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Groundwater Overdraft, Electricity, and Wrong Incentives: Evidence from Mexico

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Abstract

Groundwater overdraft is threatening the sustainability of an increasing number of aquifers in Mexico. The excessive amount of groundwater extracted by irrigation farming has significantly contributed to this problem. The objective of this paper is to analyse the effect of changes in groundwater price over the allocation of different production inputs. I model the technology of producers facing groundwater overdraft through a Translog cost function and using a combination of multiple micro-data sources. My results show that groundwater demand is inelastic, -0.54. Moreover, these results also show that both labour and fertiliser can act as substitutes for groundwater, further reacting to changes in groundwater price.

JEL codes: Q12, Q25

Key words: Groundwater, Electricity, Subsidies, Mexico, Translog Cost

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Introduction

The high rate of groundwater extraction in Mexico is threatening the sustainability of an increasing number of aquifers in the country. Today in Mexico 1 out of 6 aquifers is considered to be overexploited (CONAGUA, 2010). Groundwater overdraft is not only an important cause of major environmental problems, but it also has a direct impact on economic activities and the wellbeing of a high share of the population. Indeed, overexploited aquifers in Mexico are the main source of fresh water for 75 million people in Mexico (CONAGUA, 2010).

Groundwater overdraft has been mostly driven by the agricultural sector. Agriculture accounts for 70% of all the groundwater extracted in Mexico. Policies trying to improve the competitiveness of the agricultural sector have distorted the price of groundwater. These include the lack of an adequate pricing scheme and the provision of subsidies for production inputs. In the case of the latter, subsidies embedded in electricity fees have been probably one of the most important factors promoting groundwater overdraft. This follows from the fact that electricity is the main source of energy for pumping groundwater in Mexico; and that under the current system of concessions the price of groundwater is practically equal to zero.

Although during the past decade the possibility of decoupling this subsidy has been the centre of important debates, there is little empirical evidence on the effects of changes in groundwater price over the allocation of key production inputs. This paper contributes to evidence-based policy making in Mexico by estimating cross-price elasticities for groundwater, labour and fertiliser.

My analysis builds on previous empirical work analysing the factors driving groundwater demand[1]. Irrigation technology appears in the literature as one of the most

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[1] For a more detailed discussion on the economic aspects of groundwater extraction and a more extensive review of the literature see Koundouri (2004) and Schoengold and Zilberman (2007).

important determinants of groundwater consumption. More precisely, the choice of irrigation technology has a direct impact on groundwater demand. Traditional irrigation methods like furrow and flooding are more water intensive than sprinklers and drip technologies. Moreover, the choice of irrigation method is closely linked to the type of crop being produced. Caswell and Zilberman (1985) study the determinants of irrigation technology in six counties in California using a multinomial econometric model. Their results show that the likelihood of adopting a more water-saving technology increases when the price of water increases. Moreover, according to these results the adoption of more efficient technologies seems to be more important in the case of irrigators relying exclusively on groundwater. Following a similar methodology, Green et al. (1996) show that the adoption of irrigation technologies is highly dependent on crop choice. Their results show that the price of water does influence the adoption of more efficient technologies, however it is not the most important factor. Instead, physical and agronomic characteristics seem to play a more important role.

Another important area of research within the literature from which my analysis builds on is the estimation of groundwater elasticity. Although estimation methods have varied mostly depending on data availability and the type of pricing scheme (or lack of it), previous results show that the demand for groundwater is inelastic. Since in most cases groundwater lacks of a proper price system, it is a common practice to use an indirect method to identify the marginal cost of groundwater extraction (also known as pumping costs). For instance, Nieswiadomy (1988) computes the price of pumping water as the energy needed to pump one acre foot of water per foot of lift times the average lift expressed in dollars. This study uses county data to analyse the adaptability of irrigators in Texas to changes in the relative prices of different inputs including groundwater. To capture input substitution effects this study uses a Translog cost function. This model provides an estimate for groundwater's elasticity equal to –0.25. In addition, these results suggest that groundwater is used as a substitute for both labour and furrow (irrigation method). Having access to a richer dataset, Ogg and Gollehon (1989) analyse a sample of farms in 16 Western states in the United States. Price of groundwater is computed as the total cost of the fuels used for groundwater extraction divided by the total amount of water used. These authors use different specifications while controlling for different climatic regions. Their elasticity estimates, despite varying across regions, are similar to the one from Nieswiadomy (1988) ranging from –0.24 to –0.34. Moore et al. (1994*b*) also accounts for differences across regions and across different types of crops. These results further suggest that the response to a change in the price of groundwater is different among crops, and in some cases could even be positive.

All these studies assume that the marginal cost of extraction remains the same independently of the pumping intensity, but this may not be the case in practice. Kanazawa (1992) considers this assumption to be inadequate and highlights the possible presence of endogeneity when estimating water demand through a specification relying on a single equation. This author proposes to use a system of equations accounting for both the demand and supply of groundwater while controlling for certain hydrological characteristics of the aquifers under study. The results following this analysis not only confirm the presence of increasing marginal costs of pumping water, but they also suggest that water and capital can be considered as substitutes for production.

The linkage between energy and groundwater has received increasing attention in the economic literature. For instance, Zilberman et al. (2008) provide an extensive discussion on the linkage between energy and water, highlighting the fact that higher energy prices will make extraction and conveyance of water more costly.

The latter suggests that energy prices could be considered as a useful policy tool for coping with environmental issues related to groundwater overdraft. Nevertheless, these authors further highlight that technological improvements making extraction and transportation cheaper can offset the effects of rising energy prices. For this reason, institutional capacity and mechanisms that improve water allocation will be key for future reforms aiming to improve water sustainability.

Empirical studies confirm the presence of an inverse relationship between energy prices and ground water consumption. In the case of developed countries, Schoengold et al. (2006) is one of the first studies using panel-data for analysing the energy water linkage. These authors analyse the effects of changes in the prices of energy over the water demand in California's San Joaquin valley. The results from this study show that farmers respond to changes in the marginal price of water, both by reducing the consumption of water and by modifying land allocation. The total own price elasticity estimated in this study is –0.78, which is a value significantly higher than previous estimates. Pfeiffer and Lin (2014) also analyse a panel data for Kansas between 1996 to present. Their results also show that a decrease in the price of energy increases the quantity of water consumed and influences the allocation of crops. According to their results, the estimated elasticity of water extraction with respect to energy's price is –0.26. In the case of developing countries, India has received particular attention. Kumar (2005) provides a theoretical model to analyse farmers' response to changes in electricity tariff and groundwater allocation regimes. This analysis shows that unit pricing of electricity promotes a more efficient use of groundwater. Moreover, this author also suggests that a combination of electricity pricing schemes, along with fixed allocation of groundwater, can further enhance both water and electricity productivity. Also for India, Badiani and Jessoe (2013) empirically analyse the effect of an increase of the price of electricity on the consumption of groundwater at the district level. According to their estimates, groundwater elasticity equals –0.13. Moreover, these authors further suggest that electricity subsidies in India promote the production of water intensive crops such as rice.

Only a small number of studies has empirically analysed the effects of groundwater overdraft in Mexico. The increasing number of overexploited aquifers in the country, and the recognition of Mexican authorities of the perverse incentives created by electricity subsidies, has caught the attention of a small number of academics. However, so far, most of these studies have been limited to analysing the political economy behind the linkage of groundwater overdraft and electricity. Shah et al. (2004) compare the Indian and Mexican experience in terms of groundwater management, and provide a comprehensive review of the water reforms carried out in Mexico during the last two decades. Scott and Shah (2004) provide an insightful review of the institutional context and key policy constraints characterising the groundwater sector in India and Mexico. Based on the experiences of both countries, this study further suggests that regulatory instruments based on power supply controls could provide incentives for a more efficient use of groundwater. However, these types of instruments could impose certain technical and political costs that should be considered before any attempt of implementation. To my knowledge, Munoz et al. (2006) is the only study at present analysing the effects of changes in electricity prices over groundwater consumption in Mexico. This study uses a cross-sectional sample of irrigators in different Mexican states. The price of groundwater for each farmer is computed using a methodology similar to Ogg and Gollehon (1989), i.e. groundwater's price is considered as the ratio of the electricity bill with respect to the total water consumed. The value of groundwater's elasticity found by these authors is equal to –0.16. More recently, following the efforts of Mexican authorities in reducing poverty, the World Bank carried out a study analysing the linkage between groundwater overdraft and poverty at the municipal level (WorldBank, 2009). This study agrees with Munoz et al. (2006) on the role of electricity as one of the main drivers of groundwater overdraft, but concludes that the effect of aquifer overexploitation on the level of municipal poverty is not significant. The latter may be due to the fact that poor producers do not use groundwater, instead they rely on water-wheels and surface water. Despite the important contributions provided by these studies there are still some important issues to be addressed, including the way in which producers substitute groundwater for other production inputs, as well as policy alternatives for decoupling the electricity subsidy.

In this paper I focus my attention on irrigators based in aquifers suffering from groundwater overdraft in Mexico. I analyse the different effects following a change in the price of groundwater over the allocation of production inputs. To this end, I use a combination of data sources to estimate a cost function that further allows to compute different types of elasticities. These data sources include a unique dataset containing micro-data on the most relevant characteristics of firms based in aquifers suffering from high extraction rates, official statistics, as well as information on environmental characteristics built through geographic information systems (GIS).

