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Water scarcity and optimal pricing of water

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WATER SCARCITY AND OPTIMAL PRICING OF WATER

by

Yiğit Sağlam

An Abstract

Of a thesis submitted in partial fulfillment of the
requirements for the Doctor of Philosophy
degree in Economics
in the Graduate College of
The University of Iowa

July 2010

Thesis Supervisors: Professor Harry J. Paarsch
Professor Srihari Govindan

ABSTRACT

In the first chapter, I consider the institutional structures as well as the doctrines typically encountered in the surface water sector. To investigate the sources and methods of government support in the water sector, I categorize different sorts of government support according to the location of water along the water cycle. I conclude the section with examples of observed water markets.

In the second chapter, I consider the problem of water usage, developing a model to analyze the optimal pricing of water within a second-best economy. As a water supplier, the local government may price discriminate across consumers and farmers. I introduce the second-best pricing scheme, derive conditions for the marginal-cost pricing and inverse-elasticity rules, and analyze when the government optimally deviates from these two pricing schemes.

In the third chapter, I provide an analysis of the data I collected from Turkey. First, I examine the data on reservoir flows, including service share and fixed costs of the reservoirs. Then, I provide details about the relationship between the quantity and price of irrigation and of tap water.

Finally, in the fourth chapter, I apply the theoretical framework to the data from Turkey. In Turkey, the current water-pricing policy is dictated by the sole objective of breaking-even in each period. This results in large withdrawals, which is not sustainable in the long-run, hence not optimal. I analyze the dynamic optimal water resource management problem of a benevolent government. I compare the implications of the current and the optimal pricing policies.

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CERTIFICATE OF APPROVAL

PH.D. THESIS

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INSTITUTIONS, LAWS, AND GOVERNMENT IN THE SURFACE WATER SECTOR

1.1 Introduction

Apart from being a commodity that is commonly consumed for many purposes, water has important implications to an economy at the national level: not only is water necessary to the human body and for other purposes, but it is also an important input to energy, industrial and agricultural production, as well as transportation.

Water scarcity has become a major problem, particularly in arid regions such as Africa and Australia as well as parts of Asia. A growing world population brings the need for additional food and industrial production and, thus, additional water. To supply additional water, the world has more than $45,000$ large dams (dams more than fifteen meters high), most of which were constructed in the second half of the last century; see WCD (2000). According to WMO (1997), these dams have increased storage capacity by seven hundred percent since 1950, but water demand has risen sixfold between 1900 and 1995, while the population has increased threefold.

Some countries experience periodic water shortages—a situation when a water supplier cannot meet the sectoral demands in a given period—including Southern European countries such Italy, as noted in Rossi and Somma (1995), and Turkey as well as Denmark, as noted in Thomsen (1998). The effects of a water shortage on an economy can be substantial because the government may have to refuse to provide water to sectors and this can result in lost profits in industry and agriculture.

To understand how a resource is managed and operated, it is first crucial to find out what sort of institutions exist. Institutions play an important role in the structure of political, economic, and social interaction because they can affect efficiency and welfare. Such institutions include not only informal constraints (such as sanctions, taboos, customs, traditions, and codes of conduct), but also formal rules (such as constitutions, laws, and property rights). These formal and informal rules create a system of mutual coercion, by which humans relate to one another; see Samuels (1972). As mentioned in Schmid (1972), "institutions are sets of relationships among people which define their rights, exposure to the rights of others, privileges, and responsibilities." I shall refer to Griffin (2006) in the following sections for a definition of economics of institutions, doctrines, properties of a public good, and market failures.

1.2 Economics of Institutions

The ownership of a resource can be described in four ways. First, an open access resource has no ownership as well as no rules nor regulations controlling the consumption of the resource. Second, a common property resource is owned "in common" and managed according to social institutions of the "common"; see Ciriacy-Wantrup and Bishop (1975). In this context, a common refers to a group of all users who have a right to consume a resource. Some examples include fisheries, the atmosphere, pastoral lands used for grazing, and water settings with plentiful resources. Third, a state property resource is owned by the government and managed by formal rules. Finally, a private property resource is privately owned by one or more legal entities, and the ownership is enforced by property rights. A key feature of this private property resource is that trading property rights enables market activity. Problems may occur in establishing private property rights: concerns over equity may arise, the cost of maintaining private property rights may be high, externalities as well as public goods may exist.

Several factors may cause market failures, including public goods, externalities, information costs, natural monopolies, and discounting. A public good (or a bad) is a good which has two properties—nonrivalness and nonexclusion; see Myles (1995). More specifically, a public good is nonrival if the consumption by one agent does not affect the consumption by other agents, and a public good is nonexclusive if it is prohibitively expensive to exclude someone from consuming the good. Because a public good may be nonrival or nonexclusive, this creates an externality in an economy, so the First Welfare Theorem may no longer hold. In the case of public goods, however, the First Welfare Theorem has been successfully reconstructed for situations where the public good is nonrival, as shown in Myles (1995). To solve the problem, market prices are modified for each nonrivaled good. In other words, instead of having a single price for each commodity, the nonrival goods have a different price for each person.

In general, externalities occur when the welfare of an agent depends on the actions taken by other agents without regard to consequences; see Baumol and Oates (1988). "An externality represents a connection between economic agents which lies outside the price system of the economy. Myles (1995) has noted that as the level of the externality is not controlled directly by price, the standard efficiency theorems on market equilibrium can not be applied." Return flow, pumping costs, well interference externalities, and pollution by industries are other externalities listed by NCR (1992). Possible solutions to account for externalities are establishing property rights, mergers by firms, subsidizing or taxing by governments, regulating the items, and convincing the agents creating the externalities to not continue their actions. Nevertheless, Dahlman (1979) has stated that the possible solutions listed above cannot be performed without transaction costs, otherwise called information costs. Transaction costs can be important, especially when they exceed the gain from correcting the externality. In this situation, the solution may not even be put into action since the information cost is higher than the gain from correcting the externality.

Natural monopolies, which occur due to declining average costs, may also affect efficiency. As more of the good is sold, average costs may decrease because of the monopolist's large fixed capital investment costs; per unit costs of production would also decline as the firm sells more product. A potential problem with natural monopolies is that since average costs are decreasing (assuming that the monopolist follows marginal cost pricing) not enough revenue will be generated to cover the costs of production. This monopolist structure in the supply side of the market may result in different choices of pricing schemes in resource management. Finally, when privately motivated, agents make dynamic decisions regarding the property rights they control. For example, they employ private discount rates, assigning less weight to the future than indicated by social discount rates. as a result, overdiscounting may lead to underinvestment in long-term projects. Since I focus on surface water in this chapter, it is necessary to understand rules and doctrines of the world.

In his paper, Cox has reported that "water law development has often occurred in a crisis atmosphere in which resolution of a pressing but narrowly defined water resource problem was the primary objective. Thus, water law generally does not consist of a comprehensive, integrated body of legal principles for managing the resource, and problems of coordination among different bodies of law frequently arise." These institutions occur as a result of difficulties faced in the water sector. The following section reviews several doctrines commonly observed in surface-water management and their use in different regions of the United States.

1.2.1 Riparian Doctrine

A riparian is a land owner whose land is connected with a watercourse. Scott and Coustalin (1995) have stated that the riparian doctrine is observed in the United States as well in countries of the English Commonwealth. Some of the key provisions of the riparian doctrine; i.e., common Property in surface water, are:

- only riparians have the right to make use of surface water;
- these water rights are not quantitatively specified;
- each riparian's water consumption must be in line with that of other riparians in the basin.

The riparian doctrine can be problematic when water scarcity is an issue because none of these features provide enough control over riparians' water consumption. If, however, water is abundant and conflicts rarely occur, then the riparian doctrine will be desirable.

1.2.2 Eastern Permit Systems

In this doctrine, the watercourse is owned by the state. The state issues planning and permitting reforms to control water consumption. Moreover, the state creates and assigns new administrative duties. Institutions as well as regulations and rules over water consumption are stricter. The state issues temporary permits which are valid for some time; e.g., ten years; permits are to be renewed immediately after they are void.

1.2.3 Prior Appropriations Doctrine

This doctrine is based on the ethical principle "First in time, first in right." This doctrine provides the basis for water markets. The prior appropriations doctrine, which is also known as the Colorado Doctrine, is used to govern water use in many states in the United States. Water around Rocky Mountains is also managed by this doctrine. According to this doctrine, although water in a stream belongs to no one, municipalities and firms have the right to divert and to use water for beneficial purposes. The prior appropriations doctrine has the following key features:

- **Seniority**: Conflict over water scarcity is resolved by seniority. In other words, whichever water use was initiated earlier has a priority in water usage. This feature brings higher quality water rights so that in the case of a water supply shortage, due for instance to climate fluctuations, agents who started to use water earlier had a priority in using the scarce water.

- **Quantification**: These water rights are quantitatively expressed, unlike the rights defined in the riparian doctrine; see Gould (1988).

- **Transferability**: Rights may be sold independently, regardless of the surrounding. This feature increases efficiency since water is used by agents who value it most. Thus, whoever pays the proper price for the water rights, owns the right to divert and use water on his own land. Two types of water rights exist based on time of water use. A water right is absolute when an appropriation has been completed by diversion and a permit for the beneficial use is issued. Alternatively, water rights can be conditional if an appropriator wants to obtain the rights before water has actually been used. There are also two types of water rights based on the way it is permitted to use. A direct flow is measured in terms of a rate flow (e.g., one c.f.s. where c.f.s. stands for cubic foot of water per second). A storage water right is measured in terms of volume. For example, a storage right holder can divert up to a thousand acre feet of water each year, where an acre foot is the amount of water estimated to cover an acre of ground with one foot of water.

Diversions of surface water will result in some return flow to the originating system, thus creating opportunities to reuse water. In this case, Gould (1988) emphasizes that transferability is forbidden in excess of consumptive use to avoid externalities. This leads to changes in water rights which necessitate that consumptive water rights be adopted. However, this prior appropriations doctrine is accompanied by provisions that may lead to some inefficiencies

- **Beneficial Use Requirements**: The legitimacy and the extent of a water right are related to the amount of water the right holder allocates for beneficial use. Thus, the right holder has to divert water from a watercourse for a beneficial use, such as irrigation, domestic use, or farming. However, there are three problems with this idea. First, only offstream diversions are originally listed. Second, given that most western streams are fully appropriated, there is not much space for hoarding and speculation. Finally, efficiency is handled by the water markets, so there is no need to understand what is or is not efficient. Employing beneficial use requirements, according to Neuman (1998), exposed the barrier for achieving efficient water use.

- **Preference Ordering**: There is a preference ordering in beneficial uses of water. The usual list is (1) domestic, (2) municipal, (3) irrigation, (4) mining and manufacturing, and (5) power generation. However, this ordering as well as seniority feature may potentially cause inefficiencies in water use.

- **Forfeiture Clauses**: A water right is terminated after a sustained period of non-use (ten years). However, this may potentially lead to overconsumption of water. Thus, the right-holders do not want to lose some or perhaps all of their rights. In this case, water may be wasted, which causes inefficiencies.

1.2.4 Correlative Shares

Because of potential problems, which may cause inefficiency in private property shares, shares of the resource are made transferable. However, this approach brings little efficiency improvement inside a local district. Moreover, it is an indirect mechanism for valuing more secure rights. Transferable correlative shares to surface water can approach the achievements of prior appropriations, with the exception that the prior appropriations doctrine better encourages infrastructural investments which are sensitive to the security of water rights during dry periods.

1.2.5 Other State Property Interests

Other crucial uses of water also depend on whether water is left instream. Some examples include fishing, sustenance of wildlife, vegetation support, scenic beauty, hydropower, waste-water dumping, and channel maintenance. Legal scholars point out that water rights of all types are normally usufructuary in nature—water right holders are entitled to the use of water, but do not possess strong ownership or interest in specific units of water, even when transferability is allowed. Thus, the public sector may exert some explicit control over some portion of a watercourse Getches (1990). In addition, there is also absent quantification of these rights by the public sector.

1.3 Water Management

1.3.1 Private-Sector Participation

Three basic forms of government subsidy of the agriculture sector exist: capital subsidies, operating transfers (which serve to keep average prices below the full economic cost of provision), and cross-subsidies (which involve differentiating prices of water across different user groups). In recent years, subsidies for agriculture producers in the water market have drawn some attention; because of this, recovery of all the economic and social costs, which is usually referred to as *full cost-recovery charging*, has been offered as a solution to this issue. Meanwhile, privatization of water management and decreasing governmental involvement in the water sector has been discussed as another solution. Regarding the private sector's involvement in water markets, some countries have started to let private firms provide and sell water. The government's main role has shifted to be one of establishing and regulating an operating environment in which the private sector and non-governmental organizations become more active in the process of providing water and sanitation services.

Because of the natural monopoly feature of the water market, supplying water largely remains a public duty. In this system, the private sector is responsible for providing services. However, it is estimated that less than ten percent of the world's population is provided drinking water through private sector services. According to the World Bank, private-sector participation is more common in Latin America, East and Central Asia, and Eastern Europe.

Private-sector participation has some advantages: it brings technical and managerial expertise to water markets, encourages and necessitates efficiency in the use of capital, reduces the need for subsidization, and increases responsiveness to consumer needs and preferences. Because equity and efficiency are both concerns for the government, the government may still find it necessary to regulate the water market via quotas as well as taxes or subsidies so that water is neither overpriced nor under-provided.

1.3.2 Government Intervention

Agricultural production makes up seventy percent of water use worldwide. In OECD countries, it makes up forty-five percent. Moreover, water use in agriculture has risen more quickly than any other water use in the last decade. Overuse of water in agriculture production is crucial, especially in the regions where water scarcity is severe. Agricultural use of water is also responsible for water pollution from nutrients, and pesticide run-off. Government support and input subsidies, including subsidies for the supply of water and the maintenance of water infrastructure, discourage efficient use of water, leading to the overuse of water in agriculture. This causes households and industrial sector to pay relatively more for water than agricultural sector. Given that property rights to use water may not be well-defined, the "polluter pays" principle is not usually valid for the water markets.

The correct choice of pricing regime for agricultural water is an important step in improving the efficiency of water use, perhaps even without necessarily introducing a financial burden. Such a regime should treat water as an economic good, and should account for the opportunity cost of supplying water to particular uses and user groups. Since equity might be as much a concern for the government as efficiency, the government may still apply taxes or subsidies to the relevant user groups. Regarding the cost of projects and fixed capital investment costs, the government finances water works and irrigation projects from the general budget, particularly in countries with large irrigated areas. Among various user groups, agricultural water users currently pay the smallest share of the real cost of providing water. This practice should be discontinued progressively, bearing in mind the economic consequences of more expensive water being used for irrigation. In this manner, some of the OECD countries have already made significant progress, while others are considering such changes. New pricing structures with social support are key features of these reforms; see the OECD (2003).

Government support in the water sector can be analyzed according to the position of the support along the water cycle; see Kraemer (2003). However, in the current thesis, I shall focus on government support on water abstraction, water storage and water use. I illustrate the types of government support according to different user groups and different positions along the water cycle:

- **Water Abstraction**: In the water abstraction stage, government support may be in the form of charges below cost recovery or in the form of financial assistance. Prices set by the government may not cover the full costs or may not consider environmental externalities; e.g., reduced size and stability of wetlands. Farmers may also be exempted from paying certain taxes such as ground abstraction fees, or farmers may get payments to practice environmentally friendly farming methods.

- **Water Storage, Supply and Distribution**: The government support can be categorized with respect to the targeted user groups. For the whole network of users, low interests may be offered by the government. In some OECD countries, such as Australia in the past, the government may cover the deficits when revenues do not exceed the costs of projects. On the other hand, water services may be offered at a lower rate of return or at prices below cost recovery. In agriculture, the support at this stage along the water cycle can be in the form of charges for irrigation water being set lower than costs. Meanwhile, industries usually meet their own water demand trough self-provision, with costs not fully recovered and resource costs being excluded from water prices. This leads to underpricing for the industries, if environmental effects of their water use are not internalized through taxes or subsidies. Finally, support for households in this case is usually in the form of prices being lower than cost recovery levels so that more people can afford to buy more water.

- **Water Use**: In irrigational water use, government support is usually in the form of cross-subsidization and tax exemptions. These subsidization programmes lower the prices agricultural producers are required to pay, causing implementation water-inefficient methods in farming and overuse of water supply. As agricultural water use is more than the industrial and household water use in most OECD countries, the effects of the government support has economic and environmental effects. Industries may be exempted from certain tax schemes such as deducting the tax on water consumption from their value-added-tax bills. Households may be subsidized through averaged prices (cross-subsidization from urban to rural center to the periphery, etc.).

1.4 Country Experiences

Water scarcity is dealt with by supply-enhancement and demand-management policies. In many countries, the focus is more on the demand-management policies for surface water. Although I shall not analyze all of the possible pricing schemes for a water supplier, I find it useful to review observed pricing schemes even without providing much detail; see Monteiro (2005).

Water rates are usually composed of two main categories: charges that are based on water consumption (such as meter charges and new connection fees) and water charges that depend on the amount of water used. An example of the fixed charges involves a new user being charged a fixed fee to gain access to a water supply system, or an existing user being charged a tap fee for a new location. In agriculture, this non-volumetric price may be based on a per-output basis, a per-input basis, an area basis, or land value. Alternatively, a user may be charged a volumetric (quantity-based) price, which depends on the volume of water used. Included among quantity-based pricing schemes are nonlinear pricing schemes with block tariffs (often referred to as *tiered pricing*) and the uniform-price. A tiered-pricing scheme can have an increasing block rate (IBR) structure or a decreasing block rate (DBR) structure, or a mixture of both. The marginal cost of water equals the price of the current block. In a DBR scheme, price decreases as water consumption gets to the next block. DBRs may be explained by the presence of a natural monopoly or by revenue stabilization, whereas equity and poverty concerns may explain IBRs. Meanwhile, uniform prices may be set so that price equals average cost (average-cost pricing) or marginal cost (marginal-cost pricing). Uniform pricing may be favored because, at any moment, marginal consumption by all consumers who use water from the same supply has the same impact on supply costs. In order to cover fixed costs, a two-part tariff may be implemented. Under this pricing scheme, a fixed service fee is charged accompanied by a volumetric pricing scheme. Alternatively, another pricing scheme involves setting different prices according to user classes or by season (time-of-year pricing), thus exploiting population or temporal variation or considering seasonal effects on the water supply. Capacity constraints may also imply that water prices increase during periods of high demand; such pricing schemes are usually referred to as *peak-load pricing*. Because of the increasing demand for water, there is a trend in the OECD countries away from fixed charges and towards volumetric water charges. Even when fixed charges still exist, perhaps as a component of a two-part tariff, volumetric pricing schemes, particularly IBR rather than DBR, have been preferred by many countries such as Hungary and Poland as well as the Czech Republic.

