease from 5 to 15% within a long-term horizon (from 2040 to 2100). Moreover, significant changes are expected in the short to medium term, 2011–2040 (Llasat *et al*., 2009). The Spanish Ministry of Environment projected a decrease in mean hydrological yields of between 3 and 9% for the internal basins of Catalonia by year 2030 for a scenario of 1 °C temperature increase and 5% decrease in the mean rainfall values (Moreno, 2005).

Projections under climate change also suggest, with a high level of certainty, that the frequency of drought events may double and that their duration and intensity may increase (medium level of certainty) owing to the decrease in the minimum rainfall and increased evaporation (Agència Catalana de l'Aigua & Fundación Nueva Cultura del Agua, 2009). Other factors associated with climate change, that is agricultural demand increase, are expected to magnify the effects of droughts.

In relation to the 2007/2008 drought, the main measures carried out to address the drought were adopted under the law passed by the Regional Government of Catalonia[5], including both demand and supply measures. Table 1 summarizes chronologically the main events related to the 2007/2008 drought in Catalonia and the main measures carried out by the authorities. An important feature of the strategy for addressing the drought was the role given to informing the public. Regular communication was established and several public communication mechanisms were set up, having an important effect on the very significant reduction in demand during the drought period. The Decree was derogated in January 2009 after the risk of shortage for human consumption ended owing to increased precipitation in mid-2008.

3. Methods

The methodologies that have been used in the literature to assess the costs of drought are very heterogeneous and include linear programming models (e.g. Salami *et al*., 2009), input–output (IO) models (e.g. Llop, 2008; Perez y Perez & Barreiro-Hurlé, 2009), computable general equilibrium (CGE) models

[4] As usual in the field of climate change projections, the authors warn about the uncertainty surrounding these figures.
[5] Decree 84/2007, 3rd April, *on the adoption of exceptional and emergency measures regarding the use of water resources.* Diari Oficial de la Generalitat de Catalunya Núm. 4860 – 12.4.2007. http://www.gencat.cat/dogc/

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Table 1. Chronology of main events and measures during the 2007/2008 drought episode in Catalonia.

Date	Main events	Main measures
End 2006 Jan 2007	First warning reports of significant lack of precipitation (pre-alert status) Reserves at 52% of capacity	Establishment of the Drought Management Plan and the Drought Permanent Committee
Feb 2007	Persistent lack of precipitation	First public communication campaign for water saving
Mar–Apr 2007	Drought Decree by the Catalan Government (3rd April, enters into force 17th April) Ter-Llobregat River Basin enters level 1 of exceptionality	15% decrease of irrigation resources Cancellation of spill-overs for purely hydroelectric uses Intensified user controls and waste-water restrictions All drought-related information is published in the river basin authority website
May–Aug 2007	Reserves at 40.5% of capacity All river basins at level 1 of exceptionality	General water saving measures (restrictions in public use of water: gardening, swimming-pools, etc.) Subsidies for the improvement of distribution networks, water re-use and external supply options at the municipal level Public warning campaign and communication campaign (letter, fax, telephone) to stakeholders
Sep–Dec 2007	Reserves at 30% of capacity Drought Decree prorogued	Authorization and subsidies for the reopening of not-in-use water sources Actions for groundwater use Desalinization plants enlargement and improvement Intensification of the activities of the Drought Permanent Committee New communication campaign
Jan–Feb 2008	Reserves at 24% capacity Drought intensifies Ter-Llobregat system reaches level 2 of exceptionality	Actions on groundwater sources Prohibition of the use of potable water for municipal uses (gardens, recreational parks, etc.) Periodic press conferences by the Catalan Minister of Environment to inform about the drought Distribution of 650,000 'water-saving kits' among the population
Mar 2008	Reserves at 21% of capacity Organization and contracting of water shipping from Tarragona and Marseille	Set up of an specific drought web-site www.sequera.gencat.cat and a telephone information system for users Public announcement of the water shipping programme
Apr 2008	Precipitation Spanish Central Government Royal Decree	Plan of a water transfer from Ebro River and authorization of water rights acquisition from Ebro River's irrigators Constitution of the Drought Committee
May 2008	Precipitation. Reserves at 29% of capacity Modification of the Catalan Drought Decree Ter-Llobregat systems gets back to level 1 of exceptionality (Muga system remains at level 2)	Water shipping 13th May, first ship arrives at the port of Barcelona

(*Continued.*)

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Table 1. (*Continued.*)