My empirical strategy exploits regional variation across producers in different Mexican states. Using the the neo-classical theory of the firm as main theoretical framework, I model producers technology through a Translog cost function. The main advantage of this approach is that it allows to compute cross-price effects, i.e. the effects of changes in the price of one input over the quantity consumed of other variable inputs. To improve the robustness of my results I use simulation techniques to compute standard errors and confidence intervals of all estimates. The latter follows the concerns highlighted in recent literature about classical statistical test (relying on linear approximations) applied to Translog elasticity estimates (Anderson and Thursby, 1986; Krinsky and Robb, 1991).

The results from this study have relevant policy implications. In the first place, they provide more compelling evidence on the link between electricity and groundwater extraction by showing that water for irrigation does respond to changes in electricity tariffs. According to my estimates, an increase of 10% in groundwater price in overexploited aquifers *on average* could reduce water consumption by 5%. In addition, changes in the price of electricity further affect the allocation of other production inputs. Cross-price elasticity estimates show that labour and fertilisers act as a substitute for groundwater. In other words, an increase in the price of groundwater increases the quantity consumed of both labour and fertilisers. Despite the latter, implementation of programmes aiming at decoupling electricity subsidies and raising electricity fees will face important challenges. Only 11% of the producers considered in the sample analysed will be keen on decoupling the subsidy and receiving it as a direct transfer. The small willingness to accept the potential decoupling of electricity subsidies imposes real and critical challenges for Mexican authorities. Moreover, this percentage hides important regional variations. Producers in northern states close to the U.S. border are significantly less interested in such a policy alternative, while for those in central states this policy alternative seems to be more appealing. The latter suggests that existing policy strategies should not only account for territorial difference, but further acknowledge the spatial heterogeneity of policy outcomes.

This paper is structured as follows. The first section provides background information on the main characteristics of aquifers and consequences of groundwater overdraft. This section also describes the institutional settings and regulatory mechanisms governing groundwater extraction in Mexico. Section two presents my empirical strategy including the analytical framework and econometric model used to estimate cross-price elasticities. Section three provides a description of the data, and section fours presents the results of the econometric model estimating the parameters of the cost function. Section five discusses the policy implications of the empirical analysis including the willingness to accept the possibility of decoupling electricity subsidies. Finally, the paper provides a short conclusion.

1 Background

1.1 Groundwater overdraft?

Contrary to the common belief, aquifers are not shallow reservoirs of water. They are instead layers of sand, soil and rocks where groundwater flows through. Groundwater is naturally brought to the surface by springs or is discharged into lakes and streams. Aquifers are recharged by rainfall or snow melt. The area in the aquifer filled with water is called the saturated zone; the top of this zone is called the water table[2]. Water tables can be found a few meters below the land surface or hundreds of meters below the ground.

Groundwater overdraft refers to the consumption of large amounts of water disturbing the relationship between the extraction and the recharge of an aquifer. Groundwater overdraft not only has a direct effect on aquifers water tables, but it also affects groundwater flow patterns. These disruptions are the main cause of a series of environmental problems compromising the availability and quality of groundwater, as well as contributing to the degradation of a wide variety of ecosystems.

A direct effect of high extractions rates is the reduction of the water table. Lower

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[2] http://www.groundwater.org/

water tables tend to be associated with groundwater of a lower quality. The latter is due to presence of higher concentrations of salts and minerals in lower levels of the water table. In the case of over-exploited aquifers close to coastal areas, lower water tables can favour seawater intrusion which can further compromise water quality by increasing salts concentration.

Groundwater quality can be also compromised by irrigation activities. Not all irrigation water is absorbed by the plants or evaporated, instead it infiltrates or percolates into the aquifer. Irrigation water percolating into the soil usually contains higher concentrations of salts. Moreover, in some cases, irrigation water may also contain pollutants coming from fertiliser and pesticides. Changes in groundwater flow patterns can further reduce water quality by favouring the infiltration of polluted irrigation water and by contributing to the displacement of saline water bodies (Custodio and Botín, 2000).

A significant reduction in the water table can also affect the capacity of the aquifer to support the soil above, making the land in the surface to settle and compress. This phenomenon is called land subsidence. Land subsidence manifests through changes in the surface elevation. These changes in the surface can go from a small depression to the total collapse of the aquifer. Land subsidence can seriously affect certain types of infrastructures like buildings and roads.

The over-exploitation of aquifers can also have an impact on water bodies in the surface. Aquifers belong to an hydrologic system that interconnects groundwater to surface water. Thus, groundwater overdraft further affects springs discharges, rivers base flow, and the surface area of wetlands (Custodio and Botín, 2000). Moreover, the latter directly affects the ecosystems embedding these water sources by reducing the population of flora and fauna, and threatening endemic species with extinction (Zektser et al., 2005).

Groundwater overdraft also has a direct impact on economic activities. The reduction in groundwater level forces irrigators to drill deeper wells, which implies higher pumping and maintenance costs. Moreover, if the quality of groundwater has been compromised, irrigators have to incur into additional filtration costs. Under normal circumstances, higher production cost will translate into higher output prices or into lower revenue.

The number of Mexican aquifers classified as over-exploited or suffering from salinisation problems has increased in the past decades. Mexican authorities consider an aquifer to be overexploited when the amount of water extracted is higher than the amount of water filtering in and recharging the aquifer. According to the Mexican National Water Commission (CONAGUA), by the end of 2010 there were 101 (out of 653) aquifers in the country classified as overexploited, compare to 32 overexploited aquifers in 1975 (CONAGUA, 2010). Despite groundwater overdraft contributes to reducing the quality of groundwater, some aquifers not considered as overexploited can also suffer from salinisation and pollution-related problems. Custodio and Botín (2000) suggests that, in some cases, even moderate extraction rates can affect the balance of the aquifer and deteriorate water quality. By 2010, among exploited and non-exploited aquifers, there were 16 aquifers suffering from seawater intrusion and 32 suffering from salinisation problems (CONAGUA, 2010). In addition to the environmental concern raising from this situation, further issues regarding population's wellbeing are becoming key topics in the agenda of Mexican authorities. Indeed, overexploited aquifers in Mexico supply close to 60% of all the groundwater consumed by the agricultural, industrial and municipal users (CONAGUA, 2010).

1.2 The elusive quest for groundwater management in Mexico

The management of groundwater resources in Mexico relies on an allocation system that does not provide the right incentives for a sustainable use of this resource. Indeed, despite the existence of a complete institutional framework regulating the extraction of groundwater, failures in the design of the current regulatory instruments and inconsistent crossed-sectoral policies have contributed to the excessive extraction of groundwater by the agricultural sector.

Agriculture is the most intensive water-user in Mexico. In 2009 agriculture accounted for 77% of all the water consumed and for 69% of all groundwater extracted in the country. Moreover, groundwater is the main input for irrigation activities in arid and semi-arid regions in the centre, north-west, and north side of the country. Some of the main advantages of groundwater-based production include reliability on the water supply, a better control on the volume of water applied to crops, and amenability to improved irrigation technologies (Scott and Shah, 2004). In the past three decades, important reforms attempting to regulate the extraction of this resource were implemented by Mexican authorities. These reforms attempted to move from a water management approach based on the supply, to a regulatory system controlling for the demand of water (Roemer, 1997). In practice, this translated into a more robust regulatory system and into governmental bodies explicitly in charge of managing water resources.

Water resources are regulated by a system of complementary laws at the federal level. The Mexican Constitution establishes that all water bodies, on the surface and underground, belong to the Mexican State who is the one and only one in charge of providing concessions to firms, individuals or public agencies for the use and extraction of water resources (Article 27). The instruments and mechanisms managing water resources aiming at implementing the latter constitutional mandate are embedded in the National Water Law (Ley de Aguas Nacionales, LAN). The LAN is the most important law regarding water resources in Mexico. It is complemented by the Federal Duties Law (Ley Federal de Derechos, LFD), which defines the fees for water consumption.

In practice, the management of water resources is carried out by the National Water Commission (Comision Nacional del Agua, CONAGUA). Being a federal agency, CONAGUA's jurisdiction applies everywhere in the country. CONAGUA is not only in charge of defining water policy at the national level, but it is also in charge of verifying water availability and of granting permits and concessions.

The allocation of water resources in Mexico is based on a system of concessions. A concession defines the maximum amount of water, as well as the number of water sources, that a concession holder is allowed to use. Concessions are priced according to both the type of activity the water is used for and the water availability in the municipality where the consumption (or extraction) is taking place[3]. Concessions have a duration of 5 to 10 years. Once the concession fees are paid, the concession holder is entitled to extract water up to the maximum limit defined by the concession without any additional costs. In case of extracting water beyond the limit of the concession, the user is charged with a volumetric fee. It is compulsory for all irrigators to have a concession. The LAN establishes that all irrigators lacking of a concession are incurring into an illegal activity. In regions with high water stress, the provision of additional concession is banned; thus, for these regions, concessions serve as an entry-control tool. Holding a concession also grants them access to cheaper electricity prices.