1.4.1 OECD Countries

Several OECD countries have experienced periodic water shortages, based on high levels of leakage in the water supply systems, or inefficient usage encountered by insufficient pricing policies. Supply-side management is an important factor as leakages prevent reservoirs from accumulating enough water in their stock. For example, in Italy, precipitation was lower than long-run average in the late 1990s. Nonetheless, inappropriate water pricing systems cannot be overlooked since they cause excessive use of water. For instance, in Denmark, as water consumption stays at high levels, the accumulation of water is not enough for long-term sustainability. Thus, Thomsen (1998) has predicted that if the ground water level goes down to fifty percent, it would cause a catastrophe.

The OECD countries can be categorized according to per capita daily water consumption. According to table 1.1, Australia, Canada, Japan, and the United States make the top of the list with water consumption higher than 250 litres per capita per day (lhd). In some southern European countries including Italy, Spain, and Italy, along with Sweden, per capita daily water consumption is about 200 lhd. Portugal and Germany are among the last in water consumption between 100 and 200 lhd.

Table 1.1: Daily Water Consumption in Some OECD Countries

Per Capita Daily Water Use	Countries
Highest Use (> 250lhd)	Australia, Canada, Japan, U.S.A.
High Use (≈ 200lhd)	Italy, Spain, Sweden, Turkey
Medium Use (≈ 130–190lhd)	France, New Zealand, the U.K.
Low Use (≈ 100–200lhd)	Germany, Portugal

1.4.2 United States of America

Water use by sectors are displayed in table 1.2. Thermoelectric power and agriculture are among the biggest water users, while public water use is around eleven percent.

Table 1.2: Water Use in the United States

Sector	Water Use (in %)
Agriculture	34
Thermoelectric Power	48
Public Water Supply	11
Industrial	5
Other	2

Nearly all water districts in the United States charge for water on the basis of their average costs. Costs for wastewater treatment may be included in charges for water, particularly for residential urban customers. The practice of setting prices to reflect average costs derives principally from the legal requirement in most districts that charges must be set to recover costs, but no higher; water suppliers are not profit-making enterprises. Rate structures employed by water districts include flat-rates, declining block rates, and increasing block rates. Some utilities in water-short areas use increasing block rates. But flat rates by customer class are the most common.

An analysis of different rates structures by urban districts has become more common, and an increasing number of water utilities have tried to modify their rate structures to avoid disincentives to conservation (such as declining block rates) and, in some cases, to incorporate incentives for conservation. Dinar and Subramanian (1997) has provided examples of incentive pricing instituted by a few irrigation districts in California's Central Valley seeking to reduce the application of irrigation water to lessen the outflow of contaminated drainage water from agencies obtain water from their districts. For example, in 1988 the Broadview Water District increased its charges for water used above ninety percent of historical averages by 2.5 times, from \$16 per acre foot to \$40 per acre foot, where water application rates are computed by crop.

The state of California is a major producer of mostly vegetables—i.e., mostly tomatoes, almonds, avocados, grapes, artichokes, onions, lettuce, olives, and so forth. According to table 1.3, flood irrigation is the most common irrigation method in the state which has a total irrigated area of 10.1 million acres. However, it is also important that about thirty percent of the irrigation lands is done through drip irrigation, the most efficient among the three in terms of water consumptions. California has faced severe water shortages, and these have had major economic implications. In 2008, 100,000 acres out of 4.7 million acres were left fallow, and this led to losses of about \$300 million. In 2009, it is projected that 850,000 acres would be left fallow, and this would result in losses of about \$2.2 billion. Also, unemployment rate is projected at thirty-five percent, compared with twenty percent in normal years.

Table 1.3: Irrigation Technologies in California

Irrigation Technology	Percent of Total Irrigable Area
Flood	54
Spray	16
Drip	30
Total	100

Even though precipitation is part of the reason for these water shortages, pricing schemes of sectors are also crucial in sectoral usage. Agriculture pays to water and electricity about 5 and 7 percent of what households pay, respectively. Due to government subsidies in irrigation, low costs lead to production of water-intensive crops in dry regions. Ten percent of nation's growers get almost 78 percent of annual farm subsidies. This does not help with water conservation and efficient use of water.

1.4.3 Turkey

I display the water resources of Turkey in table 1.4 [1]. Turkey's utilizable water resources were approximately $1,650$ m^3 per capita per year in 1997, and are projected to decline to about $1,300$ m^3 per capita per year in 2010. The annual safe yield of ground water is 12.2 km^3, which is only 6.5 percent of surface water. Of the total safe yield, seven km^3 is already consumed.

[1] The information I provide in this subsection about Turkey is mostly based on Cakmak (2000).

Table 1.4: Water Resources of Turkey

Runoff Balance	Groundwater Balance	Total Balance
Mean annual precipitation	n.a.	n.a.
501 km^3 (643 mm)		
Runoff	n.a.	n.a.
186 km^3 (238 mm)		
Usable surface runoff	Safe Yield	(-16 km^3) to Iraq and Syria
95 km^3	12 km^3	91 km^3
Consumption	Consumption	Total Consumption (1998)
30.4 km^3 (32%)	7 km^3 (58%)	37.4 km^3 (41%)

The DSI (2000) has reported water consumption by sectors in table 1.5. The industry uses the least amount of water among the three, around 3.5 km^3, while domestic use varies around 5–6 km^3. Even though water consumption by all three sectors have increased over time, agriculture share in total consumption has consistently gone up from 72.1 percent to 75 percent. This increase in water consumption by agriculture is due to the increase in irrigated land.

Nonetheless, agriculture's share in total output in Turkey has decreased over time, from about 12.13 percent to around 8.44 percent, which is displayed in table 1.6. The proportion of the irrigated area that whose water is supplied from groundwater resources was only ten percent, half a million ha. The remainder was using surface water. The average cultivated area per holding (farm size) was about six ha in

Table 1.5: Water Use (km^3) in Turkey

Sector	1990	1994	1998	2000
Irrigation	22.0	23.7	28.1	31.5
Domestic	5.1	5.2	5.7	6.4
Industry	3.4	3.6	3.7	4.1

Table 1.6: Agricultural Output Share in Turkey

Year	Percent of GDP	Year	Percent of GDP
1998	12.14	2004	9.26
1999	10.21	2005	9.10
2000	9.86	2006	8.02
2001	8.63	2007	7.42
2002	10.11	2008	7.48
2003	9.71	2009	8.44

1991, and eighty-five percent of the holdings, on forty-two percent of the land, were smaller than ten ha. The average farm size increases from west to southeast, due to differences in the climate and the fertility. Percentage area irrigated with sprinkler or drip irrigation techniques is only 3.5 percent of the total irrigated area.

The percentage of the population that is connected to a network on tap water is about eighty-five percent in rural areas, and ninety-eight percent in urban areas.

Table 1.7: Different Water Uses in Total Domestic Use in Turkey

Households Use	Toilet	Clothes	Faucet	Shower	Leak	Other
Percent	26	22	17	16	14	5

Drinking and utility water supplied has increased from 1.7 km^3 in 1980 to about 5.7 km^3 in 1998, due to the initiation of the International Drinking Water Supply and Sanitation Decade by the United Nations Environmental Program (UNEP). On table 1.7, I illustrate the share of different households uses in total domes consumption. Among the variety of domestic uses, water used in toilet and for clothes are among the biggest users.

Table 1.8: Industry Use of Water in Turkey

Industry	Percent	Industry	Percent
Food & Drinks	28	Mining	8
Textiles	17	Chemical	7
Pulp & Paper	14	Oil & Pertoleum	4
Steel & Iron	10	Other	12

Among the industries, food and drinks and pulp and paper are among the biggest users; see table 1.8. Due to the high population density, and concentration of industrial production, almost every river in western Turkey suffers from some degree of water pollution.

1.5 Conclusion

In this chapter, I have reviewed the institutions and the doctrines observed in the resource management. Institutions act as both informal constraints and formal rules. Consequently, management of a resource can be open to everyone as in open-access resource or very limited to a groups of users as in private-property resource. Although private-property resource seems to be the basis of a market activity and is useful for efficiency purposes, market failure can still occur due to various reasons. Meanwhile, the doctrines used in surface-water management can be as flexible, as in the riparian doctrine, without any quantification feature of the rights, and as strict, as in prior appropriations doctrine, which has some features which may lead to inefficiencies. The degree of water scarcity, in this sense, determines how strict a doctrine should be. Other than the riparian and prior appropriation doctrines, Eastern permit systems are also observed, in which the state owns and manages the water resource. In most of the OECD countries, the government is responsible for all the duties in the surface water markets, from water abstraction to selling water. However, the private sector has started to take over some of these duties from the government.

When I consider the private-sector participation in surface water market, I find that there is such a trend in most countries. Private-sector participation is especially observed in the providing and supplying water. However, the government is still the dominant supplier in most OECD countries, with huge support to several user groups in many different ways. The most obvious and most criticized government support is to agricultural producers in the form of cross-subsidization. This has some economic, social, and environmental consequences. More specifically, government support to the agricultural producers leads to overuse of water, larger government deficit, and more pollution due to the nitrate and pesticide use. Since a huge part of this government support is subsidizing price of water charged for agricultural use, households and industries pay nearly a hundred times as much. This situation requires a set of solutions. First, one solution is for the government to let the private sector take some of its duties such as providing and selling water. This solution is sure to suggest the private-sector participation. However, as I discussed earlier, private-sector participation is not as common in surface water management as it is expected to be, considering most OECD countries. Thus, even though the private sector provides water and sells it in the market, the government may still need to intervene in the market. The government cannot risk overpricing or underprovision of water due to its equity concerns. This asks for government regulation to the market via taxes or subsidies as well as quotas. A second solution involves the government as a natural monopoly in a surface water market due to large capital investment costs; the government covers full costs of selling water, including both accounting and opportunity costs of selling water, to agricultural producers and uses different pricing schemes to improve efficiency. In this case, the government may choose to adopt different pricing schemes which potentially deviates from average cost pricing or marginal cost pricing.

CHAPTER 2
OPTIMAL PRICING OF WATER: OPTIMAL DEPARTURES FROM THE INVERSE ELASTICITY RULE

2.1 Introduction

As water becomes relatively scarce, government protection through subsidization of the agricultural sector has become increasingly questionable. Water policies are important in many aspects, including water conservation, because among all these sectors, about seventy percent of water withdrawals in all OECD countries are by the agriculture. Water used for irrigation has consequences on the land allocation in agriculture, so crop composition depends on the amount of water available for irrigation. Irrigation water does not only affect other agricultural input demands (such as capital, fertilizers, and labor), but it also has implications for the composition of agricultural output. Furthermore, inefficient use of water by the agricultural sector may cause overuse of water as well as water pollution, which is a problem in both developed and developing countries. In figure 2.1, I illustrate sectoral water prices in several OECD countries in late 1990s. The agricultural sector paid substantially less than industry and households; specifically, the ratio is around one percent; see the OECD (1999a,b,c). For example, on average, farmers in the United States pay about \$0.05 per cubic meter, while industry pays \$0.50 per cubic meter. In France, these prices are \$0.08 and \$0.92 per cubic meter, respectively. Finally, in Spain, on average, farmers pay \$0.05 per cubic meter whereas industry pays \$1.08 per cubic meter. In some countries (including Italy, Japan, and Turkey), marginal cost of using an additional unit of irrigation water equals zero, because of non-volumetric pricing

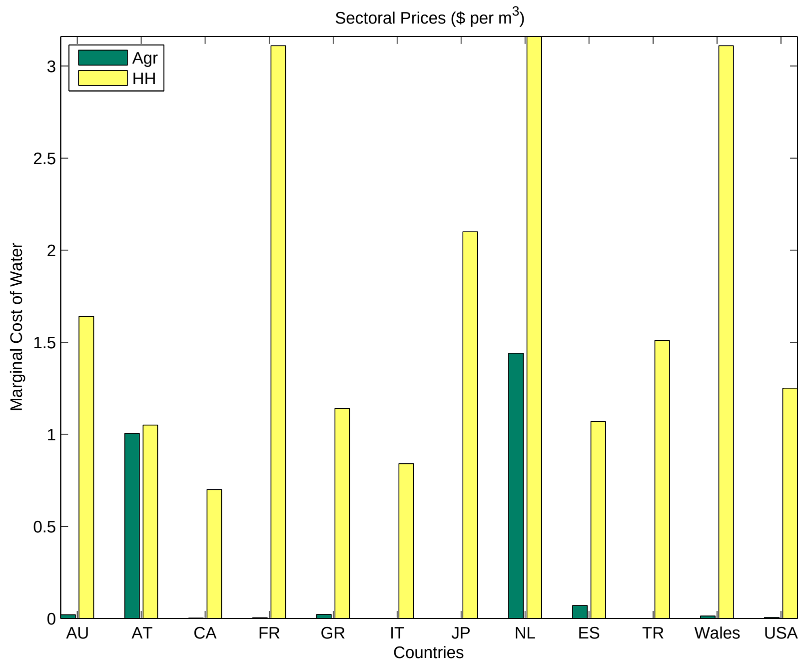

Figure 2.1: Water Prices for Different Sectors in OECD Countries

schemes. Part of this difference can result from quality of water provided to the three sectors. For example, households and industries may require pressurized water, whereas the agricultural sector does not require a high quality of water. However, one would not expect the effect of differences in quality to be this much. Putting cost differences aside, another factor is government protection of the agricultural sector. Subsidizing the agricultural sector can result in inefficiencies such as overuse of water consumption and water pollution. Without government protection, marginal-cost pricing implies equal prices across sectors, after accounting for differences in water quality and assuming that all sectors withdraw surface water from the same reservoir.

In this paper, I attempt to explain why the observed pricing schemes may differ from marginal-cost pricing. I do not attempt to explain each of the many pricing schemes, but rather I concentrate on a commonly-observed pricing scheme: two-sector pricing. Under two-sector pricing, a water supplier, which I shall refer to as the (local) government, charges different customer groups different prices. I construct a partial-equilibrium model where both domestic households and agricultural producers demand. The government seeks to maximize net social welfare of the economy, subject to a resource constraint as well as a revenue constraint. The government achieves its goal through price discrimination between domestic demand, which is the demand by households, and agricultural demand.

Domestic demand has two parts—drinking water and other uses of water, the second of which I shall refer to as *bathing water*. These are supplied from the same tap, so the two different uses cannot be priced differently. Drinking water is, however, more important than bathing water, but charging a sufficiently low price for drinking water may result in an "overuse" of bathing water. Agricultural output is as important to well-being as drinking water. Thus, charging low prices for agriculture and high prices for tap water is a solution which avoids the need to monitor bathing-water usage, while still providing for basic needs.

This paper is in four more parts: In the next section, I provide a brief summary of the use of the Ramsey pricing on the water literature, while in section 3, I introduce the model. In section 4, I analyze the dynamic Ramsey pricing problem of the local government. Then, I focus on the static problem to analyze prices, derive conditions that make two-sector pricing efficient, and present a numerical example for an assumed objective function, a cost function, and constraints. Finally, I shall discuss the qualitative results of my paper in light of the inverse elasticity rule. I summarize and conclude the paper in section 5.

2.2 Literature Survey

Ramsey pricing has been used in the water literature in several ways. For instance, van der Ploeg and Withagen (1991) considered a pollution-control problem by setting up a social-welfare function and then examining the solution to the Ramsey problem. Both flow and stock externalities exist in their model of pollution control. Pigouvian taxes are used to induce people to clean the environment. They constructed a general Ramsey problem with pollution and then considered several cases of the general model: the Ramsey problem with flow externalities, the Ramsey problem with both flow and stock externalities, and the Ramsey problem with abatement activities. For each case, they showed that a locally asymptotically-stable steady state exists.

Kim (1995) focused on the comparison of marginal-cost and second-best pricing rules, where the utility served different user groups. Kim employed a translog multiproduct cost function to estimate a cross-section of water utilities in the United States using the method of maximum-likelihood estimation. He computed the own-price elasticities of the residential and non-residential demand for water, and derived the marginal costs of providing water to these sectors. He concluded that the pricing rule employed by the utilities are quite different than the marginal-cost pricing, but similar to second-best pricing rule.

Ramsey pricing has also been used to examine optimal prices in the water market. Decaluwé, Patry, and Savard (1998) performed comparative analyses of different pricing schemes using an applied general-equilibrium model. The government was assumed to maximize the consumer surplus of different sectors given a tax-revenue constraint, and efficiency of Ramsey pricing was compared with that of marginal-cost pricing, considering several cases in which income tax increases or decreases. Several simulations were ran to see which pricing scheme would be more efficient. Their results indicated that Ramsey pricing with reduction in production taxes is the most efficient among the schemes considered.

Nauges and Thomas (2003) contributed to the literature of water pricing in a dynamic setting, considering a partial-equilibrium model in which a benevolent government maximizes the utility of a representative consumer, subject to a debt constraint. Selling water to the consumer has two purposes—consumer utility and debt coverage. They estimated residential water demand in both the short- and the long-run, and found that residential water demand is more elastic in the long-run than in the short-run because people do not adapt to changes in prices quickly and, thus, waste water after a long period of low prices. They also concluded that long-run, rather than short-run, elasticities should be taken into account by local authorities whose objective is to maximize social welfare.

2.3 Model

In my model, water can be used in three different ways—as an input to agricultural production, as drinking water for consumers, and as bathing water for consumers. For simplicity, the following scenario might be useful: a representative agent has two taps that provide water. One tap provides water for drinking and bathing purposes, while the second tap can only be used for food production. As I shall discuss below, these three water uses are valued differently.

2.3.1 Households

Suppose households have a fixed income I in every period and do not save. Income is completely spent on three commodities—food f, tap water w_1, and a consumption good y which represents all other commodities except food and water. Tap water can be used for drinking and non-drinking purposes. Drinking use represents the necessary uses of water, while non-drinking use, which I shall refer to as bathing water, is associated with all other uses of water except drinking water[1].

With their income, households purchase food and consumption good as well as tap water. The prices of food and tap water are denoted by p_f and p_1, respectively. I assume that all the prices and income are in terms of the price of the composite good. The price of food may vary because water is used in agricultural production, and there it may have a different price. I shall discuss this in the agricultural-production section. Moreover, the reason why drinking and bathing water have the same price is that both are tap water. Even when drinking and bathing water are different commodities, they typically cannot be priced differently because they come out of the "same" tap. Thus, the price of drinking water and bathing water are assumed to

[1]In some countries, such as Italy, drinking and bathing water are priced differently. There, this problem does not arise.

be equal. The household's budget constraint then is

$$p_1 w_1 + p_f f + y = I. \tag{2.1}$$

At this point, I do not assume specific preferences for the per-period utility function, except to assume that preferences are locally non-satiated and strictly concave. Let w_{11} and w_{12} denote drinking and bathing water, respectively, and their sum equals the total tap water use w_1. The utility-maximization problem of the representative agent is a static maximization problem:

$$\max_{<f,w_{11},w_{12},y>} U(f, w_{11}, w_{12}, y)$$
$$\ni p_1(w_{11} + w_{12}) + p_f f + y = I.$$

By solving the optimization problem, one can derive the indirect utility function $\Upsilon(\cdot)$, and the Marshallian demands as a function prices and income $(\mathbf{P}, I)$.