Date	Main events	Main measures
June 2008	Partial recovery of water reserves (58.5% of capacity) Water shipping finishes Spanish Royal Decree derogated Water reserves increase (70% of reserve capacity for Ter-Llobregat system, Muga system remains at 31.5%)	Water shipping ends (7th June) Water transfer from Ebro River cancelled
July–Sept 2008	Water reserves decrease owing to summer lack of precipitation and increase in water consumption	Irrigation in the Muga system is reduced to minimum. Change from irrigated crops to non-irrigated crops (e.g. sunflower)
Oct 2008	Reserves at 59% of capacity at the Ter-Llobregat system, 22.8% at the Muga system	
Nov 2008	Ter-Llobregat system recovers to pre-summer levels. Muga system's reserve continues to decrease	Specific measures for improving water supply at the Muga system (desalination, emergency sources, water transport by lorry)
Dec 2008 Jan 2009	Ter-Llobregat system gets back to 2004 levels Drought Decree prorogated for the Muga system (reserves at 22% of capacity) End of December: intense precipitation. General reserves at 77% of capacity. All river basins get back to normal (including Muga). Catalan Drought Decree derogated (13th January)	Establishment of the Water Debate in Catalonia (public participation dialogue)

Source: Elaborated with the information provided by the Agència Catalana de l'Aigua (2009a).

(e.g. Berrittella *et al.*, 2007), hybrid models (Cochrane, 1997), and surveys and econometric models like the one proposed by Carroll *et al.* (2009) based on life satisfaction data. In general, these studies focus on only one specific aspect of the drought, such as direct cost, or only on certain affected sectors, for example, Perez y Perez & Barreiro-Hurlé (2009) analyze the cost of the drought in the Ebro river basin region in Spain for agriculture and hydroelectric production. Finally, the literature very sparsely reports on non-market welfare losses (Carroll *et al.*, 2009). In this study we aim to provide a more comprehensive assessment of the costs of the drought.

3.1. Assessment of direct production losses

According to the river basin authority, the most affected sectors were agriculture and hydropower and other water-related sectors such as gardening, floristry and flowers and swimming-pool companies and other related water companies. Next we explain how the production losses affecting each of these sectors were estimated.

- Agriculture: The methodology of estimating losses in agriculture is based on the apparent water productivity in the region. The river basin authority, following the methodology proposed by Velazquez

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et al. (2006), estimates the water apparent productivity in 1 Euro of gross added value (GAV) per cubic metre (Agència Catalana de l'Aigua, 2009b). During the drought, water use restrictions were imposed on irrigators according to the different levels of 'exceptionality' of the situation based on the existing water reserves (see Table 1). These restrictions ranged from 15 to 45%. In some specific areas restrictions reached 100% at certain times. Applying an average reduction of 20% for the whole drought period to the baseline agricultural water consumption (around 750 cubic hectometres (Hm^3)) and multiplying it by the water apparent productivity, provides a conservative estimate of the losses in agriculture.

- Hydropower: The main effect of drought in the energy sector is that it reduces hydropower production. The losses to society caused by this reduction in hydropower production can be approximated on the basis that, while the use of water is restricted, production has to be substituted by other technologies, for example, by gas-fired power plants, which are normally more expensive. We estimate the loss by multiplying the decrease in hydropower production (2.277 GWh) by the difference between the average price of the spot Spanish electricity market in 2008 (59.12 Euros/Mwh) and the average production cost from hydropower (9 Euros/Mwh, according to the CNE, 2009).
- Gardening, florists, swimming pool services and other water-related activities: Owing to lack of better data[6] we have relied on the estimates reported by the river basin authority based on a survey of the companies (Agència Catalana de l'Aigua, 2009b). Although the sector representatives claimed losses ranging from 5 to 25% of its production, the basin authority established that this was probably an overestimation. We have applied the lower bound (5%) as a more reasonable approximation, to the average total production prior to the drought reported in the Catalan Statistic Institute (IDESCAT: http://www.idescat.cat/).

3.2. Assessment of indirect costs to the Catalan economy

The direct impact of the drought measures also generates additional indirect impacts in the other sectors of the economy that need to be accounted for. The basic hypothesis is to consider that the drought generated a direct production loss in some sectors of the economy and, therefore, a decrease in GAV. As all sectors in the economy require intermediate inputs of consumption from other sectors, any decrease in the output/GAV from one sector will be spread to the others reducing their production/demand.

The approach used here consists of estimating the direct GAV losses from the direct economic losses and, from there, the total GAV losses (direct and indirect) for each sector. To estimate the economy-wide[7]

[6] There is no information available on the apparent water productivity of water for this type of activity. An analysis based on the evolution of the gross added value was not possible because there are no data available disaggregated at this level (IDESCAT: http://www.idescat.cat/). Besides, the sector has experimented with important structural changes in the last few years affecting to its contribution to the general GAV (Gremi de Jardineria de Catalunya, 2007).

[7] Other approaches to estimate economy-wide impacts are the computable general equilibrium models. These models are well-suited for long-run impacts as they consider no-linear effects and behaviour based on microeconomic theory. However, these models need more assumptions and data and the input–output model is normally preferred in the short-run analysis, such as the one carried out here, for its transparency.