Irrigation activities benefit from highly subsidised electricity tariffs. Since 2003, Mexican authorities have promoted the competitiveness of the agricultural sector

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[3] The LFD classifies municipalities in nine different zones depending on the scarcity of water

by subsidising the electricity tariffs for irrigation activities. There are two different groups of electricity tariffs for irrigation. The first group corresponds to those tariffs accessible for concession holders; these tariffs are coded 9CU (day tariff) and 9N (night tariff). Despite the LAN establishes that it is compulsory to have concession in order to irrigate, a second group of tariffs is available for those irrigators without a concession: 09 and 9M. Both groups of tariffs are subsidised, though the first group receives a bigger subsidy. Indeed, estimates suggest that the first group of tariffs has received a subsidy up to 83% (Cob and Romero, 2011).

The main source of energy used to extract groundwater in Mexico is electricity. In 1993, water pumping for irrigation accounted for 6.5% of total electricity yearly consumed in the country (Tsur, 2004). However, due to illegal connections, this author further suggests that the actual electricity consumption of water pumping could have been close to 10% (Tsur, 2004). The incentives created by these subsidies are not the only cause behind the overexploitation of aquifers in Mexico; there exist additional policy and institutional failures contributing to groundwater overdraft.

Inefficiencies in the internal design of the concessions, along with external factors blocking the implementation of the LAN, prevent the adequate allocation of water resources in Mexico. Probably the most important deficiency in the design of the concessions is the method establishing the maximum limit for extraction. The maximum limit established by the concessions is based on the technical characteristics of the pumping system (Shah et al., 2004; Cob and Romero, 2011) and not on a scheme promoting the conservation of the resource. The latter implies that the constraints imposed by the concessions are rarely binding. Moreover, even when this constraint is binding, the price paid by any additional cubic meter is really low. Actually, the LFD assigns to agricultural activities the lowest price in the country. This price is the same for all the regions in the country, independently of the availability of water in the region.

External factors preventing the proper implementation of the LAN include high monitoring costs and inefficiencies in law procurement which hamper the capacity of Mexican authorities to control for illegal water extraction. Illegal water extraction is a recurrent problem, specially in semi-arid regions. Scott and Shah (2004) found that in the state of Guanajuato wells were continuously sunk in spite of the official ban. Technically, illegal extraction also includes all irrigators lacking of a concession. In addition, the lack of compliance with the conditions imposed by the concession seems to be also a current problem. Indeed, due to high administrative cost (including inspection costs) and lack of personnel, Mexican authorities cannot verify that water users comply with the limits of the concession. Moreover, it is common knowledge that not every concession holder has a water metering unit; even if they do, in some cases, the metering units are trafficked (Scott and Shah, 2004). Aware of these issues, Mexican authorities have promoted the implementation of participatory instruments. These instruments attempt to complement the system of concessions and to induce a better management of groundwater resources at the local level.

The main participatory instrument promoted by CONAGUA is the Technical Committees for Groundwater (Comites Tecnicos de Aguas Subterraneas, COTAS). The main objective of the COTAS is to provide technical advise to farmers whose water supply comes from overexploited aquifers. However, in practice, it seems that its main objective is helping in the application of the LAN, and more precisely, contributing to the regularisation process of groundwater users. COTAS are expected to mediate between both federal and state authorities and water users, as well as to constrain the illegal extraction of groundwater and help to respect the limits stipulated by the concessions. COTAS were born in the state of Guanajuato, but by now they are implemented in over-exploited aquifers all around the country. The domain of each COTAS is defined by the boundaries of the corresponding aquifer. The main limitation of the COTAS is that on the one hand they depend on the contributions made by their members, while on the other hand their objective is to apply the LAN. In other words, they are designed to spy and denounce their members who pay a contribution for their own existence (Shah et al., 2004).

2 Empirical Analysis

The main objective of this paper is to analyse producers' behaviour following a structural approach. To this end, I model the production technology through a Translog Cost Function. This approach not only allows estimating price elasticities, but also testing for the existence of cross-price effects between groundwater and other production inputs. This section presents the analytical framework used to model producers behaviour and the resulting specification of the empirical model. This section also describes the covariates included in the econometric model, which are further described in Table 1 and Table 2.

2.1 Analytical Framework

As defined by Chambers (1988), the cost function is the minimum cost for producing a given level of output during a given period of time expressed as a function of output and factor prices. The cost function can be expressed in mathematical terms as follows:

$$c(w,y) = min_{x \geq 0}[w \cdot x : x \ \in \ V(y)] \tag{1}$$

Where w is a vector of strictly positive prices, x is a vector of input quantities, y is a vector of production outputs and $V(y)$ is the input requirement set (all input combinations producing the same output level y). Under this setting, producers are atomistic competitors who cannot have an influence on the price of production factors, i.e. factor prices are seen as exogenous.

As mentioned at the beginning of this section, the empirical model I have chosen for representing the cost function follows a Translog approximation. The Translog cost function is a flexible form that provides a second order approximation of the production frontier evaluated in a given point. Thus, it inflicts less restrictions than commonly used specifications like the Cobb-Douglas and CES, which impose a constant elasticity of substitution. In other words, through the Translog specification it is possible to identify cross-price effects.

The Translog function considers the variable cost of production as function of input prices, output quantities and quasi-fixed factors; all these variables are expressed as logarithms. The Translog cost function is defined as:

$$\begin{aligned} ln(VC) = \alpha_0 &+ \sum_{i=1}^{n} \alpha_i lnP_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{i,j} lnP_i lnP_j \\ &+ \sum_{i=1}^{h} \beta_i lnQ_i + \frac{1}{2}\sum_{i=1}^{h}\sum_{j=1}^{h} \beta_{i,j} lnQ_i lnQ_j \\ &+ \sum_{i=1}^{m} \gamma_i lnZ_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} \gamma_{i,j} lnZ_i lnZ_j \\ &+ \sum_{i=1}^{n}\sum_{j=1}^{h} \eta_{i,j} lnP_i lnQ_j \\ &+ \sum_{i=1}^{n}\sum_{j=1}^{m} \theta_{i,j} lnP_i lnZ_j \\ &+ \sum_{i=1}^{h}\sum_{j=1}^{m} \zeta_{i,j} lnQ_i lnZ_j \end{aligned} \tag{2}$$

Where P_i, Q_i and Z_i respectively correspond to the i-th element of the vectors of prices, output quantities and quasi-fixed factors. In order to account for theoretical properties characterising a cost function, the parameters of the Translog function have to be constrained as follows:

$$\begin{aligned} &\sum_{i=1}^{n} \alpha_i = 1 \\ &\sum_{j=1}^{h} \beta_{i,j} = 0 \ ; \ i = 1, \ldots, n \\ &\sum_{i=1}^{n} \gamma_{i,j} = 0 \ ; \ j = 1, \ldots, m \end{aligned} \tag{3}$$

A convenient property of the Translog specification is that factor demands can be expressed as input cost shares. The input cost share for the i-th input is defined as the cost the i-th input divided by the total variable cost. Under this approach, a cost share is a function of input prices, output quantities and quasi-fixed factors (Equation 4).

$$S_i = \alpha_i + \sum_{j=1}^{n} \alpha_{i,j} lnP_j + \sum_{j=1}^{h} \beta_{i,j} lnQ_j + \sum_{j=1}^{m} \gamma_{i,j} lnZ_j \ ; \ i = 1, ..., n \tag{4}$$

Price effects cannot be assessed directly from the parameters of the Translog's cost share equations. Instead, elasticities are computed using the price parameters along with the predicted values of the corresponding cost shares evaluated at their means. The formulas for computing prices elasticities and cross-price elasticities are described in Equation 5.

$$\begin{aligned} \epsilon_{ii} &= \frac{(\alpha_{i,i}+\hat{S}_i^2-\hat{S}_i)}{\hat{S}_i} \\ \epsilon_{ij} &= \frac{\frac{\alpha_{i,i}}{\hat{S}_i\hat{S}_j}+1}{\hat{S}_j} \; ; \; i \neq j \\ \mu_{ij} &= \epsilon_{ij} - \epsilon_{ii} \; ; \; i \neq j \end{aligned} \tag{5}$$

Where ϵ_{ii} is the derived-demand elasticity of the i-th input, ϵ_{ij} is the cross-price elasticity of inputs i and j; and μ_{ij} is the Morishima elasticity of substitution for inputs i and j. Despite other previous studies have used Allen partial elasticities of substitution, I decided to adopt the approach suggested by Chambers (1988) and focus instead on derived-demand and Morishima elasticities[4].

2.2 Model specification

For the purpose of this analysis I consider that the irrigators' cost function is composed by three variable inputs, four types of outputs, and a set of quasi-fixed factors.

