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Drought risk and water conservation expenditures as a household production problem

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ABSTRACT

Water rationing is the ultimate demand management strategy, which must be used when all other strategies have failed to keep demand below the available supply. Most household water consumption is used for the production of services (e.g. bathing, laundry and irrigation of landscaping), typically using capital goods (e.g. showers, appliances and irrigation systems) to combine time, water and sometimes energy. The likelihood households will face rationing depends at least in part on the success of the other demand management strategies, such as pricing. The household choice of time allocation, planned water use, and water and time augmenting conservation capital investment, is modeled as a household production problem in an environment with a risk of water use restrictions. A utility manages the levels at which restrictions are imposed, and equilibria are identified where these restriction trigger levels are consistent with household planned water use. When conservation capital is water augmenting, demand for capital is decreasing in the price of water and in the likelihood of restrictions being applied. If water demand is decreasing in water price, then increasing water prices reduces the likelihood of restrictions being applied, and can reverse the relationship between water price and the demand for conservation capital. Empirical investigations into household investment in conservation capital should account for the likelihood that households face water use restrictions, and practitioners should be aware that the effectiveness of campaigns to encourage greater investment in conservation capital may depend on both how water is priced and how it is rationed.

1. Introduction

The average human nutritional need for water is less than four liters per day [45]. Daily per capita water use in most parts of the world is far above this, often by at least an order of magnitude [50]. This water is used to provide services, ranging from basic hygiene and sanitation to irrigating landscaping and filling swimming pools. With by far the largest share of household water use being for service production, the demand for water is perhaps best understood as a derived demand, derived from the demand for the services of water. Households use assets they own to combine water and time (and in some cases energy) to produce these services. The services produced and the required mix of water and time depends on the assets owned. Some assets, such as dual flush toilets, save water but may require a bit more cognitive effort in selecting the appropriate button and time for more frequent cleaning. Similarly, low flow shower heads may require more time to remove soap. On the yard, using rain barrels saves water but requires time for distributing water and cleaning the barrels. Other assets may save time and water. Irrigation system timers save time. If set to water at night, they can save water, and if coupled with a moisture probe, save even more water. Planting drought

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resistant landscaping can save water, if less water is applied. Being drought tolerant, it will also be less impacted by supply interruptions. However, care is more specialized than for lawn, requiring time to learn effective management and possibly more time to undertake that management. A landscaping company can be hired to save this time, but then the effective cost of drought tolerant plantings is larger.

Price has long been advocated as an effective tool for water demand management [39,35]. However, in many jurisdictions price is only one among a range of tools that water managers use. Among non-price policies, mandatory measures are found to be effective at reducing water demand, while the results for voluntary measures are mixed [43,33,34,20]. Most of the work examining price and non price policies has examined the relative effectiveness of these approaches rather than considered interactions between them, a gap we attempt to address. The ubiquity of non-price policies may at least in part reflect the nature of the problem that water managers face. Water managers are managing the distribution of water to users through a system with a fixed maximum capacity and a risk that natural inflows will not fill the system to capacity - they are managing drought risk. Price and non-price demand management policies do not create new water, and if they are not effective at bringing demand in line with available supply during a drought, then water managers must implement mandatory measures to ration what water there is between users.

In many jurisdictions, drought risk is managed with a set of drought stages and trigger levels - based on reservoir levels, water table levels, stream flows, etc. - that are used to activate different drought stages [22,46]. At the initial drought stages, voluntary reductions in water use are encouraged. At higher drought stages, an increasing set of mandatory reductions are implemented. In the highest drought stage, all but essential water uses are prohibited. Drought plans and the conditions which trigger the different drought stages are public information. Considerable effort is generally put into informing water users about what the current drought stage is and how close the system is to the next higher stage. Water users can therefore be expected to account for this uncertainty in their planned water use. In this paper, a household production function approach is used to examine how a drought response strategy involving progressively tighter restrictions on water use impacts on planned water use and the investment in water conservation.

This work provides a theoretical perspective on a thinly studied area of water use, residential water conservation investment. It is one of a few papers that use the household production function approach to examine water conservation investment (e.g. [28,17]). It extends this earlier literature by examining the intersection between water use restrictions and water prices using the household production function approach. The results demonstrate that the econometric relationship between water prices and investment in conservation capital can depend on the likelihood that households face water use restrictions, and consequently that the success of efforts to encourage household investment in conservation capital may depend on both the price charged for water and the role of water use restrictions.

The remainder of the paper is organized as follows. In the next section, empirical results that motivated this investigation are briefly described, namely finding no relationship between the price for water and the adoption of water conserving technologies in a community with multiple water providers. This is followed by a literature review highlighting that little work has looked at the interaction between water prices and water use restrictions. Subsequently a theoretical model is developed, and then it is parameterized in a way that serves to illustrate the key results. The paper then returns briefly to data collected in Kelowna, British Columbia to present a very preliminary examination of one of the model predictions. Following this limitations and extensions are discussed, prior to a brief conclusion.

2. Empirical context

Kelowna, British Columbia, Canada is a unique community, having five major water providers (Table 1). Their existence is a historical accident, a consequence of the need for irrigation on the valley floor, and the most cost effective way of delivery being gravity from small upland watersheds. Each of these providers has their own water source and delivery infrastructure, and applies its own rate structure. Two of these bill by volume, the remaining three charge a flat rate, independent of the amount of water used. For the city, water is one of many services that are provided. The other four utilities are a level of local government enabled by the same legislation under which cities and towns exist [25]. These other utilities each have an elected board of trustees that oversees the

Table 1
Characteristics of the five main water providers in Kelowna. The five water providers in Kelowna are the City of Kelowna (CITY), Rutland Waterworks District (RWW), South East Kelowna Irrigation District (SEKID), Black Mountain Irrigation District (BMID) and the Glenmore Ellison Improvement District (GEID) (Source: Kelowna Joint Water Committee [32]).

	City	RWW	SEKID	BMID	GEID
Pricing	Volumetric	Volumetric	Flat	Flat	Flat
Water source	Lake	Wells	Upland	Upland	Upland
Total deliveries (ML)	16,462.0	2920.0	11,114.0	13,180.0	7800.0
Min monthly Deliveries (ML)	752.0	122.5	101.1	343.0	214.0
Max monthly Deliveries (ML)	2438.0	450.6	1967.2	2481.0	1516.0
Min/max ratio	0.31	0.27	0.05	0.14	0.14
Agriculture and parkland (%)	3.5	7.4	79.8	44.9	44.1
Single family residential (%)	40.5	54.1	12.7	36.3	37.0
Multi family base (%)	17.4	27.2	0.4	7.7	2.8
Other (%)	38.6	11.4	6.9	11.1	16.1