2.3.2 Producers

Producers are farmers who require water to produce food. Farmers demand irrigation water w_2 at its price p_2, which may be different from the price of tap water p_1, because the government may set different prices for different sectors. Note that, in this model, no quality differences exist between irrigation water and tap water, so I shall assume that the cost of supplying tap and irrigation water are the same[2].

As the price of irrigation water changes, producers determine how much inputs to employ and how much to produce. I assume perfect competition in agricultural

[2] Even though this assumption is not critical, it is useful to compare the two water prices.

markets, so maximized profits are zero in equilibrium. Land is taken as fixed, and consumers are assumed to supply labor inelastically. Agricultural production is assumed to follow constant returns-to-scale (CRS), having the following production technology:

$$f = f(w_2) = \kappa w_2, \;\; \kappa > 0. \tag{2.2}$$

A representative agricultural firm's profit maximization problem becomes:

$$\max_{<w_2>} \; \Pi(w_2; p_f, p_2) = \max_{<w_2>} \; p_f f(w_2) - p_2 w_2.$$

Three points are worth noting: first, since the market is competitive, the price of food equals the marginal cost of producing food, so p_f equals (p_2/κ). Second, the equilibrium profits will be driven to zero. Finally, since equilibrium profits are zero, the volume of water used as input is found from the Marshallian demand for food. This means that w_2 equals (f/κ). In other words, the agricultural sector has a derived demand for water.

2.3.3 Government

I assume that the government acts as a benevolent water supplier. This assumption is reasonable as it is estimated that less than ten percent of the world's population is provided drinking water through private sector services; see the OECD (2006). In each period, the government is responsible for supplying water and taxing consumers as well as the agricultural sector. It does so by choosing the price of tap water, p_1, and of irrigation water, p_2. The two water prices may be equal, in which case the government prefers to charge both sectors the same price, or they may be different, in which case the government price discriminates across the two sectors.

The government seeks to maximize the net social welfare of households and producers. Since profits in the agricultural sector are zero in equilibrium, the only component of the government's objective function is the indirect utility function of the households. The indirect utility function is taken as a criterion function for the maximization problem. The government has to satisfy two constraints. The first constraint is that it must collect enough tax revenues to fund supplying water; i.e., it must generate enough revenue to cover fixed capital investment, operating and maintenance costs of the water supply. The second constraint on the government involves intertemporal resource allocation of water. Specifically, it must decide how much water to save for the future.

The optimization problem faced by the government is to maximize the net social welfare in the economy subject to the resource constraint as well as raising revenues. In this respect, I shall refer to this problem as the Ramsey problem. That the government must collect revenues to cover its costs introduces a distortion in the economy. However, even without this distortion, it is not necessarily the case that the solution to this problem is no price discrimination, in which both domestic households and agricultural producers are charged the same price. To make a complete analysis, I shall first examine the maximization problem without a tax revenue constraint and then introduce this constraint and analyze its effects on the economy.

Let τ and $\mathbf{P_t}$ denote the fixed cost of production and the vector of water prices, respectively. The water prices depend on the current water stock w_t. Notice that water saved for next period w_{t+1} is not stated as a control variable because it is determined once the prices of water are chosen. Note, too, that prices, quantities, and the criterion function depend on the water supply saved from the pervious period as well as the additions to the water supply. Specifically, the government determines the water prices according to the available water stock in the reservoir. Within this framework, the stochastic version of the Ramsey problem is as follows[3]:

$$\max_{\{p_{1t}(w_t),p_{2t}(w_t)\}_{t=0}^{\infty}} \mathcal{E}\left[\sum_{t=0}^{\infty}\beta^t\Upsilon(\mathbf{P_t};I)\right] \tag{2.3a}$$

$$\ni p_{1t}\left(w_{11t}+w_{12t}\right)+p_{2t}w_{2t}-\Psi\left(w_{11t}+w_{12t}+w_{2t}\right)\geq\tau, \tag{2.3b}$$

$$w_{t+1}=S\left(w_t,E_t\right)-\left(w_{11t}+w_{12t}+w_{2t}\right), \tag{2.3c}$$

$$p_{ft}=p_{2t}/\kappa; \tag{2.3d}$$

$$w_{11t},w_{12t},w_{2t},w_{t+1}\geq 0, \tag{2.3e}$$

$$w_0 \text{ is given} \tag{2.3f}$$

where the quantities $\{w_{11t},w_{12t},w_{2t},w_{t+1}\}$ depend on $(\mathbf{P_t};I)$. Under the assumption that there is no quality differences among different water uses, the cost of water, denoted by $\Psi(.)$, is a function of only the total withdrawals. The available water stock, denoted by $S\left(w_t,E_t\right)$, depends on both the water saved from previous period and a random shock E_t which may follow a specific, stochastic Markovian process. The available stock may also be limited by capacity constraint.

[3]Note that the water supplier in this problem may tax more than τ in order to discourage water use, thus ensuring a larger stock in the future. What is done with this surplus in tax revenue is currently not modelled.

2.4 Analysis

The Ramsey problem stated in the previous section is a two-stage maximization problem. In the first stage, the government chooses w_{t+1} optimally, and the rest of the water supply will be released for sectors in the current period. In the second stage, the government chooses the two water prices optimally for efficient use of water by the sectors. Given amount of withdrawals, the problem of choosing the optimal prices becomes a static problem for the government. Since the focus of this chapter is on the differential prices, analyzing the prices in the static setup is sufficient. Suppose that the government collects the revenue from selling water and does not use the money for any purposes. In this case, households have no other income source than their per-period income. Thus, their budget constraint is given in equation (2.1).

2.4.1 Analysis with Resource Constraint

First, I shall focus on the resource constraint and thus, I shall ignore the tax-revenue constraint in this first part of the analysis. The static version of the dynamic Ramsey problem becomes:

$$\max_{<p_1(w),p_2(w)>} \Upsilon(\mathbf{P};I) \tag{2.4a}$$

$$\ni w_1(\mathbf{P};I) + w_2(\mathbf{P};I) = WD(\mathbf{P};I) \leq \bar{w}, \tag{2.4b}$$

$$w_1(\mathbf{P};I), w_2(\mathbf{P};I) \geq 0, \tag{2.4c}$$

$$p_f = p_2/\kappa; \tag{2.4d}$$

$$f(\mathbf{P};I) = \kappa w_2(\mathbf{P};I) \tag{2.4e}$$

where WD denotes the total withdrawals from the water stock, and $\bar{w}$ is the available water supply. For notational simplicity, I shall continue with the following notation:

$$w_1(\mathbf{P}; I) = w_{11}(\mathbf{P}; I) + w_{12}(\mathbf{P}; I).$$

Let λ and δ be the Lagrange multipliers on the resource constraint and the budget constraint of households, respectively. Note that the budget constraint is not given in the maximization problem since using Marshallian demands and the indirect utility function will make the budget constraint hold. The economic interpretations of λ and δ are the marginal value of water and marginal utility of income, respectively. The Lagrange multiplier δ can be ignored through normalization, so I shall interpret the ratio (λ/δ) as the marginal value of water. The first order conditions (henceforth, FOCs) of the static Ramsey problem are

$$\begin{aligned}
\frac{\partial \Upsilon(\cdot, I)}{\partial p_1} &= MU_1 \frac{\partial w_1(\cdot, I)}{\partial p_1} + MU_2 \frac{\partial w_2(\cdot, I)}{\partial p_1} + MU_y \frac{\partial y(\cdot, I)}{\partial p_1} \\
&= \lambda \left[\frac{\partial w_1(\cdot, I)}{\partial p_1} + \frac{\partial w_2(\cdot, I)}{\partial p_1} \right] \\
\frac{\partial \Upsilon(\cdot, I)}{\partial p_2} &= MU_1 \frac{\partial w_1(\cdot, I)}{\partial p_2} + MU_2 \frac{\partial w_2(\cdot, I)}{\partial p_2} + MU_y \frac{\partial y(\cdot, I)}{\partial p_2} \\
&= \lambda \left[\frac{\partial w_1(\cdot, I)}{\partial p_2} + \frac{\partial w_2(\cdot, I)}{\partial p_2} \right]
\end{aligned}$$

where MU_i is the marginal utility with respect to commodity i. Note that the first component of the partial derivative of the indirect utility function with respect to the two water prices equals:

$$MU_1 \frac{\partial w_1(\cdot, I)}{\partial p_i} = MU_{11} \frac{\partial w_{11}(\cdot, I)}{\partial p_i} + MU_{12} \frac{\partial w_{12}(\cdot, I)}{\partial p_i}; \ \forall \ i = 1, 2.$$

The solution to household's utility-maximization problem requires that the marginal utility of a water use equals its price. Using this property, one can rewrite the FOCs in the following way:

$$\frac{\lambda}{\delta} = p_1 + (p_2 - p_1)\frac{\partial w_2(\cdot, I)/\partial p_1}{\partial WD(\cdot, I)/\partial p_1} + \frac{\partial y(\cdot, I)/\partial p_1}{\partial WD(\cdot, I)/\partial p_1} \quad (2.5a)$$

$$p_2 + (p_1 - p_2)\frac{\partial w_1(\cdot, I)/\partial p_2}{\partial WD(\cdot, I)/\partial p_2} + \frac{\partial y(\cdot, I)/\partial p_2}{\partial WD(\cdot, I)/\partial p_2}. \quad (2.5b)$$

To see the relationship between the two water prices, I derive a condition that makes the two prices equal. Assuming that equal prices solve these FOCs, the FOCs can be simplified to

$$p_1 = p_2 = \frac{\lambda}{\delta} - \frac{\partial y(\cdot, I)/\partial p_1}{\partial WD(\cdot, I)/\partial p_1}$$
$$p_1 = p_2 = \frac{\lambda}{\delta} - \frac{\partial y(\cdot, I)/\partial p_2}{\partial WD(\cdot, I)/\partial p_2}$$

where (λ/δ) is the marginal value of water. Notice that, because total withdrawals are expected to decrease with the water prices, the two water prices are not less than the marginal value of water. assuming that both tap water and food are both substitutes of the consumption good. It is also important to realize that without such a composite good, the optimal pricing scheme is the marginal-cost pricing rule. Including a non-water-related commodity is crucial here to ensure that a commodity unrelated to food or water exists, and households can substitute among the three commodities when the price of food or water changes. Thus, when the water supplier changes the water prices, demand for the consumption good also changes and the revenue collected from selling water will change. These two equations imply the following condition for prices:

$$\frac{\partial y/\partial p_1}{\partial y/\partial p_2} = \frac{\partial WD/\partial p_1}{\partial WD/\partial p_2} \Leftrightarrow \frac{\epsilon_{y,1}}{\epsilon_{y,2}} = \frac{\epsilon_{WD,1}}{\epsilon_{WD,2}}$$

where $\epsilon_{WD,i}$ and $\epsilon_{y,i}$ denote the elasticity of total withdrawals and the composite good with respect to the water price p_i, for $i = 1, 2$, respectively. The condition above is a necessary condition for marginal-cost pricing, and is interpreted in the following way: the local government sets p_1 equal to p_2 as long as the ratio of the price elasticity of y with respect to p_1 and p_2 equals the ratio of elasticity of total withdrawals with respect to p_1 and p_2, at the optimum. The last term on the right-hand side of both FOCs in equation (2.5) leads to this condition. This is due to the change in the consumption good with respect to changes in the water prices. If the consumption good is unaffected by the water prices, then changing water prices will have no effect on the consumption good and water prices could be set equal to the marginal value of water. Since I assume that substitution between water-related commodities and the consumption good is possible, the consumption good changes with at least one of the water prices.

Although this result seems to replicate the inverse-elasticity rule, described in Baumol and Bradford (1970), the inverse-elasticity rule does not necessarily apply in this case. Specifically, I shall show that, although households have a relatively more elastic demand for water, they are charged a higher price than the agricultural producers. To see the intuition behind the result, consider the problem below.

First, I shall start with the case where there is no consumption good. Assume that the cross-price elasticities of different water uses are zero, and further suppose that households have a relatively more elastic demand for water than the agricultural producers do. The government targets to maximize utility subject to only the revenue constraint. In this case, households would pay a lower price, because of the inverse-elasticity rule (i.e., enough revenue can be generated by charging a higher price for the relatively less elastic demand). With only the resource constraint, the government would adopt marginal-cost pricing rule; i.e., both sectors are charged the same price which is the marginal value of water. As a result, without any consumption good, the revenue constraint would imply inverse-elasticity rule, and the resource constraint would lead to marginal-cost pricing rule.

Suppose now that households can also purchase a non-water-related commodity; i.e., a composite good non-taxable by the local government. Moreover, assume that households can only substitute tap water with the consumption good. In other words, the consumption good is affected by the price of tap water, but unaffected by the price of irrigation water. In this case, the water supplier prefers to charge a higher price to households. This is because, in the absence of the consumption good, enough revenue may be generated by setting p_1 higher than p_2, but at a larger cost, which means less utility than optimal. However, utility may now be maximized by setting p_1 higher than p_2 since increasing p_1 also increases the demand for the consumption good. In other words, more income can be allocated to the consumption good. As an optimal solution, the water supplier prefers to allocate as much income as possible for the consumption good, which is equivalent to collecting as less revenue as possible. Thus, it charges more to the households who have a relatively more elastic demand than the agricultural producers, still generates enough revenue to cover costs, and aims to maximize utility. Although this result contrasts with the inverse-elasticity rule and second-best pricing scheme, it may explain why it is observed that households pay a higher price for water consumption than the agricultural producers although the demand for tap water is usually predicted to be more elastic.

2.4.2 Analysis with Both Constraints

The corresponding Ramsey problem with both constraints becomes

$$\max_{<p_1(w),p_2(w)>} \Upsilon(\mathbf{P};I) \tag{2.6a}$$

$$\ni w_1(\mathbf{P};I) + w_2(\mathbf{P};I) = WD(\mathbf{P};I) \leq \bar{w}, \tag{2.6b}$$

$$p_1 w_1(\mathbf{P};I) + p_2 w_2(\mathbf{P};I) \geq \Phi\left(WD(\mathbf{P};I)\right) + \tau, \tag{2.6c}$$

$$w_1(\mathbf{P};I),\ w_2(\mathbf{P};I) \geq 0, \tag{2.6d}$$

$$p_f = p_2/\kappa, \tag{2.6e}$$

$$f(\mathbf{P};I) = \kappa w_2(\mathbf{P};I). \tag{2.6f}$$

Let μ and λ be the Lagrange multipliers on the revenue and the resource constraints, respectively. Using the budget constraint, the revenue constraint (2.6c) can be written as:

$$WD(\mathbf{P};I) \leq \Phi^{-1}\left(I - \tau - y(\mathbf{P};I)\right) \tag{2.7}$$

where the function $\Phi^{-1}(.)$ is the inverse of the cost function[4].

[4]One can find the inverse of a cost function since for any cost level, there is a corresponding production level and also not two different production levels can lead to the same cost level.

The FOCs lead to the following necessary condition:

$$1 = \frac{\frac{1}{w_1}\left[\mu \frac{\partial \Phi^{-1}(I-\tau-y)}{\partial p_1} + (\lambda+\mu)\frac{\partial WD}{\partial p_1}\right]}{\frac{1}{w_2}(\lambda+\mu)\frac{\partial WD}{\partial p_2}}$$

where the FOCs declare that both the numerator and the denominator in the right-hand-side (henceforth, RHS) equal $-\delta$, which is the negative of the marginal value of income.

Although it is unclear from the FOCs which constraint will bind, if not both, one can divide the solution into three cases:

- **Case 1: No Water Scarcity** Assume that the water supply is abundant ($\bar{w} \to +\infty$). In this case, one can ignore the resource constraint. The solution to the problem is unique, and the revenue constraint is binding, while the resource constraint is irrelevant. Without loss of generality, denote this solution by (p_1^*, p_2^*), so (WD^*, y^*). As long as the water supply is above the total withdrawals at the optimum WD^*, the solution stays the same, so do the prices. This is also the solution to the static Ramsey problem with no resource constraint; so the inverse-elasticity rule should apply.

- **Case 2: Water Scarcity** Assume that the water supply $\bar{w}$ is strictly lower than WD^*. In this case, the solution in case 1 does not satisfy the resource constraint, so the water prices should adjust to make the resource constraint hold. Denote the new optimum by (p_1', p_2'), and so (WD', y'). In this new solution, the total withdrawals are lower. Assuming that the total withdrawals do not increase in either water price, the tax revenue constraint should become slack in this new optimum. As the water supply gets enormously scarce ($w \to 0$), the resource constraint will be a much stronger factor, and the price changes will be more drastic. It is noteworthy that the solution is derived according to the FOCs (2.5), so water prices may exceed one another, depending on the parameter values.

- **Case 3** Assume that the water supply $\bar{w}$ equals WD^*. In this case, both the resource and the revenue constraints bind, and the water prices are determined by solving a system of these two equations. Moreover, assuming that the consumption good and the total withdrawals are monotone in water prices and also that there exists an intersection for the second equation in (2.7), the solution to the system exists and is unique.

2.4.3 Numerical Example

I assume the Stone–Geary function for preferences of consumers[5]:

$$U(w_1, f, y) = \pi_1 \log(w_1 - \underline{w}_1) + \pi_2 \log\left(f - \underline{f}\right) + (1 - \pi_1 - \pi_2)\log(y),$$

$$\underline{w}_1,\ \underline{f} \geq 0,$$

$$\pi_1,\ \pi_2 \in [0, 1].$$

where $\pi 1$ and π_2 denote the marginal budget shares of tap water, and food, respectively. The parameters $\underline{w}_1$ and $\underline{f}$ represent the subsistence level consumption of tap water and food. One can view the drinking water use under the subsistence level,

[5]Stone–Geary function is used in estimating the demand for tap water in the water literature; see Gaudin, Griffin, and Sickles (2001)

while consumers need to consume some food for survival. I assume that the composite good does not a subsistence level. Given the functional form, the demand for tap water is:

$$w_1 = (1-\pi_1)\underline{w}_1 + \pi_1 \frac{(I - p_f \underline{f})}{p_1}$$

The demand consists of two components: the subsistence level $\underline{w}_1$, and the price-responsive component. The price-elasticity of demand for tap water and food are always inelastic in its own price:

$$\epsilon_{w_1,p_1} = \frac{\pi_1(I - p_f\underline{f})}{(1-\pi_1)\underline{w}_1\ p_1 + \pi_1(I - p_f\underline{f})},$$
$$\epsilon_{f,p_f} = \frac{\pi_2(I - p_1\underline{w}_1)}{(1-\pi_2)\underline{f}\ p_f + \pi_2(I - p_1\underline{w}_1)}.$$

In addition to the preferences, I assume the following cost function for supplying water:

$$\Phi(WD) = \theta_1\ WD^{\theta_2};\ \ \theta_1 > 0 \text{ and } \theta_2 \geq 1$$

I assume the parameter κ equals one for the remainder of the paper to simplify the computations and the notation. In this way, the demand for food equals the demand for irrigation water, and the price of food equals the price of irrigation water. The per-period utility function simplifies to become:

$$U(w_1, w_2, y) = \pi_1 \log\left(w_1 - \underline{w}_1\right) + \pi_2 \log\left(w_2 - \underline{w}_2\right) + (1 - \pi_1 - \pi 2) \log\left(y\right),$$
$$\underline{w}_1,\ \ \underline{w}_2 \geq 0,$$
$$\pi_1,\ \ \pi_2 \in [0,1].$$

First, the parameters of the model $\{I, \underline{w}_1, \underline{w}_2, \pi_1, \pi_2, \kappa, \tau, \theta_1, \theta_2\}$ must be determined. There are also parameters for the state and control variables: $\{N_w, \underline{w}, \bar{w}\}$, where N_w

is the number of grids for water stock, $\underline{w}$ and $\bar{w}$ are the lower and upper bounds for water stock, respectively. Although I do not use real data to determine these parameters, I believe the values for the parameters are reasonable. I display the parameter values in table 2.1.