I consider groundwater, labour, and fertiliser as the variable inputs for production. Labour and fertilisers have been commonly considered as variable inputs in the water irrigation literature (Nieswiadomy, 1988; Dalton et al., 1997). However, irrigation water has sometimes been assumed to be a variable input and other times a fixed factor for production. The main reason for the latter assumption is the limits imposed on irrigation water by a system of quotas; similarly, when groundwater is the main source for irrigation, the incapacity to access additional wells can be also considered an important constraint for production (Moore and Negri, 1992; Moore et al., 1994*a*; Moore and Dinar, 1995). However, and despite

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[4] Allen elasticities are computed as ϵ_{ij} divided by the cost-share of the j-th input. Hence, Chambers (1988) argues that Allen elasticities just disguise the actual measure of interest, ϵ_{ij}.

groundwater is managed through a system of quotas in Mexico, I have reasons to believe that groundwater can be considered as a variable input for production. The first reason is that the maximum limits established by the water quotas do not reflect the scarcity of resource. Hence, irrigators rarely have to adjust their consumption patterns to meet the quota. Following an extensive analysis of irrigation activities in Mexico, Shah et al. (2004) concludes that quotas established by the concessions do not act as an instrument for controlling water extraction. According to this study, the rules to define the maximum extraction limits specified in the concessions are a function of the characteristics of the water pump and in some cases on the average consumption of previous years. Hence, the limits of these quotas are not designed to influence a lower consumption, instead they just formalise the actual consumption. The second reason is the inadequate pricing system embedded in the concessions. In practice, if irrigators go beyond the limit defined by their quotas, they jump to a higher price block (below the maximum limit of the quota the price per cubic meter is 0). However, the price of a cubic meter of water in this block is so low that it is really hard to think that this mechanism will make irrigators stick to the quota established in their concession. This idea is consistent with some of the comments made by the farmers included in the survey I used as main data source for the analysis. Finally, there exists additional evidence that further suggests that the quotas are not respected. Due to the lack of law enforcement in Mexico, access to illegal wells seems to be a common practice. Scott and Shah (2004) affirm that despite official data shows a decrease in the number of wells since 2000, apparently an increasing number of wells continue to be sunk.

Within the context of the analysis I assume that input prices are exogenous. Both the price of labour (P_{Labour}) and the price of fertiliser ($P_{fertiliser}$) are driven by local markets, thus it is plausible to consider that individual producers do not have a significant influence on them. Considering the inadequate water pricing scheme defined by the concessions, the actual price of groundwater can be seen as the price of electricity used to pump groundwater. Indeed, when the quota's constraint is not binding, groundwater price is equal to zero; yet, irrigators have to pay for the energy used by the pump to extract the groundwater. Almost all pumps being electric, the price of electricity can then be considered as the actual price for every additional cubic meter of groundwater consumed. The electricity tariff for legal irrigators does not vary across regions in Mexico. Nevertheless, the price paid by each irrigator differs according to geographic characteristics regarding the height needed to reach the water table, as well as some technical characteristics of the pumping system (see Table 2). This relationship is identified by the following equation:

$$P_{Water} = F \cdot S \cdot \theta \cdot P_e \tag{6}$$

Where P_{Water} is the price of groundwater, F is the maximum flow rate, S is the static head, θ is a constant accounting for gravity and P_e is the price of electricity. Both the maximum flow rate and the static head (height) are characteristics of the pipe; they are expressed respectively in $\frac{litres}{second}$ and $metres$. Gravity is a constant taking a value equal to 9.81 $\frac{m}{s^2}$ and the price of electricity is expressed in Mexican pesos per Kw/h. Despite the price of Kw/h is defined by Mexican authorities (thus not influenced by the users), the characteristics of the pipe depend on the the type of irrigation technology used. Hence, by adopting a more water efficient technology, water users may be able to influence the price of groundwater in the long term.

Producers' output is grouped in four types of agricultural products. These groups are Alfalfa and Forages ($Q_{A\&F}$), Fruits (Q_{Fruits}), Grains (Q_{Grains}), and Vegetables ($Q_{Vegetables}$). It should be noted that the inclusion of outputs in the specification of costs functions has been criticized in the literature since, depending on the type of economic activity, the quantity of output may be endogenous (Christensen et al., 1973; Fuss, 1977). In the case of agricultural activities, the amount of output is decided long time before the actual production begins and is affected by different climatic events. For this reason, I assume that in this case the amount of output can be considered as an exogenous variable.

The set of quasi-fixed factors considers some inputs directly involved in the production process, as well as environmental and geographic factors that directly or indirectly influence irrigation farming activities.

Physical and environmental conditions have an important influence on the way in which irrigation activities are carried out. For instance, they can affect the choice of irrigation technology and probably the allocation of production inputs. For this reason, the model includes the total amount of rain ($RAIN$) and average temperature ($TEMPERATURE$) during 2009. To account for differences in the topography, the model also includes the slope ($SLOPE$) of the terrain expressed as the percentage of increase in the terrain[5] around the production units. In addition, and to account for soil characteristics, I include into the model two dummy variables indicating the type of soil: clay ($CLAY_{Dummy}$) and sandy ($SANDY_{Dummy}$)[6]. Throughout the literature, these variables are commonly accepted as physical factors influencing the demand of water for irrigation. Studies like Nieswiadomy (1988), Moore and Negri (1992), Moore et al. (1994*b*), Pattanayak and Kramer (2001), Bell (2007) and Tchale and Sauer (2007) used one or more of these variables to control for environmental conditions.

Mexican authorities have defined water availability zones all over the country.

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[5] A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger.

[6] The base category being “loamy” soil.

These zones are the basis for defining water fees across water users. This classification ranks municipalities from 1 to 9; a municipality ranked as 9 is considered to be suffering from extreme water stress. I used this variable ($AVAILABILITY$) to control for additional spatial characteristics not captured through the other environmental variables.

The amount of land used for agricultural activities is usually considered as one of the most relevant fixed factors for production. However, farmers have different combinations of irrigation systems, sometimes even for the same crop. For this reason, and in order to further capture the effect of technology, I decided to use the total amount of hectares having water saving technology ($HECTARES-HT$)[7]. For the latter, I consider micro-sprinklers and drip systems as water saving technology. In addition to land, I decided to control for the number of wells used by each producer ($WELLS$). This number being defined by the concession.

The access to markets is without any doubt an important factor for any economic activity. It is particularly important for accessing input and output markets. To account for this factor, I control for the distance ($DISTANCE$) to the closest population centre with more than 25,000 inhabitants. Places having at least this number of population are officially considered in Mexico as urban places. These places usually host dynamic labour and factor markets as well as the headquarters of authorities. Considering the lack of surveillance and law enforcement that characterised Mexico, the proximity to authorities may have an additional effect on the adequate use of water resources as established by the concessions. This variable has also been used by Munoz et al. (2006).

The lack of adequate monitoring and control is considered to be one of the most relevant factors promoting inefficient use of groundwater. For this reason I con-

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[7] Technologies different from flooding methods

sidered important to control for whether the producers have been previously fined or not ($FINED_{Dummy}$).

Finally, management skills and experience in agricultural activities can influence the allocation of production factors as well as the choice of technology. To account for these managerial characteristics, I have used as proxies the number of years of education ($EDUCATION$) and the number of years carrying out agricultural activities ($TIME$).

2.3 Estimation method

Throughout economic literature Translog cost functions have been estimated following two different specifications. The first specification estimates the parameters of a Translog cost function by only focusing on the system of cost shares described by Equation 4. This is the model specification used by Fuss (1977), Nieswiadomy (1988), and Dalton et al. (1997). The second specification takes into account both the system of cost shares in Equation 4 and the cost function defined in Equation 2. This model specification can be found in Christensen et al. (1973) and more recently in Grisley and Gitu (1985), Behar (2004), and McLaren and Zhao (2009). In practice, the main benefit from the latter specification is the possibility to recover certain parameters that are not included in the system of equations (like the quadratic forms of the output variables). Since these parameters included in the cost function are not relevant to address the main research questions of this study, I opted to only use the system of cost shares (Equation 7). I use this system to estimate the parameters of the cost function through the set of covariates previously described. I achieve the latter by exploiting the variation of input prices, output quantities, and semi-fixed factor across space. Table 2 presents descriptive statistics of input prices, technology, outputs, pumping height, and rain availability across regions.

The system is composed by three equations corresponding to the cost shares of groundwater S_1,labour S_2. and fertiliser S_3. Each equation includes: the prices of groundwater P_1, labour P_2, and the price of fertilisers P_3; the quantities for each group of four different outputs Q_j; each element of the set containing ten continuous quasi-fixed inputs Z_j; and the three dummy variables - two of them accounting for soil types and the remaining one accounting for whether the producer has been fined before - represented by D_j.

$$\begin{aligned} S_1 &= \alpha_1 + \sum_{j=1}^{3} \alpha_{1,j} ln(P_j) + \sum_{j=1}^{4} \beta_{1,j} lnQ_j + \sum_{j=1}^{10} \gamma_{1,j} lnZ_j + \sum_{j=1}^{4} \delta_{1,j} D_j + \epsilon_1 \\ S_2 &= \alpha_2 + \sum_{j=1}^{3} \alpha_{2,j} ln(P_j) + \sum_{j=1}^{4} \beta_{2,j} lnQ_j + \sum_{j=1}^{10} \gamma_{2,j} lnZ_j + \sum_{j=1}^{4} \delta_{2,j} D_j + \epsilon_2 \\ S_3 &= \alpha_3 + \sum_{j=1}^{3} \alpha_{3,j} ln(P_j) + \sum_{j=1}^{4} \beta_{3,j} lnQ_j + \sum_{j=1}^{10} \gamma_{3,j} lnZ_j + \sum_{j=1}^{4} \delta_{3,j} D_j + \epsilon_2 \end{aligned} \tag{7}$$