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effects we use an IO supply model known as Ghosh's model (Ghosh, 1958). Ghosh's model is a variety of Leontief's demand model that is used to analyze the effect that a change in the final demand of one or several sectors has on total production. Ghosh's model is a supply-driven[8] model where the GAV is considered exogenous.

Considering columns from an IO table, the production structure of sector j can be expressed as the sum of the use of intermediate inputs from sector/good i ($x_{i,j}$) and primary inputs (G_j), which includes GVA (labour, capital, taxes) and imports:

$$x_j = x_{1j} + x_{2j} + \cdots + x_{nj} + G_j, \forall j \in (1, \ \ldots, n) \tag{1}$$

In matrix terms:

$$[x_1 \ x_2 \ldots x_n] = [11 \ldots 1] \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{n1} & x_{n2} & \ldots & x_{nn} \end{bmatrix} + [G_1 \ G_2 \ldots G_n]$$

$$x' = i'X + G' \tag{2}$$

Defining the distribution coefficients as $d_{ij} = x_{ij}/x_i$, where x_i is the total demand for good i, and $g_j = G_j/x_i$, we can now express Equation (1) as follows:

$$x_j = d_{1j}x_j + d_{2j}x_j + \cdots + d_{nj}x_n + g_j$$

And, in matrix terms as:

$$x' = x'D + g'$$

which finally can be rewritten as:

$$x' = g'(I - D)^{-1} \tag{3}$$

With Equation (4) we can calculate how the effect of a variation in G_j due to any supply shock (such a decrease in GVA related to a drought event) is transmitted to all the production sectors:

$$\Delta x' = \Delta g'(I - D)^{-1} \tag{4}$$

[8] This approach 'rotates' the way the input–output table is looked at, from rows to columns and instead of using the matrix of technical coefficients, a matrix of market or distribution coefficients is used.

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The data used for the model come from the input output table[9] (IOT) of Catalonia (IDESCAT, 2008) for the year 2005. We use a desegregation of 14 sectors and, in order to translate the direct loss of production into direct loss of added value (GVA), additional information must be obtained. Using the data from IOT, intermediate consumption can be estimated for each sector and then be discounted to the total production to obtain GVA losses.

Finally, it should be mentioned that the IO approach assumes that the production technology is linear, that is that each sector produces a single good or service under fixed coefficients by combining intermediate inputs, primary factors (labour and capital) and imports. This means that there is no possibility of substitution between inputs and therefore economic impacts could be considered as an upper bound. The fact that we do not account for substitution possibilities might be considered as a limitation of the study. However, we argue that this approach is appropriate in short-run analysis, like the 20-month drought event analyzed here, where technological change is difficult.

3.3. Non-market welfare losses

Besides the direct and indirect losses, when a drought event occurs there are other losses to society not necessarily reflected in the economic sectors. The prohibition of the use of water by certain households and urban uses has an impact on the welfare of the population (Carroll *et al*., 2009). Although the restrictions in Barcelona did not affect the basic uses, such as drinking and hygiene, other uses like the outdoor use of water (e.g. swimming-pools, garden sprinkling and car washing) were restricted and other household uses were affected (e.g. the lowering of tap water pressure prevented the use of washing machines and dishwashers for a period of time). Moreover, it has been shown that individuals also derive a non-market welfare loss from the environmental damage that occurred as a consequence of the negative effects of water scarcity in river basin ecosystems (Martin-Ortega *et al*., 2011).

The value people attach to unpriced natural resources and the services these resources provide is often measured in monetary terms through the concept of an individual's willingness to pay (WTP[10]) with the use of stated preferences surveys. An alternative to carrying out a new original valuation study for the estimation of environmental costs is to use existing economic value estimates from previous studies, the so-called 'value transfer'. This technique applies the results of previous environmental valuation studies to new policy or decision-making contexts.

Here we apply a value transfer of the estimates based on a case study carried out in another Spanish river basin, the Guadalquivir, in which a choice experiment was applied to assess the value attached by society to the ecological status of the river basin related to the maintenance of the river flow at times of water scarcity and the value of ensuring water supply for households (Martin-Ortega *et al*., 2011). This study was used since data on non-market welfare losses

[9] The IOT provided by IDESCAT is not symmetric but a destination table. Therefore, an assumption is needed so the unit that makes the costs is the same than the one that has the revenues. We match this disparity using the column for private consumers so the production structure and distribution coefficient matrix is not altered. Other approaches can be followed (see Llop & Pié, 2009).

[10] Willingness to accept (WTA) a payment for a loss of service is also a welfare measure, but less used in environmental economics. It has received less endorsement in the literature, among other reasons due to being more difficult to measure. (e.g. Cummings *et al*., 1986; Arrow *et al*., 1993).