Table 2.1: Parameter Values

Parameters	$\underline{w}_1$	$\underline{w}_2$	π_1	π_2	I	τ	θ_1	θ_2	N_w	$\underline{w}$	$\bar{w}$
Values	10	50	0.2	0.2	100	10	0.5	1	500	63	200

I set the marginal budget shares of food and tap water the same at 0.2, but the tap water has a lower subsistence level than food. Consequently, the demand for tap water is relatively more elastic with respect to its own price than that of the agricultural demand for water, at the same prices. This can also be seen from the elasticity equations below:

$$\epsilon_{w_1,p_1} = \frac{\pi_1(I - p_2\underline{w}_2)}{p_1\left[(1-\pi_1)\underline{w}_1 + \pi_1\frac{(I-p_2\underline{w}_2)}{p_1}\right]},$$
$$\epsilon_{w_2,p_2} = \frac{\pi_2(I - p_1\underline{w}_1)}{p_2\left[(1-\pi_2)\underline{w}_2 + \pi_2\frac{(I-p_1\underline{w}_1)}{p_2}\right]}.$$

On figure 2.2, I illustrate the case when the government has revenue and resource constraints. The two water prices, marginal cost of water (MC), and sectoral water withdrawals are plotted for various values of available water supply $\bar{w}$. When there is no water scarcity, the resource constraint does not play any significant role, and the water stock in the reservoir is sufficient to meet the demand by both sectors. In this case, the revenue constraint binds, and the solution is the unique and the same for any such levels of water supply. The inverse-elasticity rule applies, so the price of irrigation water exceeds that of tap water. Note, too, that the price of tap water is less than the marginal cost of water, so the government makes losses from supplying water to households and profits from providing irrigation. The profits made from agricultural sector compensates these losses as well as the fixed cost.

When there is water scarcity, the revenue constraint becomes slack. In this case, withdrawals equal the water supply, which is below the volume of withdrawals the government would like to supply should there be no resource constraint. In other words, WD is strictly less than $(I - \tau - y)$ in this region. As water gets increasingly scarce, the price of tap water exceeds that of irrigation water. Another interesting result is that since there is water scarcity, both water prices are higher than the marginal cost of water. The government generates profits from supplying water to both sectors, which exceeds the fixed cost. Nonetheless, I assume that these profits do not return to the economy in this partial-equilibrium setup[6].

These results are important because they show that the price of a public good does not necessarily exceed that of another good even though the demand for the first good is more elastic than the other. In fact, with the introduction of a binding resource

[6]In some countries such as Turkey, the law states that the government cannot make any profits from supplying water to the different sectors. Thus, I did not model how profits are being used in this model. However, one may consider cases where part or all of the profits is being rebated to the households.

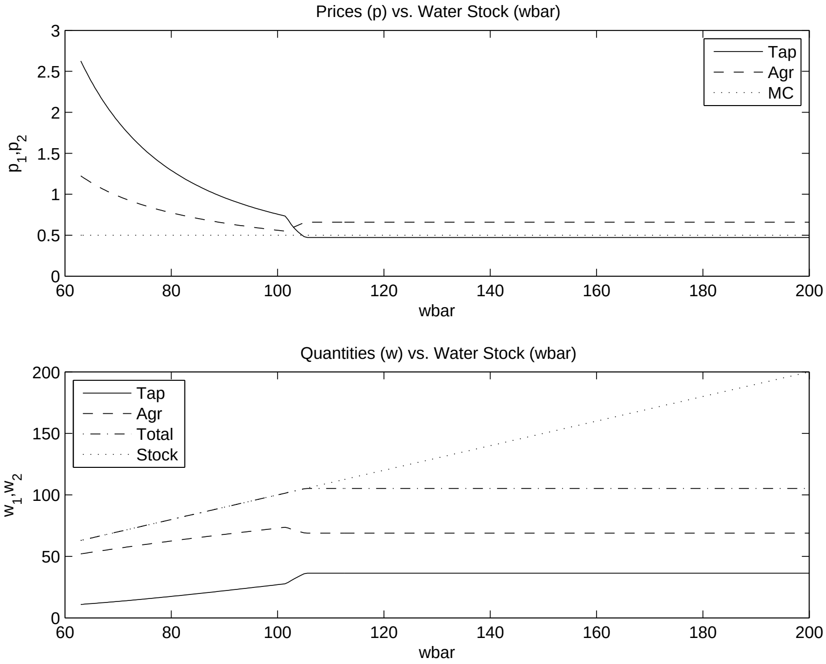

Figure 2.2: Static Problem with Revenue and Resource Constraints

constraint, the problem may be independent of the revenue constraint altogether if the two demand functions are inelastic in their own prices. As a result, the prices may optimally deviate from the inverse-elasticity rule, which is the solution of a static Ramsey problem with no resource constraint.

2.5 Conclusion

In this chapter, I have attempted to explain the price-discrimination problem of a local government in supplying water to multiple user-groups. To analyze the pricing scheme decision of the government, I constructed a dynamic partial-equilibrium model, but considered its static version, since the goal of my paper is to analyze if prices are optimally different from each other. When the water supply in the reservoir is abundant enough, the government's budget constraint plays a more significant role in the determination of the water prices, as the reservoir has enough water stock for both user groups. Thus, one expects that the inverse elasticity rule applies: Irrigation water, which has a relatively less elastic demand than tap water, is charged more, after accounting for the cross-price elasticities. However, when the water supply is scarce enough, the stock of water in the reservoir becomes crucial, as there is not enough water for both user groups anymore. For this reason, the government increases the price of tap water, and households end up paying a higher price for water than the agricultural sector. This conclusion results from the fact that the costs involved in increasing the tap water price is less those involved in increasing the irrigation water price. As a result, the local government aims to collect as less revenues as possible from households so that the households can allocate more of their income for the other commodities. Consequently, the agricultural sector pays a lower price for water than the households.

As simple as my model is, results may have interesting implications concerning the government aid to the agriculture in supplying water. Although the general understanding is that as water scarcity gets more severe, the price of irrigation water has to be raised substantially to decrease the volume of irrigation water. This idea stems from the fact that the demand for irrigation water is quite inelastic, as without water, there is no crop production. For this reason, governments may choose to subsidize the agriculture through lower irrigation prices. However, as I have shown in this paper, this may not necessarily be the case. In fact, as water gets more scarce, the increase in the price of tap water may be more than that of the price of irrigation water. Consequently, the necessity of the government aid to the agriculture may be questionable.

CHAPTER 3
DATA DESCRIPTION

3.1 General Information

The data provided by the DSI in Turkey concern two river basins on the southern Turkey; see figure 3.2. This region is exceptionally important for the Turkish agriculture since Cukurova, the largest alluvial plain in Turkey, is located here. The plain is formed the rivers Seyhan and Ceyhan, and it borders the Taseli plateau in the west. Seyhan and Ceyhan are one of the more important rivers in Turkey. The geographical map of the region is displayed in figure 3.1.

Figure 3.1: Geographical Map of Cukurova

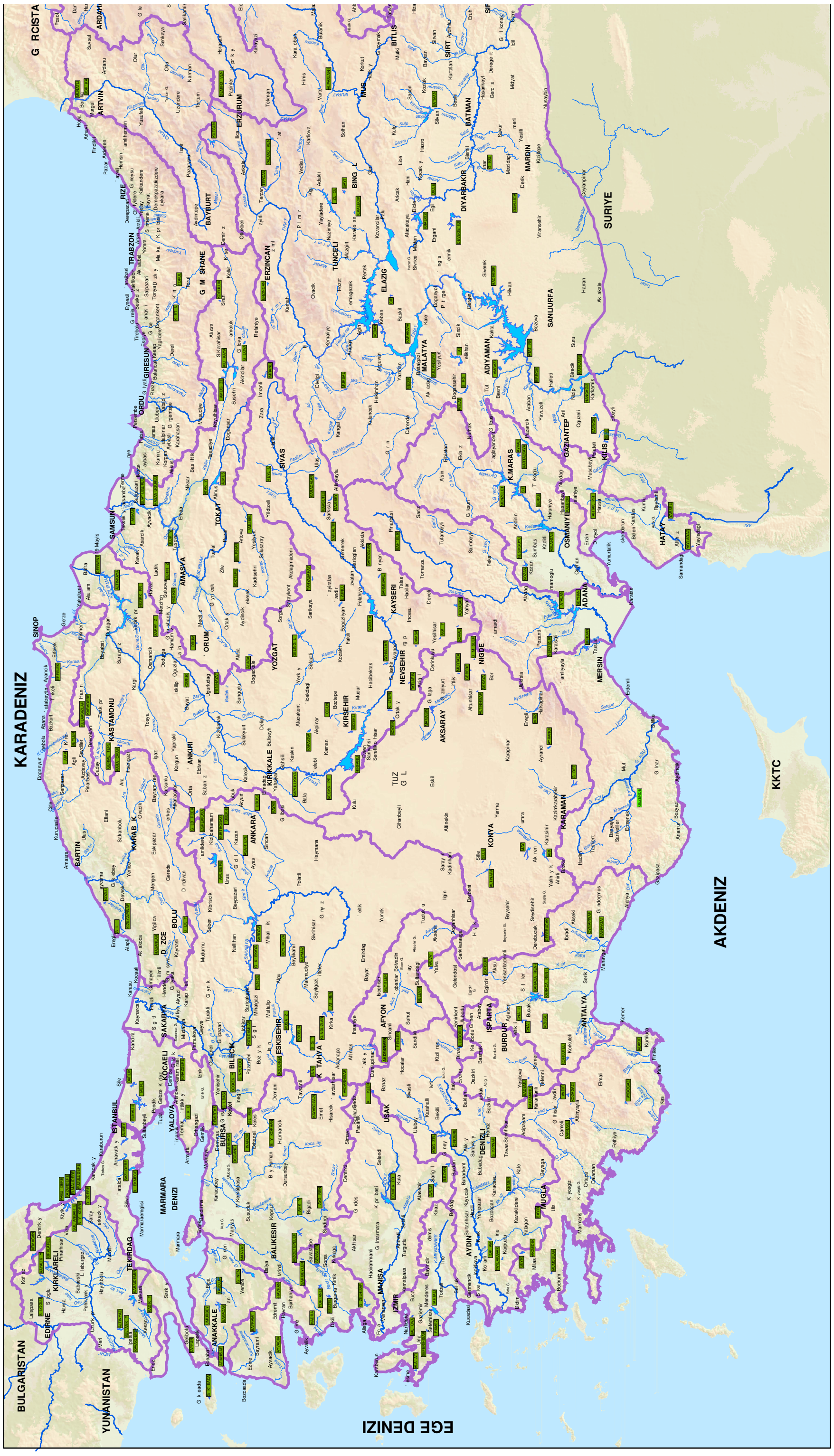

Figure 3.2: Geographical Map of Turkey

These two river basins are the focus in the data. There are several dams on these two river basins. The data are available for the following dams: Aslantas, Kartalkaya, Kozan, and Menzelet on Ceyhan river basin; Bahcelik, Catalan, Nergizlik and Seyhan on Seyhan river basin.

The Aslantas Dam is located near the city Osmaniye; construction was completed in 1984; since its completion, it has been serving water for irrigation and energy production. Like most dams, this dam is also used for flood prevention in the area. The dam volume is 8.493 cubic hectometres (hm^3) and the total irrigation area that it serves is $149,849$ ha.

The Kartalkaya Dam is located near the city Kahramanmaras. The dam belongs to Ceyhan basin, but has incoming flows from Aksu river, too. Construction was completed in 1972; since its completion, it has been serving water for irrigation and drinking purposes. Like the other dam in the region, it is also used for flood prevention. The dam volume is 2.323 hm^3 and the total irrigation area that it serves is $22,810$ ha. The dam is now mostly used for tap water.

The Kozan Dam is located near the city Adana. The dam belongs to Ceyhan basin, but has incoming flows from Kilgen river, too. Construction was completed in 1972; since its completion, it has been serving water for irrigation and drinking purposes. The dam volume is 1.680 hm^3 and the total irrigation area that it serves is $10,220$ ha.

The Menzelet Dam is located near the city Kahramanmaras. Construction was completed in 1989; since its completion, it has been serving water to mainly produce energy. it is used for flood prevention. The dam volume is 8.700 hm^3 and the total irrigation area that it serves is 22,810 ha. The dam is now mostly used for tap water.

The Bahcelik Dam is located near the city Kayseri. The dam belongs to Seyhan basin, but has incoming flows from Zamanti river, too. Construction started in 1984 and ended only recently. Its main purposes are irrigation and energy production. Like most dams, this dam is also used for flood prevention in the area. The dam volume is 1.634 hm^3 and the total irrigation area that it serves is 36,282 ha.

The Catalan Dam is located near the city Adana. Construction was completed in 1996; since its completion, it has been serving water mainly for energy production, and also for drinking water. The dam volume is 17 hm^3.

The Nergizlik Dam is located near the city Adana. The dam belongs to Seyhan basin, but has incoming flows from Ucurge river, too. Construction was completed in 1995; since its completion, it has been serving water mainly for irrigation. The dam volume is 1.474 hm^3 and the total irrigation area that it serves is 2,326 ha.

The Seyhan Dam is located near the city Adana. Its construction was completed in 1956 and since its completion, it has been serving water for irrigation and energy production. Like most dams, this dam is also used for flood prevention in the area. The total irrigation area that it serves is 22,810 ha. The dam is now mostly used for tap water.

3.1.1 Service Shares and Fixed Costs

For each dam, the DSI determines service shares. A service share is the percentage water usage right. In table 3.1, I display the service shares for the dams. These service shares are particularly important in the repayment of the costs of dam construction. Meanwhile, in table 3.2, I provide information about the dam construction and maintenance costs of the dam. For example, the total cost of Kartalkaya Dam is about $68,453,640.616$ TRY, where TRY denotes "Turkish Lira". Assuming that \$1 equals 1.5TRY, this corresponding dollar amount equals about $\$30,000,000$. Water users associations, which are responsible for providing and selling water to agricultural producers, have to pay back eighty-four percent of the total cost of dam construction and maintenance, and the municipalities which are responsible for tap water, have to cover sixteen percent of these costs.

Table 3.1: Service Shares of the Dams in Cukurova

Dam	Irrigation	Flood	Energy	Tap	Other
Aslantas	74.8	1.5	21.5		2.2
Bahcelik	77.76	0.03	0.56	21.65	
Catalan	24	71	5		
Kartalkaya	64.43	2.19	33.38		
Nergizlik	100				
Seyhan	33.3	33.3	33.3		

Table 3.2: Reservoir Costs of the Dams in Cukurova

Dam	Cost (in current prices)	Cost (in 2005 prices)
Aslantas	17,168,162.454	200,368,785.828
Kartalkaya	1,045,930.575	68,453,640.616
Kozan	67.650	32,511,441.902
Menzelet	207,145.079	526,858,627.015
Bahcelik	23,556,389.610	51,700,109.160
Catalan	2,341,136.588	709,873,814.118
Nergizlik	493,458.181	28,913,517.890
Seyhan	902.289	564,732,931.344

3.1.2 Water Users Associations

In the past, the DSI was responsible for selling water for all purposes. However, in the 1990s, the DSI started to decentralize and turned over this duty to different organizations. Specifically, water users associations (henceforth, WUA) took over this duty and started to provide and sell water to agricultural sector. Similarly, the municipalities became responsible for pricing water to households and industries.

As mentioned above, the WUAs are non-profit organizations, which are responsible for pricing irrigation water. They provide water in such a way that they have to not only cover their Operating and Maintenance (O&M) cost of providing water, but also repay their share of the fixed cost of dam construction. Their share is again determined by the service shares. All their information is kept in records by the DSI. For this reason, I was able to get a detailed dataset on the WUAs. There are thirty-seven WUAs carrying water from these eight dams to Cukurova plain. The oldest of these WUAs organized in 1988, and the most recent one in 1999. For each WUA, I have the following yearly data:

- **Prices**: Price of irrigation water and total land area irrigated for each crop type,
- **Revenues**: All sources of revenue,
- **Costs**: All cost items,
- **Employment Structure**: Number and type of employees working for the WUA,
- **Budget**: Cash holdings, claims, annual debt, etc.,
- **Repayment Schedule**: Due dates of repayments of the fixed cost of dam construction, and the investments made during the year,
- **Capital Holdings**: Buildings, autos, machines employed for the WUA.

3.2 Kartalkaya Dam

The Kartalkaya Dam is located near the city Kahramanmaras; see figure 3.3. The dam belongs to Ceyhan basin, but has incoming flows from Aksu river, too. Construction was completed in 1972; since its completion, it has been serving water for irrigation and drinking purposes. Like most dams, this dam is also used for flood prevention in the area. The dam volume is 2.323 hm^3 and the total irrigation area that it serves is 22, 810 ha. The dam is now mostly used for tap water. The Kartalkaya Dam is one of the most important dams in the region, as it provides not only irrigation water to the parts of Cukurova plateau, but also tap water to the city of Gaziantep. With a population of about 1.5 million in the year 2007, Gaziantep is the ninth largest city of Turkey and the largest city in Turkey's Southeastern Anatolia Region.