In order to comply with the assumptions embedded in the theory of the firm, the parameters in Equation 7 have to be further constrained during the estimation procedure to account for the symmetry of price effects, $\alpha_{i,j} = \alpha_{j,i}$ for $i \neq j$. Moreover, in addition to this constraint, to account for linear homogeneity in factor prices the parameters of the model should respect the following restrictions:

$$\begin{aligned} &\sum_{i=1}^{3} \alpha_i = 1 \\ &\sum_{j=1}^{4} \beta_{i,j} = 0 \ ; \ i = 1,2,3 \\ &\sum_{i=1}^{3} \gamma_{i,j} = 0 \ ; \ j = 1,\ldots,10 \\ &\sum_{i=1}^{3} \delta_{i,j} = 0 \ ; \ j = 1,2,3,4 \end{aligned} \tag{8}$$

To estimate the parameters in Equation 7, it is necessary to address a problem concerning the singularity of the covariances matrix. This problem is due to the fact that share equations sum up to 1 (Nieswiadomy, 1988). In the literature, this issue is usually solved through a series of constraints across the parameters of the model. This constraint is applied by removing one of the share equations from the system, while dividing the remaining n–1 input prices by the input price corresponding to the cost share that has been removed; this price is usually known as the numeraire. The parameters of the remaining system composed by the n–1 cost share equations can be then estimated through the method of seemingly unrelated equations (SURE) using a maximum-likelihood iteration procedure. The estimates from this procedure are invariant to which equation is removed (Christensen et al., 1973; Fuss, 1977; Nieswiadomy, 1988).

The system of cost shares taking into account all these constraints is described by Equation 9.

$$\begin{aligned} S_1 &= \alpha_1 + \sum_{j=1}^{3} \alpha_{1,j} ln(P_j/P_3) + \sum_{j=1}^{4} \beta_{1,j} ln Q_j + \sum_{j=1}^{10} \gamma_{1,j} ln Z_j + \sum_{j=1}^{4} \delta_i D_j + \epsilon_1 \qquad (9) \\ S_2 &= \alpha_2 + \sum_{j=1}^{2} \alpha_{2,j} ln(P_j/P_3) + \sum_{j=1}^{4} \beta_{2,j} ln Q_j + \sum_{j=1}^{10} \gamma_{2,j} ln Z_j + \sum_{j=1}^{4} \delta_i D_j + \epsilon_2 \end{aligned}$$

As can be seen from Equation 9, I considered the price of fertiliser as the numeraire. The parameters of S_3 can be recovered using the constraints given by Equation 8.

Table 1 – Description of variables used for the econometric model

Tag	Variable	Units	Mean	S.D.	Min	Max	N
P_{Water}	Price of groundwater	$MEX\$$ *per* m^3	13.8	21.24	0.023	131.84	433
P_{Labour}	Price of Labour	$MEX\$$ *per day*	119.3	12.56	100	150	440
$P_{Fertilizer}$	Price of fertilizer	$MEX\$$ *per Tonne*	6381.5	1450.52	4021.66	8475.72	440
$Q_{A\&F}$	Quantity of Alfalfa and Forages	$Tonnes$	259.1	923.57	0	12000	440
Q_{Fruits}	Quantity of Fruits	$Tonnes$	50.7	303.07	0	4950	440
Q_{Grains}	Quantity of Grains	$Tonnes$	47.5	188.15	0	3150	440
$Q_{Vegetables}$	Quantity of Vegetables	$Tonnes$	251.4	787.23	0	6420	440
$RAIN$	Yearly precipitation	mm	382.1	284.06	86.7	1416.2	440
$TEMPERATURE$	Average temperature	*centigrades*	17.4	3.44	10.04	25.45	440
$SLOPE$	Terrain slope	%	12.2	1.27	6	16	440
$EDUCATION$	Manager's years of education	$Years$	8.4	5.66	0	23	439
$TIME$	Time in agricultural activities	$Years$	25.6	13.29	0	65	440
$WELLS$	Number of wells	$Number$	1.8	2.61	0	21	440
$HECTARES-HT$	Area using high-tech irrigation	Ha	9.5	20.25	0	180	440
$FINED_{Dummy}$	Ever been fined?, Dummy	$Yes\ =1$	0.04	0.20	0	1	440
$DISTANCE$	Distance to closest populated centre	Km	43.9	37.08	2.70	171.75	440
$AVAILABILITY$	Water availability zone	$Level$	4.2	0.78	0	8	440
$CLAY_{Dummy}$	Clay soil, Dummy	$Yes\ =1$	0.4	0.49	0	1	440
$SANDY_{Dummy}$	Sandy soil, Dummy	$Yes\ =1$	0.4	0.50	0	1	440

Table 2 – Differences of production characteristics across regions

Variable	**Ags.**	**B.C.**	**N.L.**	**Pue.**	**S.L.P.**	**Son.**	**Zac.**
Price of labour (MEX$)	118.907	132.15	112.82	122.72	112	117.34	114.0
Price of groundwater (MEX$)	10.58	3.39	11.37	5.26	7.41	55.21	5.77
Price of fertilizer (MEX$)	4416.66	8475.72	6528.26	4021.66	5333.33	6149.74	7000
Quantity of Alfalfa and Forages (tons)	498.39	105.95	182.12	171.25	322.57	648.65	122.67
Quantity of Fruits (tons)	7.27	137.70	18.87	0	0	139.74	4.02
Quantity of Grains (tons)	55.73	2.04	143.69	32.32	15.71	114.16	23.92
Quantity of Vegetables (tons)	4.30	544.91	883.80	23.77	234.03	214.09	65.75
Cost share of groundwater	0.33	0.06	0.18	0.61	0.37	0.14	0.23
Cost share of labour	0.53	0.66	0.51	0.29	0.51	0.68	0.56
Cost share of fertilizer	0.12	0.26	0.30	0.08	0.11	0.16	0.19
Irrigation method: Gated pipes (ha)	5.69	0.23	0.25	2.03	5.17	11.84	4.36
Irrigation method: Gates (ha)	3.62	0.15	0.69	0.43	0.32	1.21	4.63
Irrigation method: cannons (ha)	0	0	0	0	0	1.39	0
Irrigation method: sprinklers (ha)	5.58	2.96	4.84	2.58	7.35	3.98	1.72
Irrigation method: pivot (ha)	0.51	0	43.87	0.96	0	14.60	0.56
Irrigation method: micro-sprinklers (ha)	0	0.03	0	0	0.71	0.22	0
Irrigation method: drip (ha)	1.81	20.34	7.76	0.12	3.28	19.18	5.53
Annual rain (mm)	473.26	242.15	416.38	547.72	401.18	185.81	431.39
Pumping height (m)	147.23	41.29	86.57	69.25	85.82	227.16	87.26

Note: Aguascalientes (Ags.); Baja California (B.C.); Nuevo Leon (N.L.); Puebla (Pue.); San Luis Potosi (S.L.P.); Sonora (Son.); Zacatecas (Zac.). Each cell represents the sample average within the corresponding state.

3 Data

The main data source for the analysis is a survey led by the National Institute of Ecology and Climate Change (Instituto Nacional de Ecologia and Cambio Climatico, INECC). This survey provides micro-data on producers in regions characterised by groundwater overdraft. The survey took place between November 2010 and January 2011. However, the information requested through its questionnaire refers to productive activities carried out in 2009. The survey collected information on the general characteristics of production units and producers, crop patterns, technology, groundwater and electricity consumption, and the perception of producers regarding water regulation. The questionnaire also included a module regarding the potential interest of producers in receiving the electricity subsidy as a lump sum rather than coupled with electricity fees. The survey was applied in seven Mexican states, from which a sample of 499 observations was collected (see Table 6). The sampling framework was based on the list of farmers having access to subsidised electricity fees. It is important to highlight that under this sampling framework all analytical results are limited to *legal* farmers, i.e. those farmers having a concession. For this reason, the technology used by *illegal* farmers cannot be modelled using this dataset. Moreover, the selection of the states was not random, instead it focused on regions characterised by groundwater overdraft. Thus, the results from this analysis cannot be extrapolated at the nation level, but mainly to regions suffering from groundwater overdraft.

The questionnaire designed by the INECC collected information on electricity facilities, but did not collect information on annual electricity consumption. Due to the latter, I matched the observations from the questionnaire to a dataset from the Electricity Federal Commission (Comision Federal de Electricidad, CFE), the main electricity utility in Mexico. This dataset included information for 2008 and

2009 on the type of irrigation tariffs, amount of electricity quota (Kwh), annual electricity consumption (Kwh), annual expenditure (MEX$), and cumulated debt (MEX$) to the CFE.

Information regarding the prices of labour and fertilisers was collected from outside sources, since it was not included in the questionnaire. Within the agricultural sector in Mexico, the daily price of labour is usually known as *jornal*. The price of a jornal varies among municipalities and depends on the type of crop for which the labour is used for. Since the questionnaire did not contain precise information on jornales, this information was recovered from another survey carried out by the INECC for which data on jornales for a wide range of different crops was collected. Moreover, since both surveys included almost the same municipalities, it was possible to match the price of the jornal of each crop in the survey. The information regarding the price of fertilisers was retrieved from the Mexican Ministry of Economy through the National System of Information and Integration of Markets (SNIIM). The price of fertiliser was computed as the mean value in 2009 of the following products: diamonic phosphate, nitrate of ammonia, sulphate of ammonia, simple superphosphate, and triple superphosphate.