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caused by water scarcity in the Catalan region were not available. Value transfer is now a widely accepted and adopted methodology (Brouwer & Bateman, 2005; Johnston & Duke, 2010). Morrison & Bennett (2000) and Barton (2002) can be consulted specifically in relation to water valuation studies. There are numerous examples in the literature of cross-regional value transfers (see, for instance, the study by Johnston & Duke (2007) on farm land preservation across states in the USA) and even international value transfers (e.g. Ready & Navrud, 2006 and Johnston & Thomassin, 2010). It should be noted, however, that there is still debate in the literature about how much transfer error[11] is acceptable (see for example Rosenberger & Stanley (2006) for a discussion of this issue).

Although not identical to the valuation conditions required for the Barcelona study, the Guadalquivir valuation set up is particularly attractive for use here, as during the drought there was both a lowering of the environmental flows in the river basins and household water restrictions for secondary uses were in place. Four possible levels of ecological status, depending on the water flow in the river, were analyzed in the Guadalquivir (low, moderate, good and very good) in terms of the deviation from the natural status (low meaning a great deviation from natural conditions). The frequency of household water restrictions was defined in the Guadalquivir study in terms of the probability of suffering restrictions expressed as number of years with restrictions in a 10 year horizon[12]. This is not exactly the situation that we have in the Barcelona case, in which we have a change from the current situation (prior to the drought) with no restrictions, to a situation with restrictions (so, not in terms of probabilities). Nevertheless, since total avoidance of probability of restrictions is not possible even in normal conditions in the Mediterranean climate, we assume that the WTP to reduce the probability of restrictions is a reasonable approximation. For more details of the valuation scenario and results see Martin-Ortega *et al*. (2011).

From the different transfer approaches in the literature (Navrud & Ready, 2007), we use a value transfer approach based on the adjustment of a model available from Martin-Ortega *et al*. (2011), which accounted for income effects. This model showed how people with higher income are WTP more for a decrease in water restrictions and an improvement in environmental quality. Adjusting the model to a Catalan's average income we partially correct for the differences between the study and the policy sites. Obviously, other socio-demographic and contextual differences still remain uncorrected, but at least this allows more accurate values to be produced than by a simple mean value transfer.

3.4. Estimation of the costs of the measures

To estimate the costs of the measures, direct primary data from the river basin authority and water supply companies were used (Agència Catalana de l'Aigua, 2009b). Measures were implemented both on the demand and supply sides. The demand side measures covered the main water-related sectors

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[11] Transfer errors refer to the difference between the value obtained via a primary valuation study and the value obtained by transferring the values estimated for another site.

[12] Low probability of water restrictions is defined as that there would be water restrictions in one year within the next 10 years and high probability is defined as a probability of water restrictions in 4 years within the next 10 years.

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Table 2 Summary of the main measures implemented to address the drought.

Demand side measures	Description
Domestic use	Contingency plans implying the restriction of private swimming-pools, car washing and sprinklers in gardens
	Communication campaigns
	Distribution of water saving devices
Public use of water	Restrictions on water allocated by local authorities for non-domestic purposes, including banning of water suitable for human consumption for ornamental fountains, street cleaning and watering of public gardens
Hydroelectric infrastructures	Water restrictions
Agricultural use of water	Restricted from 15 to 45% on average for the whole territory. In certain areas irrigation was fully banned (100%) at certain times
Recreational activities	Restrictions on sporting competitions affecting water resources. Golf courses not irrigated with wastewater were obliged to present contingency plans
Supply side measures	Description
External water supply[a]	Water shipping
	Transport of water by lorry
	Water supply by headwater cisterns
Internal water supply[b]	Start-up of three desalination plants and wastewater plants
	Improvement of distribution channels
	Re-opening of not-in-use wells, opening of new wells and intensification of groundwater extraction

Source: Agència Catalana de l'Aigua (2009b).
[a]External water supply means bringing water from outside the system (other river basins).
[b]Internal water supply means increasing the supply with resources within the system.

(domestic use, public use of water, agriculture, hydroelectric production and recreational activities) and are summarized in Table 2. Several monitoring, communication and public participation mechanisms were set up to monitor the effects of drought and promote water saving behaviour. As a result of these measures and communication campaigns, the average saving in the drought period was 14.5% (compared to the average values of 2005/2007) which is equivalent to a cumulative saving of approximately 506 Hm^3. The Catalan Water Agency states that an average saving of approximately 5% in use has remained after the drought for the region as a whole.

On the supply side, two types of measure were implemented, those aimed at increasing the supply using the resources within the system and those bringing water from outside the system (see Table 2). Among the latter, the most 'spectacular' measure (owing to its visibility and impact on the international press) was the transport of water by boat[13]. The total amount of water put into the system by the supply measures is estimated at 14.82 Hm^3.

[13] The water shipping contracts were predicted for a length of three months, but they finally only took place between the 13th of May and the 7th of June 2008, owing to the recovery of the water levels. A total of 21 trips were finally made: 18 trips from nearby Tarragona and 6 trips from Marseille (France). The total volume of transported water adds up to around less than 0.530 Hm^3.