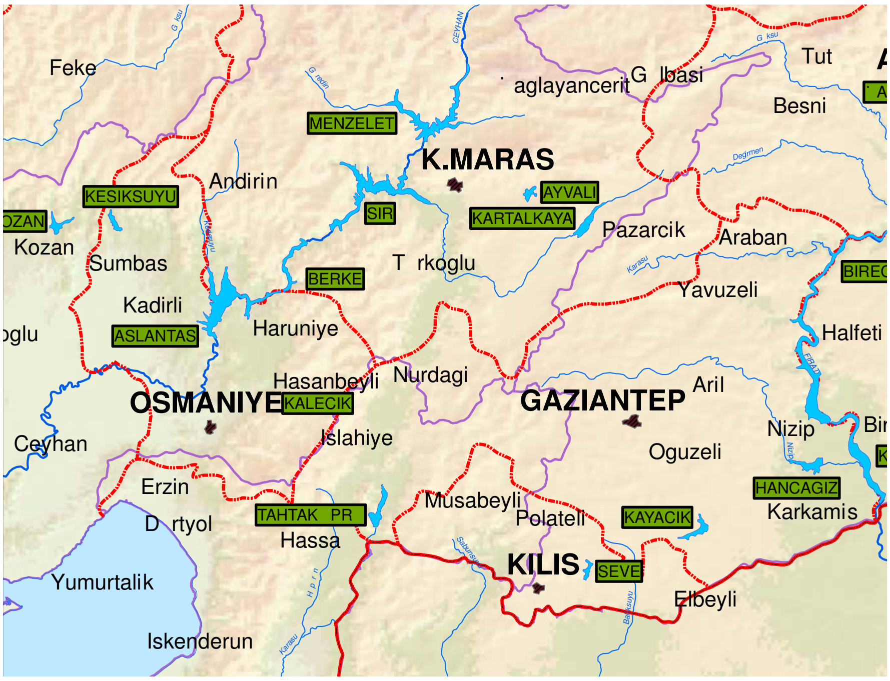

Figure 3.3: Kartalkaya Dam

I collected data concerning the flows into the Kartalkaya dam for the period between January 1984, and August 2007 (with a total of 284 observations). The values are in hm^3. In table 3.3, I provide summary statistics for the data. To keep the notation consistent with the model, w, w_3, w_2, w_1, e and x denote volume of water at the beginning of the period, water release under flood control, irrigation water release, tap water release, evaporation, and inflows, respectively.

Table 3.3: Summary Statistics for Reservoir Flows

Variable	Mean	StDev	Minimum	Median	Maximum
volume - w	92.06	55.92	5.65	94.02	177.99
other (tap) - w_1	5.45	1.938	2.4	4.5	10.713
irrigation - w_2	13.25	17.66	0	0	61.4
flood - w_3	13.66	33.73	0	0	298.5
evaporation - e	0.2877	0.5927	0	0.055	4.3
inflows - x	32.47	37.79	0.2	17.95	307.3

The volume of water in the dam averages around half of its reservoir capacity, 173.173 hm^3, over the time period. Moreover, water release under flood control is as significant as water releases for agriculture and households' use. Water release under flood control has a maximum of 298.5hm^3 during the period, which suggests large inflows to the dam: water is released for free under flood control. Over the time period, the dam has a total of available water supply of 124.53 hm^3 on average.

The average monthly share of irrigation and tap water use is about ten percent each. Due to households' demand for water, water supply has never been any less than 2.4 hm^3, whereas water is not released for irrigation for some periods at all, due to the rainfalls, and so forth.

Inflows to the dam are important for water stock as they help the government determine the total stock of water at the reservoir. The inflows are much higher during winter and spring, while during the summer, when irrigation is carried out, the inflows as well as precipitation equals almost zero; see figures 3.4 and 3.5. The government releases water for three purposes: tap water use, irrigation water use, and water release for flood control. Some volume of water is released to avoid overflows whenever available water supply is expected to exceed the maximum capacity, in particular during winter. When released to avoid overflows, most of the water is directed to irrigation fields. However, there is no agricultural production in winter, so it does not affect the agricultural output. Tap water use amounts to between 8–10 hm^3 monthly, whereas irrigation water use is only positive during the end of summer, when there is no precipitation.

Below, I shall focus on some more details of the flow data.

3.2.1 Volume of Water

I focused on the data on the volume of water reported at the beginning of the month. Using the elevation-volume-area table for the Kartalkaya dam, I compared the reported volume with the observed value. At the end, I found out that the two

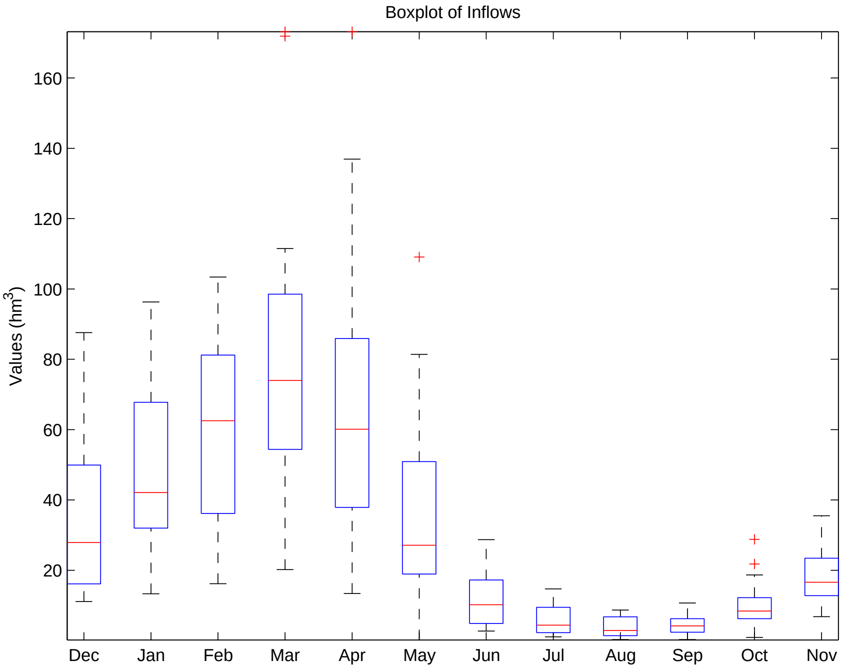

Figure 3.4: Inflows (December–November)

measures are identical up to the second decimal, so I concluded that there is no measurement error in volume of water.

3.2.2 Water-Balance Equation

In the water literature, "water-balance equation" provides the basis to check inflow and outflow data. Quite simply, the water-balance equation states that the measured water supply at the beginning of the period along with the inflows (shocks to the water supply) makes the total available water supply, and after the water releases for all uses and evaporation in the dam, the remaining amount of water should equal the measured water supply at the beginning of the next period. In

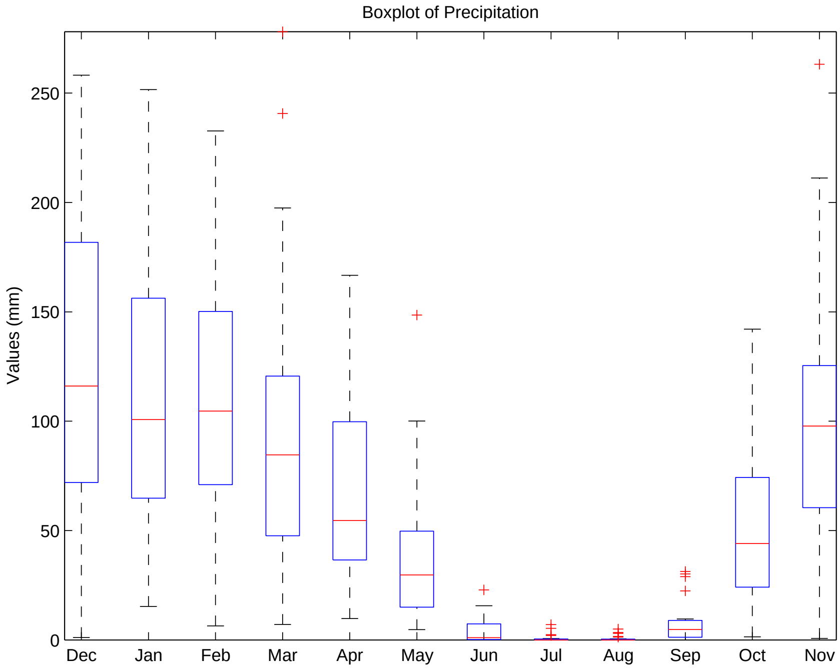

Figure 3.5: Precipitation (December–November)

mathematical terms, one can denote this equation in the following way:

$$w_{t+1} = \min\left(\bar{w}; w_t + x_t - e_t\right) - \left(w_{1t} + w_{2t}\right)$$

where $w_{t,1}$ and $w_{t,2}$ represent withdrawals for domestic (tap water) and irrigation (irrigation water) uses, respectively, and the first term on the right-hand side represents the available water stock. I display this in figure 3.6. Incorporating water release under flood control into in the water-balance equation reduces the error considerably. However, there is still measurement error in the data so that they do not satisfy the water-balance equation above. However, I shall ignore this error in my model.

$$w_{t+1} = \left(w_t + x_t - e_t - w_{3t}\right) - \left(w_{1t} + w_{2t}\right).$$

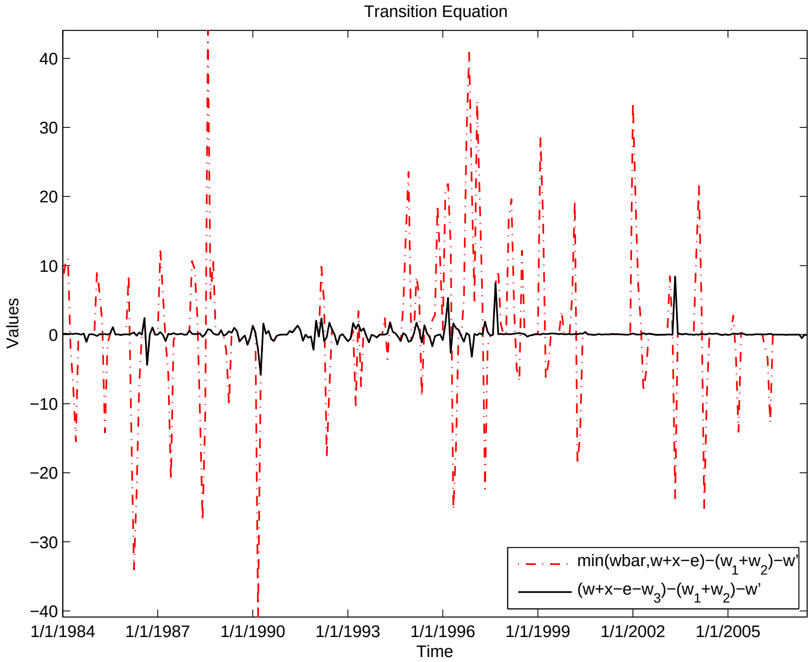

Figure 3.6: Water Balance Equation

3.2.3 Flood Control

I investigated what positive water releases under food control means. In figure 3.7, I illustrate this case with two graphs using water saved from last period w, inflows x, water releases under flood control w_3, and maximum capacity of the dam $\bar{w}$. To understand w_3 better, I first ordered the variables in an ascending order according the total water supply $w + x - e$. As can be seen from the first graph in figure 3.7, some volume of water is released to prevent overflows, and in particular, water release under flood control increases whenever available water supply is expected to exceed the maximum capacity. After being released to prevent overflows, most of the water is directed to irrigation.

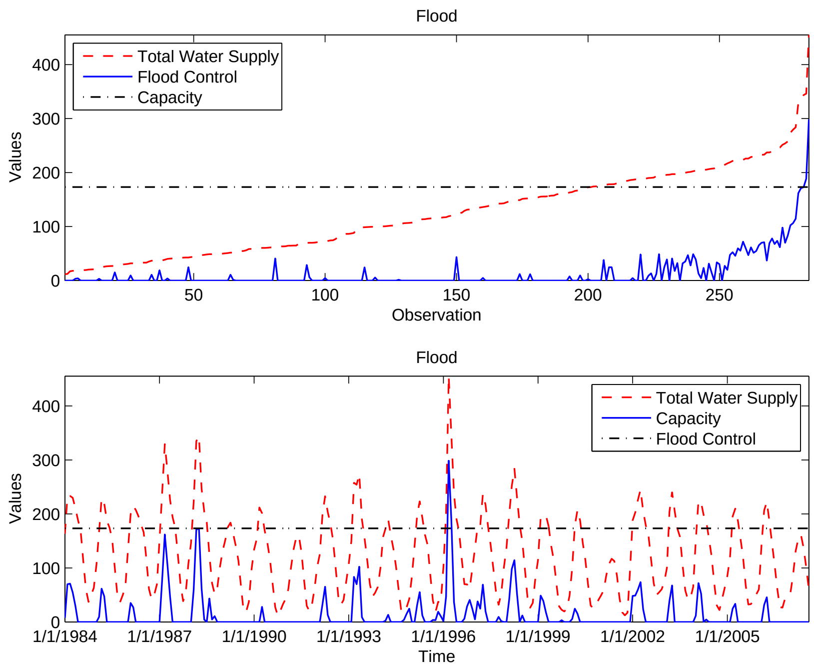

Figure 3.7: Flood Prevention

3.2.4 Water Releases

Considering water releases for irrigation and tap-water uses, one anticipates that demand for irrigation water may possess strong seasonality, whereas households' demand for water may not. In figure 3.8, I illustrate the outflows from the dam. On the one hand, irrigation water release drops to zero level during winter, and rises almost up to fifty hm^3 during summer. On the other hand, seasonality does not seem to be a serious factor for tap-water release. However, one also observes big structural shifts in the tap-water release over the years. A potential reason for this increase in tap-water release is that there is no distinction of water release for tap water and for other uses such as meeting water demand in neighbor areas. In other words, a dam may also release water to neighbor areas, if the dam which is responsible for those

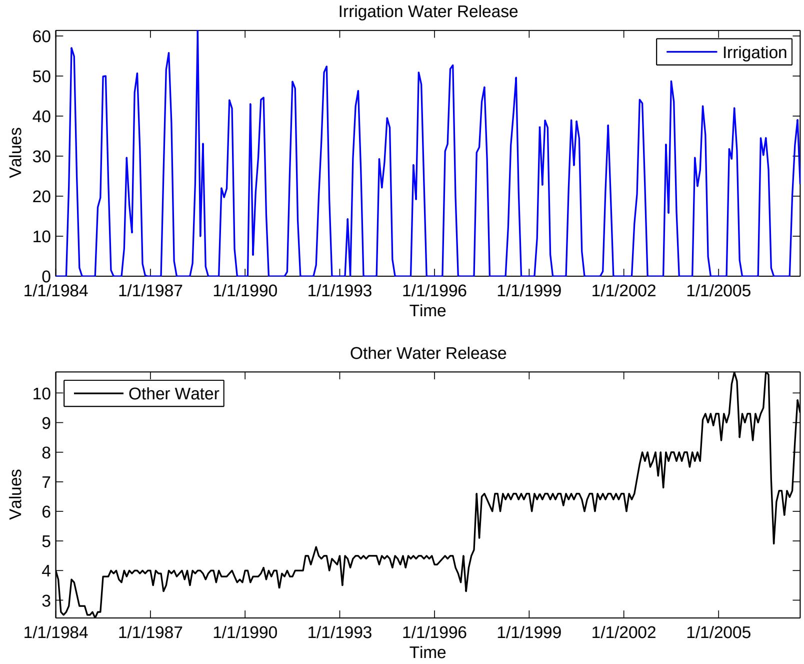

Figure 3.8: Outflows from the Reservoir

areas does not contain enough water. One can also see this as a network effect, which I shall not model in this paper.

3.3 Crops, Irrigation, and Prices

The WUAs operate to manage water from the Kartalkaya Dam: Left- (LB) and Right-Bank (RB) water users associations. The left WUA and the right WUA began February 1, 1995 and August 19, 1994, respectively. The LB WUA provides water to twenty-one villages in Narli Valley, with a total irrigation area equal to 12, 000 ha. The RB WUA provides water to seven villages, with a total irrigation area equal to 5, 000 ha. Before 1994–5, the DSI set the irrigation prices. However, with the reforms in agriculture during mid-1990s, the DSI turned over the duty of price setting to local

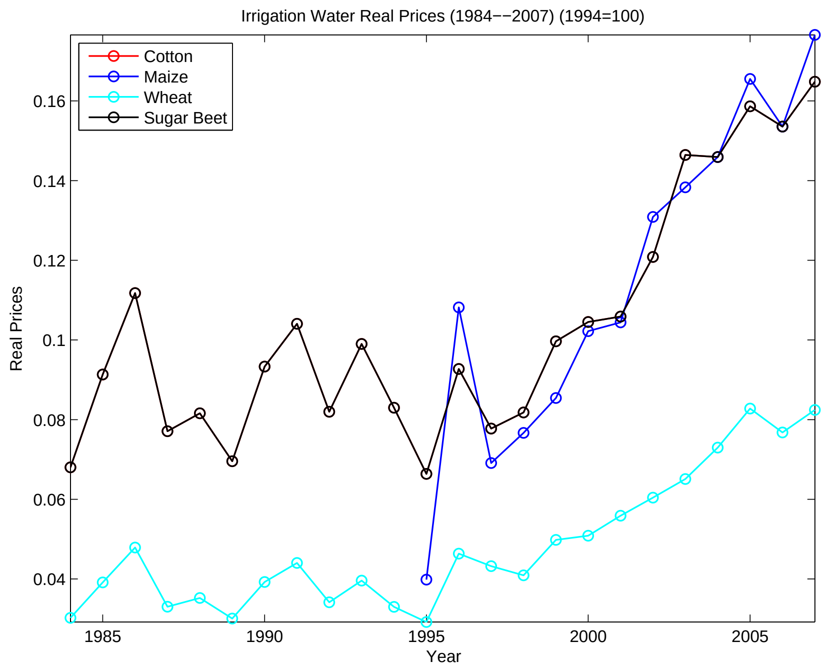

Figure 3.9: Irrigation Water Prices

associations (the WUAs). Although the WUAs are non-profit organizations, they still attempt to break-even. To do this, they began full-cost recovery, so this led to higher irrigation prices in real terms; see figure 3.9. In setting the non-volumetric irrigation prices, the WUAs consider the crop water requirements—how much water per hectare a crop needs. This has two consequences: first, the irrigation prices (in real terms) for different crops have evolved almost the same way over time, and a constant proportion among prices is preserved throughout the time period. Second, the more water a crop requires during the growing period, the higher the irrigation price of the crop is, see figure 3.9. Consequently, the irrigation price of cotton and sugar beets is the highest, while that of maize is the second largest. Meanwhile, wheat does not require much water during the growing period, so its irrigation price is the

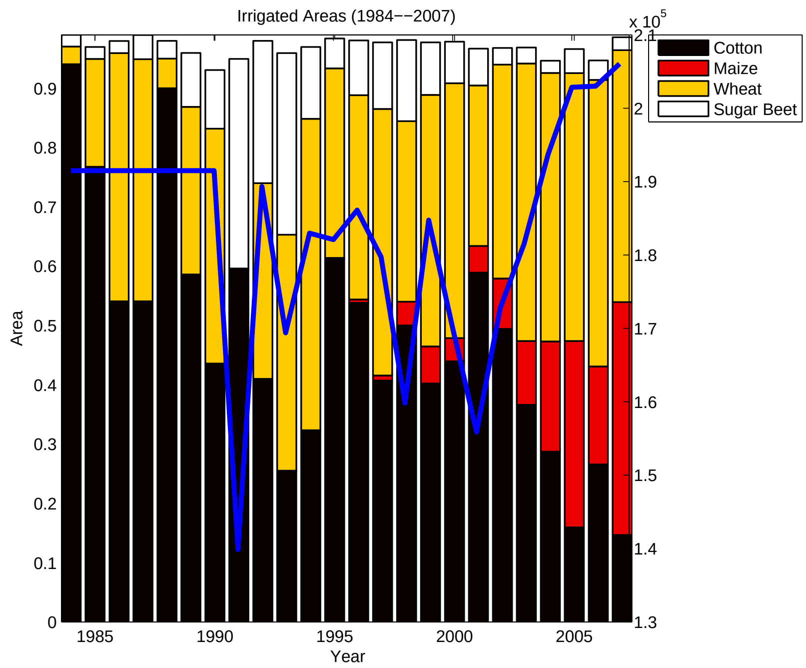

Figure 3.10: Crop Composition

least. Note, too, that the irrigation price of cotton and sugar beets are the same throughout the period. One explanation for this fact may be due to the climatic and soil characteristics of the region, cotton and sugar beets require the same amount of water per area. Given the crop water requirements, changes in crop composition leads to the changes in the irrigation water demand. The region's agriculture focused mostly on growing cotton in the mid-1980s, but after the DSI turned over the duty of setting water prices to local associations, crop composition changed dramatically from the crops that require relatively more water (such as cotton and sugar beets) to those that require relatively less, such as wheat, see figure 3.10. Although the total irrigated area is the same before and after 1995, the proportion of area allocated for cotton decreased from 60–90 percent range to forty percent and below. This decrease has been offset by allocating more area for crops such as maize and wheat. Even though the area allocation problem of farmers surely depends on many factors, such as crop prices, it seems that the change in the organizational structure accompanied by higher real prices has also had an impact on area allocations. The solid line in figure 3.10 indicates the total land irrigated. Three severe water shortages have occurred between 1991 and 2001: 1991, 1999, and 2001. During these water shortages, the government refused to provide irrigation to some portion of the land.