In addition to labour and fertilisers, throughout the literature is recognised the importance of physical and environmental characteristics during the production process of agricultural activities. Precipitation, temperature and terrain slope may not only affect output but are also key in the allocation of certain production inputs, and in the choice of irrigation technology. Moreover, these variables are highly space-dependent, i.e. they can easily change within a range of few kilometres. For this reason I built variables capturing climatic and geographic characteristics through geographic information systems (GIS). The main advantage of GIS is their capacity to capture detailed information at really low geographical levels.

To produce the information on precipitation and temperature I used the database provided by the Center for Climatic Research from the University of Delaware[8]. This database includes monthly information on the maximum, minimum and average levels of rain and temperature worldwide between 1900 and 2010. All this information is represented through a *grid* composed by cells of 1000 by 1000 meters; each cell contains the information on both precipitation and temperature all throughout the country. Using this information I calculated average and cumulated precipitation, as well as mean temperatures for 2009. Information on the terrain slope cannot be obtained from this dataset, instead it has to be retrieved from a digital elevation model (DEM). I considered the DEM provided by the INEGI to be the most adequate for Mexico. Through this DEM I compute the terrain slope for all the country using cells of one square kilometre.

I used the geographic coordinates of each observation in the sample to map its location in order to relate them to the information on environmental characteristics. In other words, every producer was represented as a point on a map; each point was then related a particular cell containing the information on precipitation, temperature and slope.

4 Estimation Results

The results of the estimated model not only confirm that the consumption of groundwater responds to changes in the price of electricity, but that also labour and fertiliser do. This section presents the estimates of the econometric model including both price and cross-price elasticities for groundwater, labour, and fertiliser.

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[8] http://climate.geog.udel.edu/ climate/

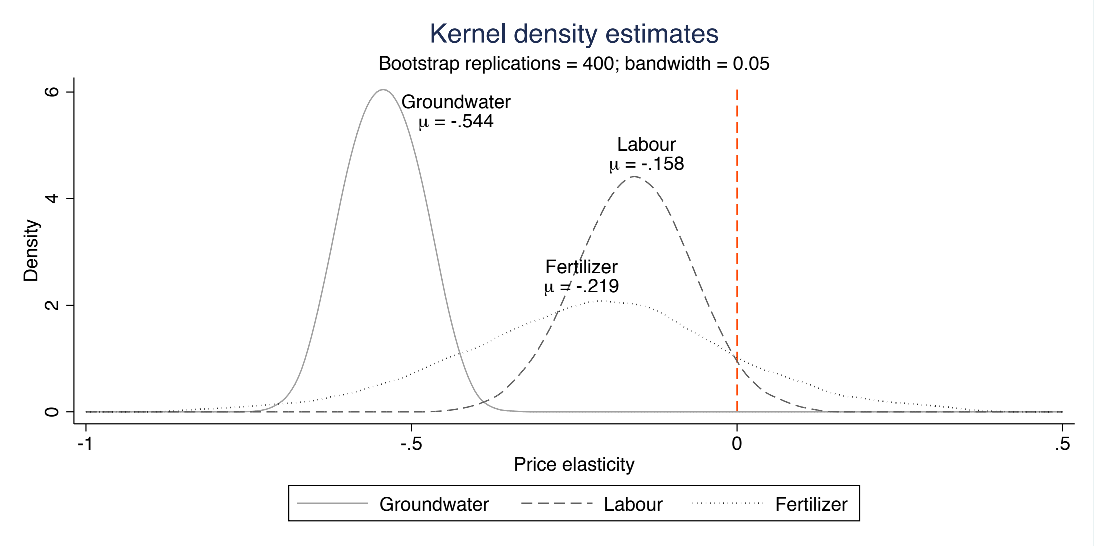
4.1 Estimates of the Cost Function

The parameters of the cost function have been estimated through the method of seemingly unrelated regression equations (SURE). As can be seen from Table 3, in the case of the groundwater equation, both price coefficients for groundwater and labour are statistically significant. The only type of outputs being statistically significant for groundwater cost share are fruits and vegetables. The sign of the estimated parameter of fruits output is positive while the one for vegetables is negative. This suggests that the set of vegetables included in the sample are less water intensive, compared to the set of fruits which seem to need larger amounts of water during their production process. Put in a different way, as the ratio of the amount of vegetables to fruits increases, groundwater share of total cost will decrease. Regarding fixed-factors, only the coefficients of the number of hectares having water-efficient technology and manager's education are both significant and negative. These results capture the differences between producers using more efficient irrigation technologies and small producers using flooding methods, as well as differences in terms of human capital. For further references, the results of the three cost share equations for the full model (5) are shown in Table 7 in Appendix A.

4.2 Elasticities estimates

Elasticities are stochastic, thus their statistical significance (i.e. whether they are different from zero) should be analysed before making inference based on their values. Indeed, elasticities are computed using the parameters of price inputs included in the cost shares equation as well as the estimated values of the cost shares evaluated at the mean; hence, elasticities cannot be considered to be deterministic. The traditional approach to estimate the statistical properties of elasticities has relied on formulas providing a first order approximation of standard errors and the assumption of normality. However, as suggested by Eakin et al. (1990), there seems to be no particular reason why non-linear statistics like the ones described in Equation 5 follow a normal distribution. Moreover, studies like Anderson and Thursby (1986) and Krinsky and Robb (1991) further suggest that inference based on the traditional approach could be misleading. For this reason, I compute the standard errors and confidence intervals for each price and cross-price elasticity through a bootstrap re-sampling technique using the methodology proposed by Eakin et al. (1990). Following this methodology, I estimate the parameters of the cost-share equations in 400 bootstrap samples and compute the corresponding set of elasticities. The latter provides a probability distribution for each price and cross-price elasticity.

Figure 1 – Kernel density estimates of groundwater, labour and fertiliser price elasticities - full model (5)



All price elasticities are negative, but not all of them statistically different from zero. The probability distribution for each elasticity is represented through a kernel density in Figure 1 [9]. The probability mass of the three distributions concentrates on the negative side of the scale. The mean value of the density distribution of groundwater is reached at –0.54, while for labour and fertiliser this point is reached at –0.15 and –0.21, respectively. Nevertheless, the estimate for fertiliser is not statistically significantly different from 0. As can be seen from Table 4 in Appendix A, these estimates are fairly consistent across the different specifications. The estimate for groundwater elasticity is higher to the one obtained in the U.S. by Ogg and Gollehon (1989) for Western regions, which range between –0.34 and –0.22; although significantly lower than the one of Nieswiadomy (1988) for the High Plaines of Texas equal to –0.95, and the one from Schoengold et al. (2006), –0.78 for Kansas. Regarding previous estimates for Mexico, my estimate for groundwater elasticity is almost three times the value obtained by Munoz et al. (2006), –0.16, for 2000. Two possible reasons could explain this difference. In the first place, Munoz et al. (2006) uses a different definition for the price of groundwater, which is defined as the yearly electricity bill divided by the yearly consumption of water. In the second place, the sample I use for this study is composed by producers placed in overexploited aquifers, mostly located in semi-arid regions, while Munoz et al. (2006) uses a sample of producers placed in different of regions in the country.

The results from the estimated cross-price elasticities show that both Morishima and factor demand elasticities are positive, implying that labour and fertilisers can act as a substitute for groundwater. In other words, an increase in the price of groundwater increases the quantity of labour. For instance, an increase of 1% in the price of groundwater would increase the quantity of labour by 0.16% (LW, cross-price elasticity) and the quantity ratio of groundwater to labour by 0.51% (LW, Morishima elasticity). In the case of fertiliser, an increase of 1% in

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[9] For practical reasons, all distributions in this figure had been computed using the same bandwidth, which in turn may lead to some over-smoothing. The kernel density of each elasticity, using an optimised bandwidth, is shown in the annex.

the price of groundwater would increase the quantity of fertiliser by 0.24% (FW, cross-price elasticity) and the quantity ratio of groundwater to fertiliser by 0.38% (FW, Morishima elasticity). These results further suggest that fertiliser is a more sensible substitute to groundwater than labour.

It should be noticed that the level of substitution between water for labour may further depend on the type of irrigation technology. For instance, in the case of surface irrigation technologies for which flooding is a common practice, the consumption of groundwater can be significantly reduced by using labour in task like field levelling or building furrows. Sprinkler systems are more water-efficient and demand a low amount of human management, thus the level of substitutability of this technology is lower than surface irrigation methods. Similarly, drip irrigations methods being highly efficient provide even less substitutability with respect to labour. However, these technologies are more demanding in terms of capital. Nieswiadomy (1988) also identifies groundwater and labour as substitutes and confirms the relationship between the type of technology and the level of substitutability. Regarding fertilisers, their cross-price elasticity with respect to water seems to be lower than the one of labour. Water can be substitute with fertiliser in order to increase crop yield and improve water efficiency. However, there are certain limits to this substitutability since an excessive use of fertilisers can have a negative effect on soils (e.g. acidification).