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In general the measures carried out can be classified into three categories:

1. Alleviation measures: these include the measures that were carried out specifically to address the drought period and that would have not been taken in the absence of this particular event. They include all the demand-side measures plus those supply measures that were not related to the distributing networks (e.g. water shipping).
2. Structural measures brought forward: these include those structural measures that were already planned by the river basin authorities, but that were brought forward as a reaction to the drought. They include the set-up, enlargement and inter-connection of water desalination plants; the enlargement and improvement of drinking water and treatment plants; and the development of infrastructures for water reuse.
3. Additional implemented structural measures: this refers to the measures that, not having been planned before the 2007/2008 drought event, were implemented as a reaction to the drought but will last in the long run. They include the recovery of not-in-use wells, the opening of new wells and the set up of water treatment plants.

For economic assessment only, items 1 and 3 are considered. The structural measures brought forward (2) are not accounted here. They correspond to an increase in the general capacity of the system to address water scarcity and it would not be appropriate to impute them to a single event. The other structural measures (3) will remain after the drought event and will also improve the adaptive capacity of the system, but they would not have taken place if the drought event had not occurred. Therefore, they are included here but the costs are amortized linearly over the lifetime of the investment, as a way of only imputing them partially to this one episode. Most of these measures are related to the construction of hydraulic infrastructures for which typically a useful life of 15 years is considered. We select a discount rate of 5% and imputed only the cost to the 20 months of the drought event[14].

4. Results

4.1. Direct production losses

For the agricultural sector we have estimated losses of 250 million Euros for the whole drought period (150 million Euros for a one-year period). Taking into account the limitations of the estimate, this figure should be taken with care and should be considered as conservative (medium level of reliability). However, it should be noted that it seems consistent with the losses found by the farmers' association (Unió de Pagesos, 2008), who report about 104 million Euros losses for winter crops for the year 2007 only.

Hydroelectric production losses have been estimated at around 114 million Euros for the whole drought period (70 million Euros for a one-year period). In relation to other economic sectors such

[14] During the drought event itself, a long-running leakage, of around 6,500 m^3/month, was repaired. This repair had been planned since 2000 and therefore it is to be considered a structural measure brought forward (2) and therefore the costs of reparation are not included here. However, during the drought event a temporary set of deposits to collect the leaking water were put in place and the water was collected by lorry for use in municipal and gardening irrigation. The costs of this temporary water collection are imputable to the drought event, as it is a alleviation measure, and are included here.

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Table 3. Summary of direct production losses caused by the drought and level of reliability of estimates.

Sector	Total production losses (M€) drought period (Apr '07–Jan '09)	Production losses (M€) for one-year period	Reliability
River basin authority	6.2	3.7	High
Irrigators	249.4	149.7	Medium
Gardening and flower companies	174.9	104.9	Medium to low
Swimming pool and related companies	75.0	45.0	Medium to low
Hydroelectric production	114.1	68.5	High
Total	619.6	371.8	Medium

as gardening, floristry and other flower-related activities we estimate a direct loss of 105 million Euros for a one-year period. Other activities such as swimming-pools companies and related activities lost around 45 million Euros for a one-year period (75 million for the whole drought period). Added up, all the direct production losses amount to 620 million Euros for the whole drought period, which equates to 370 million Euros for a one-year period (Table 3).

4.2. Indirect economic losses

Table 4 summarizes the total indirect costs using Ghosh's model presented in Section 3.3. In the first column the losses of total production are assigned to the corresponding sector in the IOT. In the second column, losses in production are transformed into losses of GVA. According to the IOT, intermediate consumption represents 22.7% of the total agricultural production, 46.9% in the energy sector, 41.6% in commercial services and 29.7% in public services. Therefore, the total loss of production of 371.8 million Euros per year represents a direct loss in GVA of 242.1 million Euros per year. Finally, from direct losses in GVA we can calculate using the model the indirect losses and total losses per sector. We provide the losses per year, a figure that can be compared with GDP.

From the analysis of the indirect results it can be seen that the reduction in GVA spread to all parts of the economy. For example, the industry sector (with no direct impact) absorbs 63% (132.7 million Euros/year) of the total indirect impact. Other sectors also suffer indirect impacts such as construction (11.4 million Euros/year), restaurants and hotels (14 million Euros/year) or transport services (8.8 million Euros/year). These effects can be explained by the backward and forward linkages that relates one sector to the others. The reduction in the output/GVA of the agricultural sector caused by drought decreases the industrial production which also affects other service sectors and so on. The results show that GVA loss accounts directly for 242.1 million Euros and indirectly for 206 million Euros; that means for each 1 Euro directly lost by drought another 0.85 Euros are lost indirectly. The total economic GVA loss per year amounts to 450 million Euros (0.27% of GDP) and for the drought event this figure goes up to 750 million Euros.