Table 3.4: Percent of Tap Water Lost

Year	Percent Lost	Year	Percent Lost
1998	63.51	2004	71.03
1999	63.90	2005	53.84
2000	68.16	2006	56.47
2001	71.72	2007	53.03
2002	74.11	2008	52.55
2003	75.29		

3.4 Tap Water Use

The DSI supplies water for tap use to the city of Gaziantep. Gaziantep Water and Sewerage Administration (the municipality, for short) is responsible for pricing tap water. The city has three water sources: the Kartalkaya dam, wells, and another

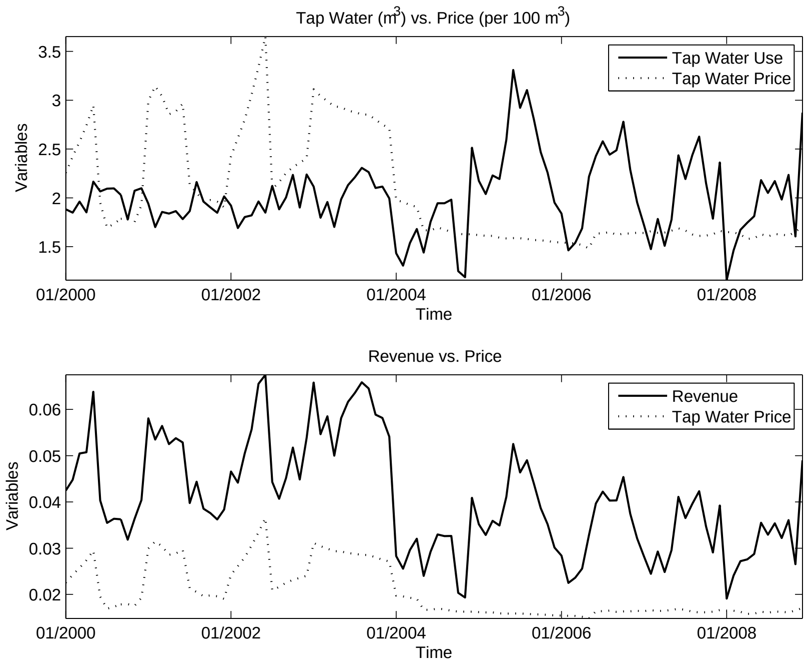

Figure 3.11: Tap Water Use and Price

reservoir at Mizmilli. The Kartalkaya Dam provides around eighty percent of this supply.

The municipality has been unable to recover all the revenue from water sales. In fact, every year around 55–60 percent of the tap water supplied by the municipality has been "lost": the revenues are uncollected. For this reason, it may be particularly difficult to find a significant relationship between tap water demand and its price. The proportion of tap water that is actually paid for, which I shall call the "recovery rate" throughout this paper, was around twenty-five percent in 2003, but increased to almost forty-eight percent in 2007. The percent of water lost in the system is shown in table 3.4.

In the top graph in figure 3.11, I depict the relationship between the tap water

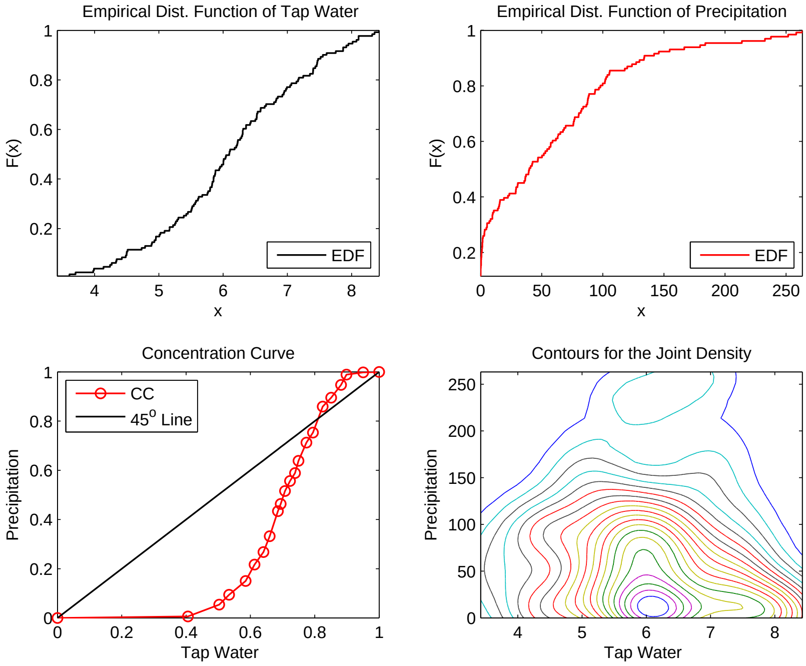

Figure 3.12: Tap Water Use and Precipitation

use and the effective price. Although there seems to be an overall negative relationship between the quantity and the price, other factors may also be present, in particular in the last three years. Households water consumption is around 74 percent of the total water consumption that is recovered. Among other sectors demanding tap water are the local government institutions, schools, hospitals, local stores and businesses, and construction. The bottom graph shows the relationship between revenue from tap water and the effective price, and it is clear that the demand for tap water is inelastic with respect to its own price in the data. This is consistent with the finding in the literature that the tap water demand is not very responsive to its own price.

One can suspect a relationship between precipitation and tap water demand in two ways: first, precipitation is highly negatively correlated with temperature, and the households may require more water to consume at high temperatures. Second, the households may have the technology to stock some of the rain water, and use it for non-drinking purposes. To investigate the correlation between the tap-water use and precipitation, I used Frank Copula from the Archimedean family of copulas. The coefficient of the Frank copula for the two-variable case, shows the sign of the relationship between the two variables. To fit the copula, I used the empirical distribution functions of the variables, and estimated the coefficient by pseudo-maximum-likelihood estimation. The coefficient equals -1.51402, which indicates a negative relationship between precipitation and the demand for tap water. I also used the kernel-smoothing method to derive the joint density nonparametrically, and I illustrate the contours of the joint density in the bottom-right graph.

CHAPTER 4
DYNAMIC WATER-RESOURCE MANAGEMENT: OPTIMAL PRICING OF WATER

4.1 Introduction

Two stylized facts characterize water markets: first, running a balanced budget has been a top priority for equity concerns, because governments manage around ninety percent of all the water reservoirs. According to the average-cost pricing rule, the government only takes into account their own budgets to set the water prices. This pricing policy does not involve the degree of water scarcity, and it leads to larger withdrawals, which is not sustainable in the long-run; see the OECD (1999d). Second, in many parts of the world (including sub-Saharan Africa, Middle East, and Southern Europe), countries suffer from temporary but frequent water shortages. Turkey and Italy as well as California in the United States are only some examples of this fact. Although low precipitation is often seen to be the biggest cause for these water shortages, inappropriate water-pricing systems cannot be overlooked since they cause excessive use of water. Several OECD countries experience periodic water shortages, based on high levels of leakage in the water supply systems, or inefficient usage encountered by insufficient pricing policies. Supply-side management is an important factor as leakages prevent reservoirs from accumulating enough water in their stock.

Hotelling (1931) setup a deterministic dynamic problem with which he showed that the complete depletion of an exhaustible natural resource may be avoided forever, given a suitable demand function. Moreover, he showed that the price of the natural resource would increase at a constant rate in an optimal policy. Compared with the work of Hotelling (1931), certain differences exist in water markets: first, water is a renewable resource, so stochastic additions to a stock of water prevents complete depletions. As a result, the observed water prices need not increase over time. Specifically, this would imply that a water supplier may run into a water shortage temporarily rather than permanently. Second, water provision to different sectors has to be self-financing, because water is mostly managed by governments using the average-cost pricing rule. Finally, because of the temporary water shortages, the focus in the water markets is on short-term consequences of the water shortages; i.e., severe rationing of the consumption by households, and pro-rating of the agricultural as well as industrial water use. Because many sectors need water for their own uses, these water shortages may have important effects on the aggregate economy.

Not enough empirical work has been done to analyze the link between water shortages and water pricing. In fact, in the literature concerning water, most researchers have focused on three issues. First, some have focused on the estimation of tap water demand, including Gaudin, Griffin, and Sickles (2001); Kim (1995), and irrigation water demand, including Iglesias, Garrido, and Gomez-Ramos (2007); Appels, Douglas, and Dwyer (2004); de Fraiture and Perry (2002). However, different sectors may often use water from the same reservoir, so analyzing the optimal pricing of water in one sector, while ignoring the changes in the demand by another sector, may have implications for the policy suggestions. For this reason, different water prices depend on each other. Second, to account for multiple uses of water and to choose optimal prices simultaneously, some researchers (such as Diakite, Semenov, and Thomas (2009); Garcia and Reynaud (2004); Griffin (2001)) have employed static Ramsey pricing scheme. However, the intertemporal allocation of water may have important effects on the second-best water prices. Consequently, rainfall and stochastic shocks to the water supply may have implications for the optimal pricing scheme. To wit, when there is a severe water shortage, the resource constraint dominates the revenue constraint, so optimal prices may be set such that the sector with a more elastic demand is charged a higher price. Finally, the dynamic water reservoir management has been an important factor in water pricing; see Castelletti, Pianosi, and Soncini-Sessa (2008); Howitt, Misangi, Reynaud, and Knapp (2002); Schuck and Green (2002). However, dynamic water reservoir management mostly fails to consider multiple uses of water, as in Schuck and Green (2002), or a revenue constraint, as in Howitt, Misangi, Reynaud, and Knapp (2002).

In this chapter, I am interested in explaining the extent to which optimal pricing policy can help avoid these water shortages. Although one can always find a pricing policy, such as a marginal-cost-pricing rule, to control the demand, it is unclear how well it would perform to avoid water shortages. For example, in a region where there is barely enough water for minimum survival, prices would play no role at all. To determine the effectiveness of water prices on water shortages, I set up a stochastic dynamic model in which a benevolent government supplies water to households and agriculture. The policy function for the water prices will provide the "optimal" pricing rule, given the organizational restrictions, which I shall explain in the model and estimation sections. My model can be generalized to analyze markets for other natural resources that display similar characteristics. However, specific to water provision, my model takes into account changes in crop composition in response to changes in water prices. Since the government may earn profits from supplying water, I analyze the effects of the rebates on the optimal prices. Using the model as well as data I collected from Turkey, I performed a structural estimation of the sectoral demands, and then examined several counterfactual experiments.

My main finding is that, under the current policy of the break-even prices, the average number of years before the government runs into the water shortage, when it cannot meet the sectoral demands on average fifteen years. In contrast, if the government were to choose water prices optimally, then water shortages would be practically nonexistent over the next century. In fact, the government has to experience a series of low inflows to the reservoir to be unable to meet the sectoral demands, but the probability of such an event is close to zero. Moreover, if the optimal pricing scheme is difficult to implement, because of political or other reasons, then the government has to improve the crop water requirements around four percent, to avoid water shortages for about eighty years, under the current policy. If the government were to choose to enhance supply-side technologies, such as preventing leakages to capture more inflows, then the annual mean inflows need to increase about six percent to have the same effect.

This chapter is in four more parts: in the next section, I introduce the model, including the demand of water by the households and the agriculture. In section 3, I perform the demand estimations and calibrated the rest of the parameters. In section 4, I analyze the results for the stochastic dynamic programming problem. I conclude the chapter in section 5.

4.2 Model

In this section, I set up a partial-equilibrium model where a benevolent government acts as a water supplier. The government supplies water for tap and irrigation uses. Households demand tap water monthly, whereas agriculture's demand for irrigation water depends on the season. The timing of the problem is as follows: At the beginning of each period (month), there is some amount of water supply w in the dam saved form last period. During the period, inflows x occur due to precipitation, return flows, and so forth. Some of the water stock is saved for the next period, while the rest is released for both the households and the agriculture. The households and the agriculture observe the prices and depending on their demands, water is withdrawn from the dam. At the end of period, the remaining amount of water in the dam is saved for the next period according to the resource constraint. The government sets the tap and the irrigation prices yearly.

4.2.1 Households

In every period, households have a fixed income I, which represents monthly labor income and other transfers. The households spend their entire income on two commodities—tap water w_1 and a composite good y. I do not admit savings for households. The households maximize their per-period utility subject to the budget constraint:

$$\max_{<w_1,y>} U(w_1, y)$$

$$\ni p_1 \; w_1 + y = I$$

where p_1 is the price of tap water. The price of the composite good is normalized to one, so all prices and income are in real values. The total demand for tap water can be found accordingly:

$$W_1 = M \; w_1(p_1; I)$$

where M and $w_1(.)$ denote the number of households and the Marshallian demand, respectively.

4.2.2 Agriculture

I assume all farmers are identical, so I can focus on a representative farmer's profit-maximization problem. Each farmer owns a unit of land, and he chooses how much land to allocate for different crops. Farmers can either allocate their land for crop production or leave some or all of it fallow, but they cannot rent or sell any part of land.

The crop production function has two inputs: land ℓ_c and water $w_{2,c}$:

$$f_c = f_c(\ell_c, w_{2,c}); \; \forall \; c = 1, \ldots, N$$

where f_c denotes the output of crop c[1]. Although there are many other inputs to food

[1] The water input $w_{2,c}$ may include all sources of water used in crop production, including irrigation water release, precipitation, and water release for flood control. However, there is no rainfall or other inflows during the months of irrigation, so I consider only irrigation in this model.

production, including capital, labor, and fertilizers, since the focus of the paper is on water allocation and prices, I assume that there is infinite supply of these inputs, and the farmers demand other inputs proportional to the land used for food production.

The representative farmer solves a mixed-choice problem: with only a unit of land, the farmer first chooses which crop to grow. Having chosen the crop, the farmer decides how much land and water to produce the crop. A representative farmer's profit maximization problem is as follows:

$$\Pi = \max \left(\Pi_1, \Pi_2, \ldots, \Pi_N, \Pi_{N+1}\right)$$

$$\Pi_c = \max_{<\ell_c, w_{2,c}>} p_{f,c}\ f_c(\ell_c, w_{2,c}) - p_2\ w_{2,c};\ \forall\ c = 1, \ldots, N$$

$$\ni \ell_c \leq \bar{\ell} = 1,$$

and Π_{N+1} is the value of leaving the land fallow, which is normalized to zero. Thus, all the profits generated by crop production are relative to the outside option. I assume a volumetric irrigation price, so $(p_2\ w_{2,c})$ is the cost of irrigation. Note, too, that the land allocations decisions are made yearly, for technological reasons, such as preparation of soil.

Since all farmers are symmetric, the deterministic profit function implies that all farmers choose to produce the crop with the highest profit at the equilibrium. However, there is heterogeneity in the data across farmers and over time. In a general equilibrium framework, the aggregate demand and supply for crops would force the farmers to be indifferent between the crops, even though the farmers are all price-takers. The equilibrium distribution of land across crops would depend on the primitives of the crop markets. Nonetheless, one can generate the same crop distribution by introducing a private shock to the profit function. Such a shock causes heterogeneity in crop choices over farmers and time, and pins down the crop composition. Hence, the profit function is not the actual profit function of the farmers; but it is compatible with the general equilibrium conditions, given randomness. Although the farmers still make a decision with certainty, the government does not observe these private decisions. In fact, it can only predict the resulting crop composition. The observed profit function becomes:

$$\Pi = \max\left(\Pi_1, \Pi_2, \ldots, \Pi_N, \Pi_{N+1}\right)$$

$$\Pi_c = \max_{<\ell_c, w_{2,c}>} p_{f,c}\ f_c(\ell_c, w_{2,c}) - p_2\ w_{2,c} + \mu_c\ \ell_c;\ \forall\ c = 1, \ldots, N,$$

$$\ni \ell_c \leq \bar{\ell} = 1,$$

where I assume that for each crop c, the corresponding demand shock has a known distribution with mean μ_c, and the shocks are independently and identically distributed across farmers and time.

Let a_c denote the decision made for crop c; i.e., a_c equals one if crop c is chosen, and zero otherwise. Given the distribution of the shocks, one can derive the probability of choosing crop c, denoted by $\Pr(a_c = 1 \mid p_2)$, which also depends on the irrigation prices. Once the distribution of crops is derived, farmers' expected total profit $\mathcal{E}\left[\Pi(p_2)\right]$, the expected aggregate demand for irrigation water $\mathcal{E}\left[W_2(p_2)\right]$ can be found accordingly. The expected revenue collected by the government $\mathcal{E}\left[Rev_2(p_2)\right]$

from supplying irrigation water equals

$$\mathcal{E}\left[Rev_2(p_2)\right] = p_2\mathcal{E}\left[W_2(p_2)\right]$$

where $\mathcal{E}(.)$ denotes the expectation operator. Crop composition is important due to two reasons. First, the crop composition affects the revenue constraint for agriculture through the expected irrigation water demand. Second, the government sometimes choose to subsidize some crops rather than all the agricultural production. Given that agriculture has the most demand for water, it may be misleading to conclude that the whole agricultural production is responsible for the large withdrawals. In fact, the equilibrium crop composition may adjust according to the degree of the water scarcity, causing crops that require less water to have more land allocated for them.