4.3 Robustness checks

To test the robustness of the previous estimates I ran the model defined in Equation 9 using a different definition for the price of groundwater. More precisely, I use the same definition as Munoz et al. (2006), in which the price is defined as the annual cost of electricity divided by the total amount of water extracted. As can be seen from Table 9 and Table 10 in Appendix A, the results using this different definition are close to the ones discussed in the previous section, although slightly higher. The price elasticity of groundwater based on this price definition is $-.57$, compared to $-.54$; elasticities for labour and fertiliser are $-.24$ and $-.32$, compared to $-.15$ and $-.21$, respectively. Cross price elasticities are also higher, in an order of magnitude of around 20%.

My definition of groundwater price depends on both the price of electricity set by federal authorities and the characteristics of the pump used to extract water. Since my analysis relies on cross-sectional data, it is thus possible that the price of groundwater is correlated with unobservables that I cannot control for. To test for the latter, I ran the model in Equation 9 using a three steps least squares (3SLS) method using as instrument the maximum amount of electricity quota of each producer. This quota is provided by the ministry of agriculture (SAGARPA) and is based on the average amount of electricity consumed during the last three years before requesting a concession. The quota allows producers to benefit from the subsidised and fixed electricity fees up to its maximal value; after this threshold producers pay a higher rate for each extra Kwh. The quota is thus correlated with the electricity price, but does not directly affect the cost share of groundwater at present time. To validate the 3SLS model I ran a Hausman test comparing the estimates from this model to the ones obtained from the SUR model. The test provided a Chi-square(22) equal to 6.52; thus, I do not reject the null hypothesis of no systematic difference between of coefficients and opted to keep the SUR model.

Table 3 – SUR Regression - different specifications for the cost share of groundwater

	(1)	(2)	(3)	(4)	(5)
P_{Water}	0.042***	0.051***	0.047***	0.053***	0.051***
	(5.30)	(6.77)	(6.19)	(6.59)	(6.62)
P_{Labour}	-0.040***	-0.048***	-0.041***	-0.050***	-0.049***
	(4.70)	(5.99)	(5.14)	(6.08)	(6.03)
$P_{Fertilizer}$	-0.002	-0.004	-0.007	-0.003	-0.002
	(0.38)	(0.65)	(1.15)	(0.47)	(0.38)
$Q_{A\&F}$	-0.003	-0.007*	-0.007*	-0.007*	-0.006
	(1.08)	(1.78)	(1.85)	(1.78)	(1.55)
Q_{Fruit}	0.006	0.011**	0.011**	0.010**	0.009**
	(1.53)	(2.53)	(2.34)	(2.32)	(2.05)
Q_{Grains}	0.008*	0.001	0.003	0.003	0.003
	(1.93)	(0.15)	(0.62)	(0.68)	(0.75)
$Q_{Vegetables}$	-0.010***	-0.005*	-0.006**	-0.006**	-0.006**
	(3.81)	(1.74)	(2.06)	(2.00)	(2.00)
$HECTARES-HT$		-0.038***	-0.037***	-0.039***	-0.037***
		(4.39)	(4.38)	(4.42)	(4.11)
$EDUCATION$		-0.066***	-0.063***	-0.067***	-0.065***
		(3.92)	(3.83)	(4.13)	(4.09)
$TIME$		-0.032	-0.028	-0.031	-0.030
		(1.57)	(1.37)	(1.49)	(1.42)
$WELLS$		-0.028	-0.032	-0.033	-0.035
		(1.25)	(1.43)	(1.45)	(1.55)
$FINED_{Dummy}$		0.076	0.084	0.074	0.071
		(1.38)	(1.50)	(1.34)	(1.27)
$DISTANCE$			0.042***	0.022	0.022
			(3.50)	(1.31)	(1.30)
$AVAILABILITY$			0.027	0.062	0.061
			(0.35)	(0.74)	(0.72)
$RAIN$				-0.082	-0.093
				(0.86)	(0.97)
$TEMPERATURE$				-0.029	-0.032
				(0.20)	(0.21)
$SLOPE$				0.138	0.144
				(1.03)	(1.08)
$CLAY_{Dummy}$					-0.047
					(1.27)
$SANDY_{Dummy}$					-0.007
					(0.18)
Constant	0.429***	0.742***	0.547***	0.590	0.641
	(8.56)	(8.03)	(3.42)	(0.73)	(0.78)
Adjusted R2	0.38	0.45	0.46	0.46	0.47
N	433	432	432	432	432

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: Results show the estimated coefficient from the cost share equation of groundwater; t statistics in parenthesis.

Table 4 – Point estimates for cross price elasticities - full model (5)

	Cross-price Elasticities	Morishima Elasticities
WL	0.365***	0.710***
	(10.89)	(17.19)
LW	0.165***	0.519***
	(9.97)	(6.29)
FW	0.240***	0.385**
	(6.58)	(2.06)
WF	0.179***	0.784***
	(7.01)	(14.75)
FL	-0.0341	0.194
	(-0.17)	(0.76)
LF	-0.0115	0.119
	(-0.17)	(0.45)
N	432	432

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Results show the estimated Cross-price and Morishima elasticities for groundwater (W), labour (L), and fertilisers (F); t statistics in parenthesis.

5 Policy implications

The results from the previous sections show that water for irrigation does respond to changes in its price. According to these estimates, an increase of 1% in the price of groundwater could reduce the quantity extracted by approximately 0.54%. Moreover, an increase in groundwater price of the same magnitude can rise the quantity demanded of labour and fertiliser by 0.1% and 0.2%, respectively. The direct policy implication from the latter is that policy reforms aiming to reduce - or even remove - the subsidy embedded in electricity fees could help to cope with groundwater overdraft.

Despite groundwater sustainability is a well understood and agreed policy objective, in practice political costs and opposition from agricultural producers and unions make removing a subsidy such as this one a difficult task to implement. Rather than removing the subsidy and increasing the price of electricity, a more viable policy alternative could be to *decouple* the subsidy. For instance, producers could benefit from the subsidy as a lump sum transfer to be used for investing in water saving technology, while facing higher electricity tariffs that better reflect the scarcity of the resource.

The survey carried out by the INECC in 2010 included questions regarding this policy alternative. More precisely, producers were asked whether they would be interested in participating in a programme from which they will be receiving the yearly amount of the subsidy they got in 2009 (expressed in Mexican pesos), so they could invest it for improving their irrigation system; or whether they would prefer to keep receiving the subsidy as part of the electricity tariffs. Only 11% of the producers surveyed were interested in this policy alternative. However, this percentage varies across the Mexican states considered in the survey.

The implementation of future reforms aiming at decoupling electricity subsidy could benefit from a better understanding of producers interest in this type of programme. To contribute to the latter, I used the information provided in INECC survey[10] to analyse the characteristics of the producers interested to participate. Thus, I ran binary choice model that analyses the interest in *hypothetically* participating in this programme based on a set of covariates including the amount of the subsidy that producers would receive, as well as producers' and aquifers' characteristics.

The dependent variable is then defined as:

$$y = \begin{cases} 1 & \text{if producer would participate} \\ 0 & \text{if producer would not participate} \end{cases} \tag{10}$$

While the structure of the model is the following:

$$Pr(y_i = 1|x_i) = F(x_i'\beta) \tag{11}$$

Where $F(\,)$ is the logit function, and x_i is a vector including the following variables: $SUBSIDY$, the transfer that the producer would receive, i.e. the decoupled subsidy (\$MEX); $INCOME$, the net income of the producer during 2009 (\$MEX); AGE, age of the manager or responsible of the production unit; $EDUCATION$, number of years of education of the manager or responsible of the production unit; $ACTIVITY$, the number of years that the production unit has been active; $QUALITY_{Dummy}$, dummy that indicates whether the aquifer is suffering from salinisation or marine intrusion; $RECHARGE$, balance of water inflow/outflow in the aquifer (millions m^3); $Price_{Water}$, price of groundwater as defined in Equa-

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[10] This is the same survey used for the analysis in previous sections and described in section 3.

tion 6, (\$MEX per m^3); $WATER$, the total amount of water consumed during the year (m^3); $TECH$, the percentage of hectares using water saving technology; $USERS$, the number of users sharing the well; $SURFACE$, the total area used for production (Ha); $DISTANCE$. distance to the closest population with at least 25,000 inhabitants; $RESPECT$, scale from 1 to 10 that ranks the respect of producers towards water regulation (10 being the highest level of respect); $Dummy_{Centre}$ and $Dummy_{South}$, dummies for northern and southern states.

The results from this model are shown in Table 5. The first thing to highlight is that the amount of the subsidy does not seem to influence the decision to participate, even when controlling for the net income of producers. In terms of characteristics of the producers, only age and time in agricultural activities are statistically significant. Indeed, older producers are more likely to participate, while those having a longer time in agricultural activities are less interested. The average age of the producers in the sample is 54 years old, and ranging up to 88 years old. Thus, older producers who feel more vulnerable may be interested in receiving this transfer as a source of additional income. What regards the time in agricultural activities, for those producers who have benefited longer from the subsidy, there may be a stronger path dependency. Another important result from this analysis is the fact that those producers facing higher levels of groundwater overdraft, and in consequence a higher price for groundwater, are more likely to participate in such a programme. The latter follows from the significance and signs of the coefficients of the price of groundwater and recharge of groundwater. Finally, as indicated by regional dummies, producers in the centre of the country are more interested than producers in Northern states to participate. These regional differences can be clearly appreciated when looking at regional difference in participation rates: in the Northern states of Baja California and Sonora only 1% and 4% of the producers in the survey were interested to participate, in contrast in Central and Southern states this percentage ranged between 12% and 20%.