4.3. Non-market welfare losses

The transferred non-market losses for the domestic supply owing to water restrictions and environmental damage are presented in Table 5 per household per year. The non-market losses associated

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Table 4. Indirect costs of the drought.

	Direct loss of production (M€) for one-year period	Direct loss GAV (M€) for one-year period	Direct loss GAV (M€) drought period (Apr ’07 – Jan ’09)	Indirect loss GAV (M€) for one-year period	Indirect loss GAV (M€) drought period (Apr ’07–Jan ’09)	Total loss GAV (M€) for one-year period	Total loss GAV (M€) drought period (Apr ’07–Jan ’09)
1. Agriculture	149.7	115.7	192.8	5.2	8.7	120.9	201.5
2. Extractive industry	0.0	0.0	0.0	0.3	0.5	0.3	0.5
3. Industry	0.0	0.0	0.0	132.7	221.2	132.7	221.2
4. Energy, gas and water	68.5	36.3	60.5	6.3	10.5	42.6	71.0
5. Construction	0.0	0.0	0.0	11.4	19.1	11.4	19.1
6. Commercial services	149.9	87.5	145.8	10.8	18.0	98.3	163.8
7. Restaurant/ hotel services	0.0	0.0	0.0	14.0	23.3	14.0	23.3
8. Transport services	0.0	0.0	0.0	8.8	14.7	8.8	14.7
9. Financial services	0.0	0.0	0.0	0.9	1.5	0.9	1.5
10. Estate agency services	0.0	0.0	0.0	6.8	11.4	6.8	11.4
11. Public services	3.7	2.6	4.3	2.2	3.7	4.8	8.0
12. Education services	0.0	0.0	0.0	1.1	1.9	1.1	1.9
13. Health and social services	0.0	0.0	0.0	3.4	5.6	3.4	5.6
14. Other social services	0.0	0.0	0.0	4.0	6.7	4.0	6.7
Total	371.8	242.1	403.5	208.0	346.6	450.0	750.1

Table 5. Non-market welfare losses.

Damage	Cost (€ per household/ year)
Water restrictions on secondary uses in households	203.65
Reduction of environmental quality owing to decrease in water flow (from moderate level to low level)	7.95
Reduction of environmental quality owing to decrease in water flow (from good level to low level)	22.22

Source: Transferred and income-adjusted from Martin-Ortega *et al*. (2011).

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Table 6. Summary of the costs of the main measures implemented to address the drought and level of reliability of estimates.

Type of measures		*Total costs (M€) drought period (Apr '07–Jan '09)	*Costs (M€) for one-year period	Reliability
River basin authority	Alleviation measures	42.2	25.4	High
	Structural measures	9.8	5.9	
Water suppliers	Alleviation measures	29.6	17.8	High
Total		81.6	49.1	High

*Amortized over an average useful life period of 15 years.

with the loss of environmental quality are estimated in the range between 8 and 22 Euros per household per year. It should be noted that this approximation implies the assumption that the environmental damage only lasted one year, which is probably not the case as the environmental consequences can remain in the system or only come out later by accumulative effect. The welfare loss of water restrictions for secondary uses in households is estimated at 203.65 Euros per household per year.

Aggregating the individual (household) values to the whole affected population (social cost)[15] leads to a total cost of 414.84 million Euros owing to water restrictions and between 15.88 to 45.26 Euros owing to environmental damage. The total aggregated non-market loss is estimated to be about 445.42 million Euros for a one-year period.

4.4. Costs of the measures

Table 6 summarizes the costs of the main measures implemented to address the drought and the level of reliability of these estimates. The total cost adds up for the whole drought period to 82 million Euros. This corresponds to almost 50 million Euros for a one-year period, taking into account a total duration of the drought event of 20 months (from April 2007 to January 2009).

The total costs of structural measures add up to 59 million Euros, but only around 10 million have been imputed to the 2007/2008 drought (taking into account the useful life of the measures). Alleviation measures add up to 42 million Euros for the whole drought period (25 million Euros per year). The total cost for the river basin authority for a one-year period adds up to 4.2% of its budget for 2008. Cost-effectiveness considerations regarding these measures are discussed later.

5. Discussion

The total costs estimated for the drought event affecting Barcelona between 2007 and 2008 have been estimated here to be 1,605 million Euros for the whole drought period, corresponding to about 963 million Euros for a one-year period, which corresponds to 0.48% of Catalan's GDP (Table 7).

Of this total, about 80 million Euros (5%) correspond to the costs of measures undertaken by the river basin and other authorities to address the drought. The rest is made up of the direct, indirect and non-market losses of the economy and society. It is worth noting how the non-market welfare losses are of

[15] A total of 5.5 million people is said to have been affected by the water scarcity conditions. According to the Official Regional Catalan Statistics Office, there is an average of 2.7 persons per household (http://www.idescat.cat/).

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Table 7. Total cost of the drought event in Barcelona.