4.2.3 Government

I assume that there is a single water supplier—the (local) government. The government seeks to maximize the net social welfare of households and producers. The government's objective function equals the indirect utility function of the households. Since I admit nonzero profits in the agriculture, I assume that these profits are given to the households, as part of the households' income. The government has to satisfy several constraints. The first two constraints are the revenue constraints associated with tap and irrigation water provision; i.e., the government must generate enough revenue to cover fixed capital investment, operating and maintenance (O&M) costs of the water supply in each sector.[2] Let FC_1 and VC_1 denote the fixed cost of tap water

[2]In some cases, the government may have a single revenue constraint. In this case, the revenues from both sectors have to at least cover the costs.

and variable cost per unit of tap water, respectively. Fixed cost FC_1 may also include O&M costs, as well as the fixed payment to the government, because of construction and maintenance costs of the dam. The variable cost equals a constant marginal cost that includes the cost of using chemicals and energy to sanitize water. Variable costs are also important to distinguish the two uses of water. I assume that the fixed and the variable costs vary across months, but not over years. Similarly, let FC_2 denote the fixed costs of irrigation water[3].

The households' demand for tap water is monthly, but I assume that the government sets a single tap water price for the year. Thus, the revenue constraint for each month is aggregated. The irrigation water demand is seasonal, the revenue constraint for irrigation is already yearly, because once the crop choice and land allocation decisions are made, they are set for the entire year. One can write down the two revenue constraints in the following way:

$$\mathcal{E}\left[Rev_1(\mathbf{p})\right] = \sum_{m=1}^{12} p_1 \ \mathcal{E}\left[W_1(\mathbf{p};m)\right] \geq \sum_{m=1}^{12} FC_1(m) + VC_1(\mathbf{p};m) \ \mathcal{E}\left[W_1(\mathbf{p};m)\right],$$

$$\mathcal{E}\left[Rev_2(p_2)\right] \geq FC_2$$

where $\mathbf{p}$ denote the vector of water prices, and $\mathcal{E}\left[Rev_1(\mathbf{p})\right]$ and $\mathcal{E}\left[Rev_2(p_2)\right]$ represent the expected revenue collected from the households and the agriculture, respectively. In this model, I assume that the government has to break even separately in each sector. Since the government charges the two water prices yearly, I assume that the

[3]In the provision of irrigation water, no significant variable costs are involved. Hence, I will not model the variable cost part of irrigation water. However, one can incorporate these variable costs, if need be.

government considers a yearly revenue constraint.

The current policy of the government in many OECD countries is to have a balanced budget; i.e., the expected revenue generated equals the expected cost of water provision in each sector. I refer to the prices that balance the budget as the "break-even prices." Since the government only considers the costs of water provision, the water supply in the reservoir does not play a role in this pricing scheme. Consequently, the current pricing policy may lead to frequent and severe water shortages.

The third constraint on the government involves intertemporal resource allocation of water. Specifically, the government must decide how much water to save for the future:

$$w' = S(w, x) - \sum_{i=1}^{3} W_i$$

where w' is water saved for next period, $S(w, x)$ is the stock of water which depends on water saved from last period w, and inflows x. The withdrawals W_1, W_2, and W_3 represent water release for tap, irrigation, and flood control. The supply of water provided to the sectors must equal the expected demand for water for both sectors at the equilibrium. Hence, the government solves an ex ante equilibrium.

In addition to these three constraints, the government may also rebate the profits it collects from water provision. Let $\tau = (\tau_1, \tau_2)$ denote the amount of rebate to the households, respectively. I assume that some portion of the profits λ cannot be rebated back to the agents due to operational costs.

The monthly value functions can be defined in the following way:

$$V\left(w, \mathbf{p}_{-1}; \theta, m\right) = \max_{<w', W_3, \mathbf{p}>} U\left(\mathbf{p}, \tau, \Pi; \theta, m\right) + \beta\, \mathcal{E}\left[V\left(w', \mathbf{p}; \theta', m+1 \bmod 12\right)\right]$$

$$\ni w' = S(w, x) - \left[W_1(p_1, \tau, \Pi; \theta, m) + W_2(p_2; \theta)\ \delta_{10}^{m} + W_3\right],$$

$$\begin{cases} FC_1 \leq \sum_{m'=1}^{12} \left[p_1 - VC_1(m')\right]\ W_1(p_1, \tau, \Pi; \theta, m');\ \text{if } m = 0, \\ p_1 = p_{1,-1};\ \text{otherwise,} \end{cases}$$

$$\tau_1 = \frac{(1-\lambda)}{12} \left\{\left[p_1 - VC_1(m)\right]\ W_1(p_1, \tau, \Pi; \theta, m) - FC_1(m)\right\},$$

$$\begin{cases} FC_2 \leq \mathcal{E}\left[Rev_2(p_2; \theta)\right];\ \text{if } m = 0, \\ p_2 = p_{2,-1};\ \text{otherwise,} \end{cases}$$

$$\begin{cases} \tau_2 = (1-\lambda)\left\{\mathcal{E}\left[Rev_2(p_2; \theta)\right] - FC_2\right\};\ \text{if } m = 10, \\ \tau_2 = 0;\ \text{otherwise} \end{cases}$$

where m is a deterministically- and cyclically-evolving state variable, which denotes the month. In this setup, the month December corresponds to $m = 0$. The term δ_{10}^{m} is an indicator function which equals one if $m = 10$, and zero otherwise. The vector θ represents any exogenous stochastic shock that may affect the environment, such as inflows, crop prices, and precipitation, and the expectation operator $\mathcal{E}(\cdot)$ is over the shock vector θ'. It is noteworthy that the land allocation decisions are made in December, but the irrigation occurs in September; i.e., $m = 10$. Thus, the irrigation revenue constraint appears in December. Also, I assume that the farmers profits are realized in September.

4.3 Estimation

In this section, I present estimates of the parameters of the model using the Turkish data I described in Chapter 3. it is important to note here that the average-cost pricing rule is the observed pricing scheme in the data. For this reason, the government does not take into account the water flows, and a possible water shortage. Thus, one can perform the estimation of the parameters in each sector in a static framework. One can also separate the estimation of households' optimization problem and the farmers' profit-maximization problem, as the government does not consider the characteristics of the other sector in determining the water price of a sector. Hence, I first estimated the primitives of the households' demand for tap water and the farmers' crop-choice problem separately. Using the parameter estimates, I solved the dynamic programming problem, the results of which are presented in the next section.

4.3.1 Tap Water

An important feature concerning the tap water demand is the price-non-responsive component of the demand, which makes the demand for tap water inelastic with respect to its own price. The inelastic demand is also commonly reported in the literature. The inelastic demand for tap water has implications on the tap water management: if a municipality is responsible for providing households with tap water and attempts to at least cover its costs, then there is a maximum volume of tap water it can sell. In other words, a minimum threshold for tap-water price exists below which the price cannot be set.

One can think of the second component as the demand for drinking water, as drinking water is a must-have for the human body, as described in Gleick (1996)[4]. Meanwhile, households may adjust their demand for non-drinking use according to the price[5].

The features of tap-water demand suggest that if one is to use a demand function for the estimations, it is important that the function delivers a non-constant inelastic demand. A potential candidate for such a function is the Stone–Geary utility function:

$$U = \pi_1 \log \left(w_1 - \underline{w}_1\right) + \left(1 - \pi_1\right) \log \left(y\right).$$

Given the functional form, the demand for tap water is:

$$w_1 = (1 - \pi_1)\underline{w}_1 + \pi_1 \frac{I}{p_1}.$$

The demand consists of two components: the subsistence level $\underline{w}_1$, and the price-responsive component, where π_1 denotes the marginal budget share of tap water. One can think of the subsistence level for tap water as the demand for drinking water as well as the minimum amount of water to sustain the standards of living. The price-elasticity of demand is always inelastic in its own price. I assume that the composite good does not a subsistence level.

I used the data on tap water, and tap price from January, 2000 to December,

[4]I assume that drinking water has no substitutes.

[5]It is also noteworthy that this assumption is used in estimating the demand for tap water in the water literature; see Gaudin, Griffin, and Sickles (2001).

2008. All the prices are relative to the 1994 prices. As I mentioned in Chapter 3, the municipality cannot recover all the revenue: some proportion of water supplied from the reservoir is lost in the system. To account for the water lost in the system, I used the volume of water actually billed and recovered as the response variable. I used least-absolute-deviation (henceforth, LAD) method to estimate the subsistence level $\underline{w}_1$, and the marginal budget share π_1. I also compared the results with those from the method of least squares (henceforth, LS). The results are more robust to outliers in LAD estimation than LS method. Moreover, no specification is needed for the error term in LAD estimation. The coefficients and their standard errors (in parenthesis) are provided in table 4.1:

Table 4.1: Tap Water Demand

Variable	LAD	LS
Constant	2.311820	1.697097
	(0.000)	(0.116)
π_1	0.000842	0.0005771
	(0.002)	(0.000)

According to table 4.1, the LAD estimates tend to differ from the LS estimates. In fact, the constant term is not significant in the LS estimation. Moreover, I predict the subsistence level to be around 77 litres per capita per day. WHO (2005) defines the subsistence level as 15–20 litres per capita per day. However, OECD (2006) states that Turkey has a higher demand for household water consumption relative to other countries, as presented in table 1.1, because it is located in a hot climate.

4.3.2 Agriculture

Like the tap water demand, irrigation water demand is usually estimated to be inelastic; see de Fraiture and Perry (2002). Although inelastic irrigation water demand implies that irrigation prices may have to be set high in order to have considerable effects on the irrigation water use, changing irrigation prices may have different types of effects on the agriculture. On the one hand, increases in irrigation prices may force farmers to switch to better water-saving technologies; see de Fraiture and Perry (2002). On the other hand, increases in irrigation prices may affect crop composition in the region via changes in land allocations; see Weinberg, King, and Wilen (1993). To estimate the land allocations, Edwards, Howitt, and Flaim (1996) uses nested Constant Elasticity of Substitution, while normalized quadratic functional form are used in Moore, Gollehon, and Carey (1994); Moore and Negri (1992) as well as Shumway (1983). However, I do not observe individual input demands in the data. In fact, I observe only the total land allocated for crops, and the total volume of water released for irrigation. For this reason, I followed a different approach in my model.

The irrigation prices in the data are determined in the following way: If a crop such as cotton requires about twice as much water per area as a crop like wheat does, the irrigation price for cotton is twice as much. Also, the irrigation prices are non-volumetric; i.e., the farmers pay for water depending on the area allocated for crops, so the irrigation water demand for each crop increases proportionally with the land allocated for that crop. The relationship between the irrigation prices suggests that the crop productions can be modelled as a Leontief production function, which has also been used widely in the literature to estimate the agricultural production. Hence, I assume a Leontief production function for crop c, which depends on land ℓ_c and water $w_{2,c}$:

$$f_c = \alpha_c \ell_c \min\left(1, \frac{w_{2,c}}{\gamma_c \ell_c}\right);\ \alpha_c, \gamma_c > 0;\ \forall\ c = 1, \ldots, N$$

where α_c is the crop land productivity, and γ_c is the per area crop water requirement. Since I assume that other inputs are used proportional to the land input, α_c may change over time, because of changes in the productivities of the other inputs, such as improvement in the quality of seeds, the use of fertilizers, and so forth.

Note, too, that given this production function, the per-area irrigation pricing scheme almost coincides with a volumetric pricing scheme. To wit, assume that the irrigation price is volumetric, so there is one irrigation price p_2. The profit maximization implies that $w_{2,c}$ is at least equal to $\gamma_c \ell_c$ in equilibrium. Moreover, given the water requirements, the crop composition determines the amount of irrigation water needed. Thus, the government would refuse to irrigate any more than this amount, as any excess supply does not have any positive return. Consequently, $w_{2,c}$ equals $\gamma_c\ \ell_c$. The cost of irrigation becomes:

$$p_{2,c}\ \ell_c = p_{2,1} \frac{\gamma_c}{\gamma_1}\ \ell_c = p_2\ \gamma_c\ \ell_c = p_2\ w_{2,c}$$

where p_2 equals $p_{2,c}/\gamma_1$, and γ_1 denotes the water requirement of crop 1. The new profit function for producing crop c is:

$$\Pi_c^* = \max_{<l_c>} (p_{f,c}\ \alpha_c - \gamma_c\ p_2 + \mu_c)\ \ \ell_c;\ \forall\ c = 1, \ldots, N$$
$$\ni \ell_c \leq \bar{\ell} = 1,$$

where the cost of irrigation water equals $(\gamma_c\ p_2\ \ell_c)$. Given that irrigation prices are set such that the ratio of two irrigation prices equals to the ratio of their corresponding per area water requirements, the cost of irrigation equals the cost when the price is volumetric[6]. I shall adopt the volumetric irrigation pricing in the dynamic programming problem.

The agricultural model has three sets of parameters: land productivity α, water requirement γ, and the mean of the shock distribution μ. Even though these parameters can be separately identified, the estimates were not significant because of little variation in the data of crop prices and the irrigation prices. Hence, I divided the estimation procedure into two steps. In the first step, I calibrated the technological parameters α and γ. Although the productivity of cotton, wheat, and sugar beets have not changed significantly over time, the productivity of maize has increased about seven times over the last two decades. In the dynamic programming problem, I assumed the most recent year–2007 values for these land productivities. Meanwhile, I calibrated the water requirements in the following way: In the data, there are times

[6]The only distinction between the two schemes is that at the equilibrium, when there is more water released than needed. However, as the government would never provide more water for irrigation than farmers needed, as any excess irrigation has zero return.

where more water is released for agriculture than needed. To get an accurate estimate of the γ, I used the irrigation prices, as the ratio of two irrigation prices equals the ratio of the corresponding crop-water requirements. For this reason, I estimated how much per area water is released for each crop, and the minimum of these values over the twenty-four years yield to the estimate of the crop-water requirements.

In the second step, I estimated the mean shock levels across crops. I collected the yearly data on land allocations from 1984 to 2007, and I considered cotton, maize, wheat, and sugar beets, as the land allocated for these crops amount to about ninety percent of the total irrigated area. To be consistent with the literature on the conditional logit models, I assumed Type I Extreme Value distribution for the shocks. Given this distributional assumption, the probability of choosing a crop equals:[7]

$$\Pr(a_c = 1) = \frac{\exp(\Pi_c)}{1 + \sum_{c'=1}^{N} \exp(\Pi_{c'})}; \ \forall\ c = 1, \ldots, N.$$

Since this is a two-step estimation procedure, one would need error correction for the parameters estimated in the second step. However, I used the yearly data on land productivities and assumed that there is no measurement error in the data. Moreover, I used the actual non-volumetric data on irrigation prices to avoid using the estimates of the water requirements in this second step.

I used the generalized method-of-moments method in the second step. In the literature, the maximum-likelihood estimation method is used more often for this type of models. However, in this setup, I do not observe the number of farmers; the data on land allocations and irrigation water use are aggregated to the regional level. In

[7]See Maddala (1983) for further details of the procedure

addition, I assumed a representative farmer, so all the farmers are ex ante symmetric. The probability definitions in the maximum-likelihood estimation method would be misleading, without knowing how many farmers are making a crop-choice decision. Consequently, I used the generalized method-of-moments estimation in my analysis. I provided the estimation results for the mean shock levels μ in table 4.2 (see Appendix for details):

Table 4.2: Land Allocations

T=24, N=4	Cotton	Maize	Wheat	Sugar beets
Coefficient	1.4963	-2.7698	0.7233	-5.049
StdError	0.1761	0.4333	0.1818	0.4333
Grad(1e-4)	0.0001	0	-0.0001	0
Obj(1e-6)	0			

According to table 4.2, the mean shock levels are significantly different from zero. In particular, sugar beets has the lowest mean shock level. This low value can be attributed to the high cost of labor in sugar beets production. The estimated land allocations are displayed in figure 4.1. In general, the trend from cotton to maize and wheat is also observed in the estimated land allocations. Using the model, I predict that around ten percent of the land is left fallow during the data period. However, the land allocated for sugar beets is estimated to increase over time, which is the

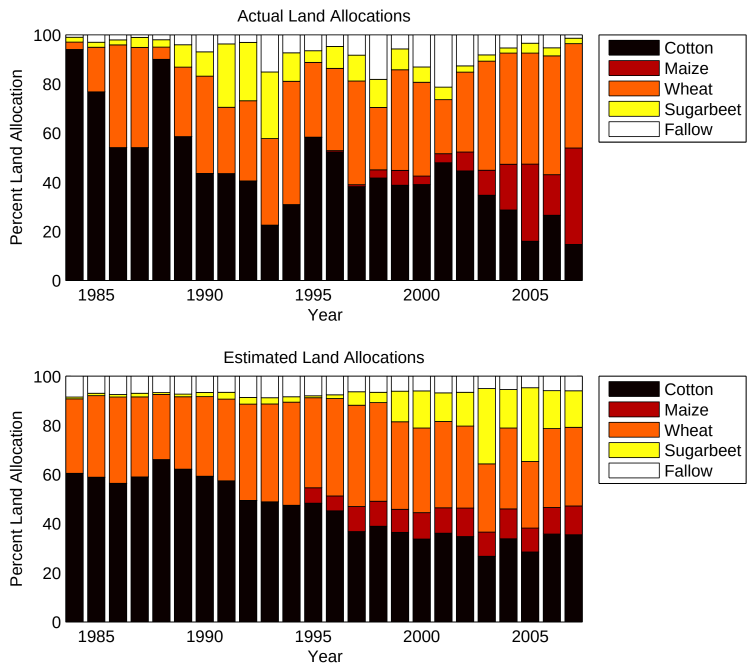

Figure 4.1: Actual versus Estimated Land Allocations

opposite in the data. One reason for this outcome is that the farmers have to form groups and to make an agreement with companies to be allowed to produce wheat by the government. However, I do not currently possess the farmer-level data to see which farmers agree to form these groups.

4.4 Results

With the revenue constraints binding, the prices lead to excess withdrawals due to inelastic demands. In times of a water shortage, the government faces the problem of not providing enough water to the sectors with maximum quantity demanded, so the government may prefer to charge higher prices according to water availability in the reservoir. To save water, the government may end up with profits. Although these profits are to be rebated back to the households and the agriculture, the government may suffer from some operational costs. Thus, the government can only rebate some portion $(1 - \lambda)$ of the profits.

I assumed that the exogenous stochastic shocks in this economy stem from two components: inflows and crop prices. Inflows to the reservoir vary considerably over the months. Meanwhile, among the crop prices, only the crop price of cotton has changed significantly over the last two decades. The crop prices of wheat, maize, and sugar beets have stayed almost constant during the time period. To incorporate these stochastic shocks, I used the empirical distribution of the inflows with four grid points. Meanwhile, I estimated the crop price of cotton, assuming log-normal distribution. Then, I used the autoregressive process of length one, and derived the transition matrix Tauchen's algorithm Tauchen (1988). For the other crop prices, I assumed their year–2006 values. I also discretized the water savings w', the tap water price p_1, and the irrigation price p_2 using 60, 25, and 25 grid points, respectively. I shall first analyze how well the model predicts the water shortages in the data, and I compare the policy implications of the optimal prices with the current pricing policy; i.e., the break-even prices.