Table 5 – Results from the Logit model

	(1)	(2)	(3)	(4)	(5)
$Dummy_{Centre}$	2.120***	2.322***	3.052***	3.416***	3.551***
	(3.09)	(3.01)	(3.03)	(2.62)	(2.82)
$Dummy_{South}$	2.525	3.073	4.216	4.091	4.335
	(1.30)	(1.46)	(1.61)	(1.39)	(1.57)
$SUBSIDY$	0.040	0.026	0.039	-0.014	-0.019
	(0.48)	(0.32)	(0.47)	(0.17)	(0.22)
$INCOME$	-0.143	-0.063	-0.066	-0.032	-0.011
	(1.29)	(0.59)	(0.63)	(0.25)	(0.07)
AGE		0.039**	0.040**	0.044***	0.043***
		(2.53)	(2.56)	(2.77)	(2.66)
$EDUCATION$		-0.033	-0.031	-0.039	-0.041
		(0.90)	(0.82)	(0.96)	(1.05)
$ACTIVITY$		-0.038***	-0.036***	-0.040***	-0.040***
		(2.75)	(2.60)	(2.78)	(2.77)
$QUALITY$			0.379	-0.034	0.029
			(0.74)	(0.06)	(0.05)
$RECHARGE$			-1.326*	-1.172*	-1.243*
			(1.91)	(1.75)	(1.78)
P_{Water}				0.039**	0.040**
				(2.28)	(2.39)
$WATER$				-0.000	-0.000
				(0.30)	(0.25)
$TECH$				-0.007	-0.007
				(1.35)	(1.27)
$USERS$					0.003
					(0.21)
$SURFACE$					-0.001
					(0.08)
$DISTANCE$					-0.001
					(0.09)
$RESPECT$					0.191
					(0.93)
Constant	-2.573	-3.518	-4.326	-3.405	-5.379
	(0.69)	(0.91)	(1.07)	(0.72)	(0.99)
N	429	428	428	420	420

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Note: t statistics in parenthesis.

Conclusions

The main objective of this paper is to model the behaviour of Mexican producers operating in overexploited aquifers using a structural approach. This approach allows to estimate not only the own price elasticity of groundwater, but also testing for the existence of cross-price effects among groundwater and other production inputs. To this end, I use a combination of different micro-data sources to estimate a Translog cost function.

The results from this analysis show that the demand of irrigation water in the sample analysed is inelastic. According to my estimates, a 1% increase in groundwater price can reduce on average groundwater extraction by 0.54%. These results are in line with previous estimates of groundwater elasticity.

My results also show that labour and fertiliser can act as substitutes for groundwater. An increase in the price of groundwater increases the quantity of both labour and fertiliser. According to my estimates, an increase of 1% in the price of groundwater would increase on average the quantity of labour by 0.16% (derived demand elasticity) and the quantity ratio of groundwater to labour by 0.51% (Morishima elasticity). In the case of fertiliser, an increase of 1% in the price of groundwater would increase the quantity of fertiliser by 0.24% (derived demand elasticity) and the quantity ratio of groundwater to fertiliser by 0.38% (Morishima elasticity).

Overall, my results show that policies aiming at reducing groundwater overdraft could use electricity price as a policy tool for reducing unsustainable consumption patterns. However, the implementation of such policies will probably face important challenges to overcome. Only 11% of the producers in the sample analysed will be keen on decoupling the subsidy and receiving it as a direct transfer. The last section of this paper further analyses which are the characteristics of those producers potentially interested in such policy alternative. Results show that the size of the transfer does not seems to influence participation (even after controlling for net income). Producers that have been involved in agricultural for longer, and thus benefitted longer from the subsidy, are less likely to participate in this type of programmes. Probably the simplest explication for the latter is path dependency, i.e. these producers are more used to receive these subsidies. However, producers operating in regions with higher water stress and facing higher extraction costs would be more likely to participate. In addition to the latter, results show that there are important regional difference. Producers in Northern states closer to the U.S. border are significantly less interested in decoupling the subsidy, while for those in central states this seems to be a more appealing policy alternative. These differences could be related to the fact that Northern producers face higher water stress and may have already invested in water saving technology.

Current environmental strategies in Mexico could be enhanced by moving away from a strong sectorial vision and acknowledging the existence of territorial difference. This is key a for big country like Mexico for which spatial heterogeneity of policy outcomes is most likely present.

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A Data and Estimation results

Table 6 – Distribution of surveys by state

State Name	Number of Surveys	Percentage
Aguascalientes	48	9.6%
Baja California	104	20.8%
Nuevo Leon	47	9.4%
Puebla	64	12.8%
San Luis Potos.	31	6.2%
Sonora	76	15.2%
Zacatecas	129	25.9%
Total	499	100.0%

Source: INE, 2010.

Table 7 – SUR Regression - full model for the three cost shares

	CS - Groundwater	CS - Labour	CS - Fertliser
P_{Water}	0.051***	-0.049***	-0.002
	(6.62)	(6.03)	(0.38)
P_{Labour}	-0.049***	0.161***	-0.112***
	(6.03)	(4.23)	(3.06)
$P_{Fertilizer}$	-0.002	-0.112***	0.114***
	(0.38)	(3.06)	(3.26)
$Q_{A\&F}$	-0.006	0.015***	-0.008***
	(1.55)	(3.75)	(4.06)
Q_{Fruit}	0.009**	-0.007	-0.002
	(2.05)	(1.26)	(0.58)
Q_{Grains}	0.003	-0.005	0.002
	(0.75)	(1.31)	(0.77)
$Q_{Vegetables}$	-0.006**	-0.003	0.008***
	(2.00)	(0.93)	(2.60)
$HECTARES-HT$	-0.037***	0.047***	-0.009
	(4.11)	(4.81)	(1.54)
$EDUCATION$	-0.065***	0.038**	0.027***
	(4.09)	(2.33)	(2.74)
$TIME$	-0.030	0.032*	-0.002
	(1.42)	(1.95)	(0.14)
$WELLS$	-0.035	-0.007	0.042**
	(1.55)	(0.23)	(2.10)
$FINED_{Dummy}$	0.071	-0.153***	0.083*
	(1.27)	(2.69)	(1.65)
$DISTANCE$	0.022	-0.041***	0.019
	(1.30)	(2.64)	(1.47)
$AVAILABILITY$	0.061	-0.026	-0.034
	(0.72)	(0.41)	(0.71)
$RAIN$	-0.093	0.074	0.019
	(0.97)	(0.80)	(0.31)
$TEMPERATURE$	-0.032	0.073	-0.041
	(0.21)	(0.59)	(0.44)
$SLOPE$	0.144	-0.366***	0.222*
	(1.08)	(2.62)	(1.95)
$CLAY_{Dummy}$	-0.047	0.043	0.004
	(1.27)	(1.37)	(0.16)
$SANDY_{Dummy}$	-0.007	0.019	-0.012
	(0.18)	(0.59)	(0.47)
Constant	0.641	1.222	-0.863
	(0.78)	(1.50)	(1.60)
Adjusted R2	0.47	0.40	0.28
N	432	432	432

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 8 – Point estimates for price elasticities

	(1)	(2)	(3)	(4)	(5)
Water	-0.581***	-0.545***	-0.559***	-0.538***	-0.545***
	(-17.47)	(-17.77)	(-17.95)	(-16.65)	(-17.40)
Labour	-0.186**	-0.179***	-0.199***	-0.154**	-0.154**
	(-2.12)	(-2.82)	(-3.17)	(-2.28)	(-2.27)
Fertilizer	-0.255	-0.268	-0.275	-0.209	-0.205
	(-1.11)	(-1.54)	(-1.56)	(-1.13)	(-1.10)
N	433	432	432	432	432

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9 – Point estimates for price elasticities - Alternative definition for groundwater's price

	(1)	(2)	(3)	(4)	(5)
Water	-0.567***	-0.575***	-0.574***	-0.573***	-0.574***
	(-28.45)	(-30.41)	(-30.96)	(-30.38)	(-30.58)
Labour	-0.237***	-0.249***	-0.244***	-0.240***	-0.240***
	(-3.46)	(-3.68)	(-3.46)	(-3.43)	(-3.43)
Fertilizer	-0.310	-0.341*	-0.329	-0.320	-0.318
	(-1.59)	(-1.71)	(-1.60)	(-1.57)	(-1.56)
N	439	438	438	438	438

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10 – Point estimates for cross-price elasticities - Alternative definition for groundwater's price - full model (5)

	Cross-price Elasticities	Morishima Elasticities
WL	0.433***	0.769***
	(24.19)	(39.10)
LW	0.195***	0.673***
	(17.26)	(9.53)
FW	0.187***	0.460**
	(10.59)	(2.23)
WF	0.141***	0.761***
	(10.70)	(31.51)
FL	0.131	0.363
	(0.64)	(1.33)
LF	0.0447	0.371
	(0.64)	(1.36)
N	438	438

t statistics in parentheses

Note: water W; labour L; and fertiliser F.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$