Type of costs	Cost (M€) drought period (Apr '07–Jan '09)	Cost (M€) for one-year period	% of total cost	% Catalan year GDP
Direct economic losses (GAV)	403.5	242.1	25.1	0.12
Indirect economic losses (GAV)	377.6	226.6	23.5	0.11
Non-market welfare losses owing to household restrictions	691.4	414.8	43.1	0.21
Non-market welfare losses owing to environmental damage[a]	50.9	30.57	3.2	0.02
Cost of the measures	81.6	49.1	5.1	0.02
Total costs	1,605.1	963.1		0.48

[a]Average of 15.88 and 45.26 million Euros per year corresponding to moderate and good environmental levels baselines.

the same order of magnitude as the direct and indirect economic losses, representing more than 40% of the total losses.

It is also remarkable how relatively small the outlays for the alleviation measures are relative to the total value of the losses. It would appear that the authorities depend much more heavily on passing the burden of adjustment to the users than in undertaking action themselves.

For policy purposes, it is interesting to look at the cost-effectiveness of the different implemented measures; that is, how costly it was for each of the measures to provide one additional cubic metre (Euros/m^3). Although a detailed analysis of each of the measures is outside the scope of this paper, a comparison of the cost-effectiveness ratio of some of the measures can be insightful (Table 8).

In the case of the supply-side measures, the river basin authority reports data on the total costs and volumes supplied both by the water shipping and the headwater cisterns (Agencia Catalana del'Aigua, 2009b). It can be observed that the transport of water by boat is a highly non-cost-effective measure, with a huge cost per cubic metre (32.6 Euros/m^3). The supply of water by headwater cisterns cost around 2.3 Euros/m^3.

Table 8. Cost-effectiveness ratio of some of the implemented measures.

Measure		Cost-effectiveness ratio (€/m^3)
Demand measures		
Communication and awareness raising campaigns for water saving	No welfare loss considerations	0.03
	Welfare loss considerations	1.36
Supply measures		
Alleviation measures	Water shipping	32.59
	Headwater cisterns	2.30
Structural measures	Well recovery and enhancement of groundwater extraction[a]	0.18
	Enlargement of existing desalination plant[b]	0.61–1.30

[a]Average cost of different wells and groundwater exploitation (Agència Catalana de l'Aigua, 2009b).
[b]La Tordera desalination plant, which has a working capacity between 6 to 20 Hm^3/day. Lower bound corresponds to 2011 costs obtained from personal communication from Agència Catalana de l'Aigua. Upper bound reported in Karagiannis & Soldatos (2008) for desalination plants with a capacity from 12,000 to 60,000 m^3/day.

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In regard to structural measures, an average cost-effectiveness ratio of 0.18 Euros/m^3 is estimated for the recovery of not-in-use existing wells and increasing groundwater extraction. Regarding desalination, data corresponding to the enlarged La Tordera desalination plant are estimated in the range 0.61–1.30 Euros/m^3. Costs of desalination are quite variable, since they depend on the working volumes (which are adjusted to the demand) and the electricity prices.

In relation to the demand-side measures, we focus on household water savings. In general it is much more complicated to measure the effectiveness of demand constraint measures as it is difficult to estimate how much of the saved water can be imputed to a particular measure. As there were no actual water cuts in the household during the drought period (the use of water for secondary uses was banned but there was always tap water available), we can assume as an approximation that the reduction of water consumption in households can be attributed to the communication campaigns and water saving measures implemented by the authorities. According to the data of the river basin authority, water savings in households adds up to 506.2 Hm^3 for the drought period (Agència Catalana de l'Aigua, 2009b). Expenditure on communication campaigns, awareness raising and water saving actions was 3.65 million Euros, producing a cost-effectiveness ratio of 0.034 Euros/m^3, which is very low. However, as has previously been mentioned, restriction of water use in households is not without consequences for the population in terms of welfare. If we add the welfare losses caused by the restrictions in households estimated in this study (691.40 million Euros) to the costs, the ratio rises to 1.36 Euros/m^3.

According to these results, the most cost-effective measure for addressing a drought is to increase the adaptive structural capacity of the system to handle water scarcity. This is even more relevant in the context of climate change, where the general water availability is expected to decrease and drought events are expected to be more frequent. Infrastructures cannot be, however, designed for extreme events, so alleviation measures are also going to be needed. When an emergency comes, demand-side measures aimed at reducing consumption should be prioritized over supply-side measures. This is very obvious in the case of water shipping, which is an exceptionally expensive measure, but also for the headwater cisterns.

6. Concluding remarks

The total costs of the extreme drought event affecting the metropolitan area of Barcelona in 2007 and 2008 have been estimated here at 1,605 million Euros (or 963 million Euros for the one-year period), representing almost half a point of Catalonia's GDP. The order of magnitude of these estimates is similar to others reported in the USA and Australia in recent years and also within the range of other studies of water scarcity in Catalonia (Freire, 2011). This calculation also suggests that the current estimation of costs realized at the European level are underestimates. This confirms the necessity of carrying out more specific and accurate studies in Europe, to help the currently ongoing design of European drought policy.