4.4.1 Model Fit

In the data, the government faced the water shortage problem several times. To see whether the model can replicate the years of water shortage in the data, I first calculated the annual irrigation water use, then computed their deviation of

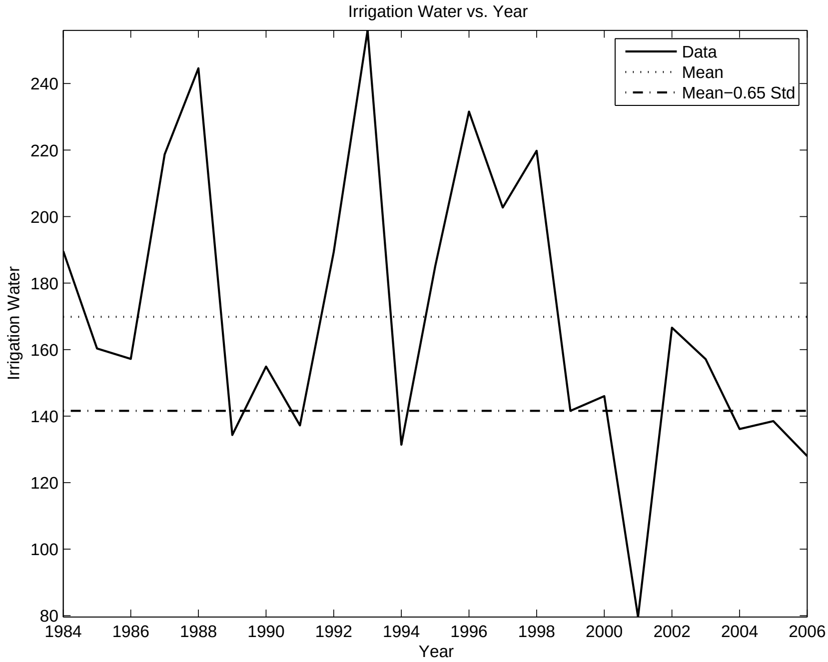

Figure 4.2: Water Shortages in the Turkish Data

from the sample mean during the data period (1984–2006). I display the irrigation water use in figure 4.2. The monthly demand for water by households can be easily met during the year, but the demand for irrigation water is yearly and withdrawn from the reservoir in September[8]. I define a water shortage when the irrigation water use is less than 0.65 times its standard deviation below the sample mean. Although changes in crop choices by the farmers will affect the irrigation water demand, I shall ignore this in this section. The main reason for my analysis is that in the data, irrigation is the main sector that is affected by the water shortages. Moreover, the recovery rate for tap water is around fifty percent, which makes it hard to detect the

[8]In the data, irrigation is carried out from May to September. This assumption is not critical because precipitation and inflows fall down to zero during the summer.

effect of water shortages. For this reason, I shall use this statistic as a measure for the water shortages. It is also noteworthy that the government pro-rates the water consumption by both sectors. In case of a water shortage, and the government saves only the minimum water volume for the next period.

Table 4.3: Water Shortages in the Turkish Data

Source	Pricing Rule	Years of Water Shortage
Data		1989, 1991, 1994, 1999, 2001, 2004, 2005, 2006
Model	Average-Cost	1989, 1991, 1994, 1999, 2001, 2004, 2006
Model	Optimal	

In table 4.3, I illustrate that water shortages occurred seven times in the data. In line with the data, my model predicts almost all of these water shortages, with the exact years except 2005. Moreover, I find that if the government had adopted the optimal pricing rule, all of these water shortages could have been avoided.

4.4.2 Counterfactual Exercises

To compare the implications of these policies on water resource management, I ran a simulation for a century. I generated pseudo-random values for the inflows and the crop price of cotton. I computed the mean water level in the data on December, which equals 35.55hm^3, and simulated the economy $5,000$ times under the optimal and current pricing policies. For further analysis, I refer to the situation when the government cannot meet the sectoral demands as "a water shortage." In each case, I recorded the years when the government experiences water shortage, and presented the results in table 4.4:

Table 4.4: Average-Cost versus Optimal Pricing Rules

Pricing Rule	Mean Years	Std. Dev. of Years	Mean Occurrences
Optimal	100.000	0	0
Average-Cost	15.818	16.159	6.059
Average-Cost	(54.623)	(35.772)	(1.376)

Under the policy of break-even prices, the government experiences the first water shortage in fifteen years, on average. More importantly, the standard deviation of the year of the first water shortage is about sixteen years. Consequently, the government's water management policy, using the break-even prices, is very vulnerable to the inflows. To wit, the government faces the water shortage whenever there is enough decrease in the inflows anytime throughout a year. I also assumed that when the water shortage occurs, the government pro-rates the consumption by both sectors, such that the government saves at least minimum water level for the next period. In this situation, the government can still run into the water shortage as much as six times, on average, in a century. In fact, households may be supplied less than their subsistence level about once every century, on average; see the values in parentheses in table 4.4. Under the optimal pricing rule, the government may run into water shortage, if it experiences a series of low shocks for inflows. However, according the simulation results, I found out that the government does not run into the water shortage, which implies that the probability of facing a water shortage is close to zero.

One difficulty, in terms of making welfare comparisons between the two pricing rules, is that the government may have to supply tap water at the subsistence level, when it pro-rates consumption. The utility of the households becomes $-\infty$. Even though this occurs only once every century under the average-cost pricing rule, this causes a discontinuity in the utility function and makes the welfare comparisons difficult. However, given that tap water use only takes up a small percentage of the households' income, the welfare gains above the subsistence level is negligible. Nonetheless, the government has to provide the households with tap water above the subsistence level.

In case the application of the optimal prices is not immediately feasible, the government may need to invest in more efficient irrigation technologies so the water requirements can be reduced. For instance, a switch from a surface to a sprinkler or to a drip irrigation technique would result in less water lost during the process. Hence, the crops would need less irrigation water. As a result, the government can avoid water shortages for a longer time period. I computed the percent improvement in the water requirements γ, and reported them in table 4.5.

If the government aims to avoid water shortages for twice the average under

Table 4.5: Crop Requirements

Target Years	Percent Improvement
31.6364	1.1900
47.4546	2.2213
63.2728	3.4906
79.0910	4.4426

the average-cost pricing rule, then the water requirements should uniformly improve by 1.19 percent. If the government targets five times the average, then the change in water requirements should be around 4.44 percent. Given that cotton requires about 860.36 m^3 per ha, such an improvement translates to around 38 m^3 per hareduction in the water requirement of cotton. Since the water requirements I calibrated in this paper reflect all the factors including leakages, such improvements can perhaps be achieved by switching irrigation technologies. In other words, instead of using surface water irrigation, the government may force farmers to use the sprinkler or drip irrigation techniques, which needs less water to get the same output.

Instead of investing in the irrigation technologies, the government may also prefer to enhance supply-side technologies. One can think that some portion of the inflows may be lost while being channeled to the reservoir due to leakages. With a more efficient technology, the government perhaps can recover more of the inflows. Suppose that the government can only affect the mean inflows; i.e., the mean of the annual distribution of inflows can be increased by adopting a more efficient technology.

In table 4.6, I depict the necessary change in the monthly mean inflows to avoid water shortages for a targeted number of years:

Table 4.6: Mean Annual Inflows

Target Years	Percent Improvement	Monthly Increase (in hm^3)
31.6364	1.5625	0.6662
47.4546	3.0859	1.3156
63.2728	4.3750	1.8652
79.0910	6.2500	2.6646

According to the table 4.6, the government has to increase the annual mean inflows by 1.56 percent to avoid water shortages for about thirty-two years. If the targeted number of years is eighty, then the annual mean inflows has to increase by 6.25 percent.

4.4.3 Reservoir Capacity

In this section, I analyze the policy function for the irrigation price in more detailed. According to the model, even though the government pro-rates the consumption by both sectors, the optimal tap and irrigation prices as a function of the water stock stay constant. To analyze what causes this constant policy function, I checked whether the reservoir capacity plays any role in the determination of the policy function. The motivation for this exercise is to understand whether the pol-

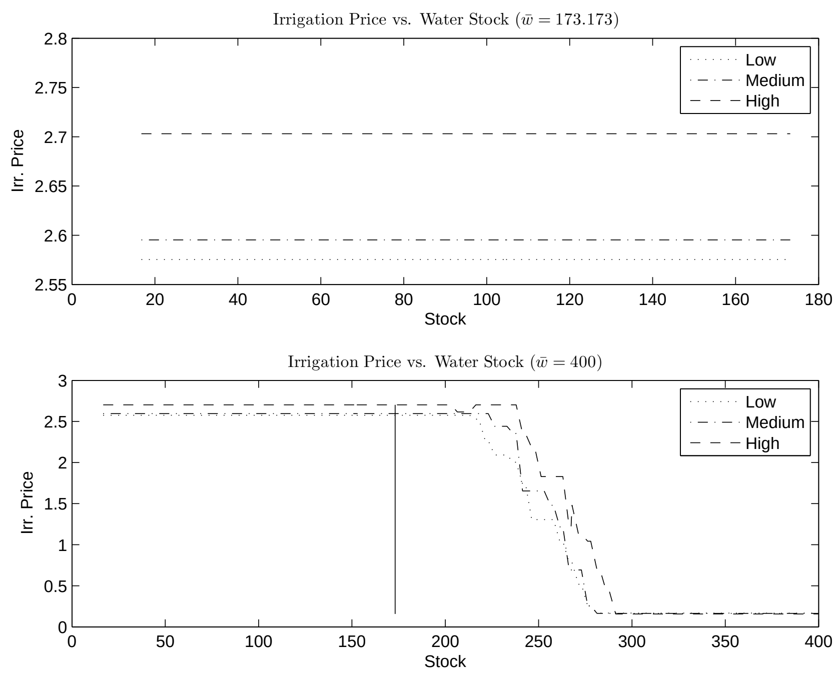

Figure 4.3: Policy Function for the Irrigation Price

icy function for irrigation water is always constant, regardless of the water stock, or whether the reservoir capacity restricts the policy function to a particular region. I generated new nodes for the water stock up to four hundred hm^3, and resolved the dynamic programming problem. Note that $\bar{w}$ is a parameter of the model, and the change in $\bar{w}$ does not affect the demand estimation of the households and agriculture, as the water flows are irrelevant with those estimation procedures. I display the policy function in figure 4.3. In each case, the policy function is plotted across the water stock for different values of the crop price of cotton (low, medium, high price). The top plot illustrates the case where the reservoir capacity $\bar{w}$ equals 173.173 hm^3, as it is in the data. In this case, the irrigation price does not depend on the water stock. The interpretation for this result is that even at the reservoir capacity, the government aims to avoid the water shortages completely by keeping the irrigation price constant. The bottom plot shows the policy function if the reservoir capacity equals 400 hm^3. The irrigation price decreases with the water stock, as the latter varies from about 5 hm^3 to 400 hm^3. The vertical line indicates the reservoir capacity in the first case. One can see that up to the initial reservoir capacity, the irrigation price stays constant. However, for higher volumes of water stock, the irrigation price decreases as more water can be released for irrigation. With a higher reservoir capacity, the water shortages can be avoided more easily, without restricting the irrigation water use too much. As the government has access to a higher water stock at the time of the decision, the irrigation price can be reduced down to the average-cost price level.

4.5 Conclusion

It is often viewed that an average-cost pricing policy (i.e., running a balanced budget) improves welfare, because charging prices only to recover costs leaves water users more income to spend on other commodities. However, in water provision, low water prices result in large withdrawals, which threatens the water management. In a water shortage, when the government cannot meet the sectoral demands in a given period, the government may refuse to provide water to agriculture as well as households. In such a case, the outcomes may be quite costly to the society. Although this pricing policy is a commitment of a public good provision by the government without making any profits, it is possible that by charging higher water prices, the government may not only avoid water shortages, but it also does so without any decrease in households' utility.

In this chapter, I analyzed the effects of the current and optimal water pricing policies on the water resource management. To obtain the optimal prices, I setup a dynamic model where the benevolent government supplies water to both households and agriculture. Since the government cannot make any profits, which is stated by the law in Turkey, I considered a situation where the government rebates all the profits, net of operational costs, from water provision. I found out that the optimal pricing rule is a better policy to avoid water shortages. For political or other reasons, if the government cannot adopt the optimal water prices, then the government may have other alternatives including reducing water requirements or enhancing supply-side technologies to prevent leakages.

4.6 Directions for Future Research

The framework I built in this paper provides a basis for an entire research agenda, and can be extended in many ways. First, I aim to incorporate water pollution. Water pricing across sectors mostly involves the accounting cost of water provision, such as maintenance and sanitation costs. Thus far in my research, I have incorporated the effect of water scarcity on the prices. However, different sectors use water for different purposes, and their water consumption may have important environmental implications by either polluting water or polluting the environment through their production process. For this reason, I aim to account for the environmental effects of the sectoral water consumption on the prices, and the role of the government in distributing water across sectors, while trying to avoid water shortages.

Second, I considered the changes in crop patterns in response to water scarcity, and analyzed the changes in irrigation efficiency as a counterfactual exercise. However, switching to more efficient irrigation technologies can be a substitute for the changes in the crop pattern. In fact, the choice of switching technologies can be internalized so farmers decide which crop to produce, and whether to switch to a more efficient irrigation technology. The farmers can respond to water scarcity by switching technologies, crops, or both. Also, the government may choose to subsidize the farmers to switch to more efficient technologies, through profits made from supplying water. In this way, the effects of water scarcity on the crop composition can be partially offset.

Third, in case of a water shortage, the government may choose to supply water from an external resource, instead of refusing to provide water. This can be achieved through adoption of a desalination technology. The adoption of a desalination technology may serve an option for the government to meet the sectoral demands during a water shortage. Dams in a region may also work as a network; they can take over each other responsibility to supply water, whenever a reservoir cannot meet the total demand. In such a situation, the government has to take into account the evolution of water supply in all the dams to determine the sectoral water prices. This would increase the complexity of the dynamic programming problem, if the cost of providing water from a dam is different for all dams. Nonetheless, these technologies can have important implications on the water resource management and water pricing.

Finally, analyzing crop composition using a farmer- or land-specific data may also reveal decisions on crop rotations. Crop rotation is a common practice of growing a sequence of crops with different soil-characteristic requirements in the same area. Incorporating crop rotation into the estimation of crop composition may generate a prediction more consistent with the farmers' decisions.

APPENDIX
DESCRIPTION OF DATA SOURCES AND METHODOLOGY

A.1 Estimation of Land Allocations

I used the two-step generalized method-of-moments (henceforth, GMM) method to estimate the mean shock levels μ. Since the distribution of shocks differs across crops, I have to estimate N parameters, one parameter for each crop.

1. Population Moment Conditions are:

$$\mu = \mu^o; \forall c = 1, \ldots, N \iff$$

$$\mathcal{E}\left[\mathbf{Y}\left(\mathbf{X}_t, \mu\right)\right] = \mathcal{E}\left[\mathbf{H}\left(\mathbf{X}_t\right)\begin{pmatrix} L^o_{t1} - \bar{L}_t \widehat{q}_{t1}\left(\mathbf{X}_t, \mu\right) \\ \vdots \\ L^o_{tN} - \bar{L}_t \widehat{q}_{tN}\left(\mathbf{X}_t, \mu\right) \end{pmatrix}\right] = \mathbf{0}_N$$

where L^o_{tc} is the land allocated for crop c, $\bar{L}_t$ is the total arable land, and $\widehat{q}_{tc}$ is the theoretical probability of choosing crop c at time t. The parameter vector μ represents the mean shock level. H is a $M \times N$ matrix of instruments, which is predetermined. In my estimation, I set $\mathbf{H}$ to the identity matrix. Thus, I focused only on the case where the moment conditions equal to the number of parameters to be estimated.

2. Sample Moment Conditions are:

$$\widehat{\mathbf{Y}}_T\left(\mathbf{X}_t, \mu\right) = \frac{1}{T}\sum_{t=1}^{T} \mathbf{Y}\left(\mathbf{X}_t, \mu\right).$$

3. Optimization:

$$\widehat{\mu}_{GMM} = \text{argmin } \mathbf{Y}_T\left(\mu\right)^\top \ \mathbf{A}_T \ \mathbf{Y}_T\left(\mu\right)$$

where superscript $^\top$ denotes transpose of a matrix. $\mathbf{A}_T$ converges in probability to a matrix $\mathbf{A}$, as the number of observations T goes to ∞.

4. First-order conditions:

$$\left(\frac{\partial \mathbf{Y}_T\left(\widehat{\mu}\right)}{\partial \widehat{\mu}}\right)^\top \ \mathbf{A}_T \ \mathbf{Y}_T\left(\widehat{\mu}\right) = \mathbf{0}_N.$$

5. Asymptotic Normality:

$$\widehat{\mu}_{GMM} \sim \mathcal{N}\left(\mu^o, \frac{1}{T}\left(\widehat{\mathbf{G}}^\top \ \mathbf{A}_T \ \widehat{\mathbf{G}}\right)^{-1} \ \widehat{\mathbf{G}}^\top \ \mathbf{A}_T \ \widehat{\mathbf{\Sigma}}^{-1} \ \mathbf{A}_T^\top \ \widehat{\mathbf{G}} \ \left(\widehat{\mathbf{G}}^\top \ \mathbf{A}_T \ \widehat{\mathbf{G}}\right)^{-1}\right)$$

where

$$\widehat{G} = \frac{1}{T}\sum_{t=1}^{T} \frac{\partial \mathbf{Y}\left(\mathbf{X}_t, \widehat{\mu}_{GMM}\right)}{\partial \mu}$$
$$\widehat{\Sigma} = \frac{1}{T}\sum_{t=1}^{T} \mathbf{Y}\left(\mathbf{X}_t, \widehat{\mu}_{GMM}\right) \ \mathbf{Y}\left(\mathbf{X}_t, \widehat{\mu}_{GMM}\right)^T.$$

If one sets $\mathbf{A}$ to $\mathbf{\Sigma}^{-1}$, the estimators are asymptotically efficient (assuming that the two regularity conditions are met). I performed the GMM estimation in the following way:

1. First, I set $\mathbf{A}$ equal to the identity matrix, and solved for μ.

2. Second, I reset $\mathbf{A}_T$ equal to $\widehat{\mathbf{\Sigma}}^{-1}$. I resolved the optimization problem for μ, and computed the standard errors in the following way:

$$Var(\widehat{\mu}_{GMM}) = \left(\widehat{\mathbf{G}}^T \ \widehat{\mathbf{\Sigma}}^{-1} \ \widehat{\mathbf{G}}\right)^{-1}$$

3. I used the LU decomposition to invert $\widehat{\mathbf{\Sigma}}$ and $\widehat{\mathbf{G}}^\top \ \widehat{\mathbf{\Sigma}}^{-1} \ \widehat{\mathbf{G}}$, as these two matrices are invertible. I defined the gradient function and verified my findings with or without the gradient function.

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