The study presented here is not exempt from limitations that should provide guidance for future research in this field. First, not all the direct costs reported here have been estimated with a high level of reliability. This limitation is due to the lack of data at the appropriate scale. Future and more accurate estimates require a refinement of the process of data gathering. For example, this is a major issue in the case of agricultural production, where water productivity (Euros/m^3) should be systematically studied and reported at the regional level. More difficult is the case of other water-related

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activities besides agriculture and hydropower, where a strong dependence on sector reporting (with the consequent potential lack of impartiality and inaccuracy) will probably still be present.

Regarding calculations of the indirect costs, the limitations of the IO models approach should be taken into account when interpreting the results. As there is no possibility of substitution between inputs, economic impacts could be considered as an upper bound. A CGE model approach could be used in the future to incorporate substitution possibilities together with endogenous price change effects.

As far as the non-market welfare losses for the environmental damage and the restrictions to household water supply are concerned, like any value transferability exercise, the estimates reported here are expected to be subject to significant transfer errors, owing to the differences in the environmental conditions of the policy and study site and the socio-demographic differences in the involved population. While undertaking primary valuation studies would be ideal, but unlikely, it should be noted that significant progress is taking place in the environmental valuation literature for the refinement of the transfer methods (see Johnston & Duke (2010) for a recent discussion). This could benefit from the recent and ongoing significant progress that is taking place at the European level for the estimation of the environmental costs and benefits of the implementation of the Water Framework Directive (WFD) – see Martin-Ortega *et al*. (2011) for a recent review. However, for this to be most effective, an important step forward would be to increase the reporting of valuation models based not on best-fit principles but on theory-driven variables which can be more easily used for transferability purposes.

Future research should also look at higher-order and longer-term effects including both market and non-market losses, as it is known that drought losses become fully observable only months and years after the end of the drought event.

Another topic that requires further research is the issue of how to attribute the costs of the structural measures to individual drought events. It has been shown in this study that structural measures that increase the adaptive capacity of the system in the face of water scarcity and drought are more cost-effective than alleviation measures. Water scarcity in general and the expected increase in frequency and intensity of drought events due to climate change will require the implementation of preventive structural measures to increase the adaptive capacity of the territories. The estimation of the costs of adaptation to climate change is still an under-researched area and any future assessment of the costs of drought should take part in that discussion. A conceptual framework for the estimation of the costs of adaptation to climate change is still missing and would require, among others, definition of the target of adaptation both in terms of reactive and preventive measures and how much residual damage is to be addressed (and therefore, which mitigation actions are needed)[16]. In the European context, this needs to be done in the context of the revision of the river basin management plans as part of the implementation of the WFD.

Finally, in this paper we have estimated the costs of the Barcelona drought event considering the measures that were actually carried out to address water restrictions for current normal demand. This does not imply that these measures were necessarily the most appropriate according to all criteria or that political controversy regarding water management in Spain has not played a role in the decision making process. Moreover, the costs of the measures to avoid restrictions are obviously dependent on the baseline of water demand over which they are calculated (in this case 2005–2007). It could be argued that the increase in the demand in recent years sets up an 'unreasonable' or unsustainable

[16] For a review of existing estimates of the costs of adaptation to the impacts of climate change in freshwater systems and key elements for a conceptual framework, see Martin-Ortega (2011).

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baseline and that the welfare losses derived from not reaching this ‘unsustainable normal’ demand represent an overestimation.

Acknowledgements

This study is part of the 7th EU Framework Program Project XEROCHORE: An Exercise to Assess Research Needs and Policy Choices in Areas of Drought: http://www.feem-project.net/xerochore/.

The authors are deeply grateful to the Agència Catalana de l’Aigua, whose help was crucial for the elaboration of this study. In particular we acknowledge the valuable assistance of Jordi Pastor, Andreu Manzano, Jorge Helmbrecht and Gemma Iturbe Iglesias. We also thank Toni Barreda-Escoda (Servei Meteorologic de Catalunya) and Vicent Altava (Astronomy and Meteorology Department, University of Barcelona) for their help with the physical characterization of the drought event and Sandra Castillo from the Department of Agriculture, Food and Rural Affairs of the Catalan government for her help with the agricultural data. We are grateful to the members of the AquaMoney Project for the use of non-market values of water under scarcity conditions used in this study for transferability. We are also grateful to Jose Munoz-Rojas for his help with the cartographic material.

This study was presented at the Xerochore Workshop on the Socio-Economic and Environmental Impacts on Droughts, held in Venice from 5 to 7 October 2009, where it received very relevant feedback from the Xerochore network experts, to whom we are grateful. Only the authors are responsible for the content of this document.

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Received 15 October 2010; accepted in revised form 19 October 2011. Available online 26 December 2011

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