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Risk Aversion and Urban Water Decisions

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Abstract

Application of the product characteristics model and the finance portfolio choice model are used to illustrate the important effects of risk aversion held by decision makers in making decisions in the urban water markets. Decision makers face uncertainty about water demand, water inflows and supply costs, and about government policy. Relative to risk neutrality assumed in many models, risk aversion changes decisions about the management of available water supply infrastructure, and about the form and timing of supply augmentation options. Recognition of heterogeneity of buyer preference with respect to risk suggest efficiency gains from offering a variety of cost-security of supply characteristic packages to water buyers.

1. Introduction

Imperfect knowledge is an important characteristic of the urban water market. There is imperfect knowledge about demand, supply and government policy. Imperfect knowledge about the demand function can arise from imperfect forecasts of future levels of key shift variables such as population growth, different available estimates of parameter values such as the price elasticity, and then only sample estimates with error bands, and an error term often explains in excess of a third of the variation in quantity demanded. Imperfect knowledge about the supply of urban water function includes the variability of inflows to dams and now the likelihood of climate change induced changes in the inflow distribution. Also, the capital and operating costs for new supply augmentation options are affected by changes in technology and relative input costs. The extensive government intervention in the urban water market brings another set of imperfect knowledge about such things as future regulated prices, quantitative regulations on demand, and restrictions on and approval processes for different supply augmentation options. A particular focus of this paper will be on imperfect knowledge, whether of the risk or uncertainty variety, about the security of urban water supply.

A number of recent economic studies of decision making about prices, regulations and water supply augmentation for urban water in Australia have explicitly recognised stochastic variability of inflows to dams, the importance of intemporal links of water demand, water inflow and the storage level, storage costs and capacity limits, and the lumpy and sunk cost characteristics of supply augments. Hughes et al. (2008 and 2009) and Grafton and Ward (2010) use stochastic dynamic programming models, and the Productivity Commission (2011) uses a very large linear programming model. These studies have maximised expected welfare, and implicitly assumed decision makers are risk neutral. This paper asks whether risk aversion would result in different decisions on prices, storage levels and on the forms of and time of supply augmentation investments. Further, it asks whether risk aversion would affect the magnitude of estimates of the efficiency costs found in these studies of regulations verses adaptive prices to influence demand in response to variable inflows, and the timing of and scale of investment in the desalination plant supply augment option.

This paper employs an interpretation of Lancaster's (1951) product characteristic model. For purposes of exposition, water has the two characteristics of average quantity supplied (or average cost) and security of supply (or probability of strong restrictions, very high prices, or both in response to quantity demanded approaching available supply)[1]. The model is used to assess the effects of different degrees of risk aversion, including the extremes of risk neutral and highly risk averse or drought proofing, on urban water market decisions affecting the management and pricing of water and the form of and time of investment in supply augmentation. A variant of the finance portfolio choice model where the water portfolio options have average cost and security of supply characteristics provides similar results. Alternatively, the stochastic dynamic programming and linear programming models noted above could be enhanced to include risk aversion in the objective functions, but with considerable additional computational

[1] In principle the model can be extended for a larger number of characteristics. These might include, minimum health risks, water taste and other quality attributes, and perceptions of quality associated with, for example, recycling and storm water.

challenges. The state contingent model of Chambers and Quiggin (2000) likely offers another framework.

The rest of the paper is as follows. Section 2 considers the different players in the urban water market and the decisions to be made. Particular attention is given to evidence for risk aversion in key decision making, and to clarifying options for the measurement of risk as seen by the decision makers relating back to the fundamental sources of risks associated with imperfect knowledge about buyer demand for water and about inflows into dams. Section 3 describes the Lancaster product characteristic model for urban water with the two characteristics of average cost of water and security of supply to households. Illustrative applications of the model to different types of decisions are provided: the choice of storage rules for a given supply infrastructure capital stock; a comparison of adaptive prices verses selective regulations in constraining quantity demanded; for heterogeneous household preferences in terms of different relative marginal rates of substitution for the average cost and security of supply product characteristics the benefits of different water packages for households; and, the choice of investment to augment supply across options with different product mix characteristics, and in particular desalination with relatively high average cost and high security. For each illustration, the effect of risk aversion relative to risk neutrality is explored. The reality of significant differences across different urban areas, and over time for each area, in both buyer preferences and in supply opportunities mean there is no one-size-fits-all set of welfare maximising decisions. Section 4 briefly discusses a version of the finance portfolio model as an alternative model.

2. Decision Players and Risk Aversion

Decision makers or players over urban water include final consumers of water, and then there are households, businesses, local governments and environmental water managers, water utilities involved in the supply and treatment of water, and in most instances government departments and agencies also are key decision makers affecting water demand, storage, price and investment decisions. In addition to describing the decisions of each player group, this section focuses on evidence of the role of and importance of attitudes to risk in the objective functions of the different players operating in an urban water world of imperfect information about water inflows, technology, input costs and the reactions of other players. The focus will be on the variability of future inflows of water to dams and aversion to the risks of demand exceeding available future water supplies, and how the risks might be allocated.

Households consume about 60 per cent of the water supplied by water utilities, and less than a half of this represents “essential to life” indoor use (ABS, 2011, 4610). Given market or government set prices and regulations, household decisions are primarily about the quantity of water to purchase.

A number of studies which have estimated the social cost of water restrictions (on the use of water for some household uses) report large social costs and some indicate significant heterogeneity of household preferences. Gordon et al, (2001), Hensher et al. (2006) and Grafton and Ward (2008) used choice modelling survey techniques to estimate the willing to pay to avoid water restrictions. Brennan et al. (2007) used a household production function model to estimate the additional costs to households of foregone leisure and poorer lawn products imposed by water restrictions. In each study, average social costs of water restrictions per household were found to increase with the severity of the restriction, and the high level restrictions of recent years were estimated to have social costs as high as a half of the annual water bill. Brennan et al. (2007) and Cooper et al. (2012) report also significant differences between different households on the costs of water restrictions providing evidence of the heterogeneity of preferences regarding the security of urban water supply.

Other studies have considered the relative costs of allocating a limited quantity of water for urban use via a general price increase verses the arbitrary ‘one size fits all’ restrictions on out-door water use. In principle, the common water price increase method is lower cost because it equates the marginal social value of water used in different ways by each household and it equates the marginal social cost across different households (Edwards, 2006, Sibly, 2006, Grafton and

Kompas, 2007, Productivity Commission, 2008, and others)[2]. These studies question also the equity advantages of the price method relative to regulations.

Formally, we can express an individual household utility function with a focus on water as

$$U = f(Q, S, O) \quad (1)$$

where, Q is the quantity of water, S is the security of supply, and O represents other goods and services. The first partial derivatives of Q and S are positive with negative second derivatives. In practice, S might be represented by the inverse of different combinations of the frequency of regulations on outdoor use and the severity of the restrictions (e.g. days and times of watering and limitations on sprinklers, washing cars and pavements), or by the inverse of the frequency and level of relatively high prices to ration limited aggregate available water. Special cases of (1) include that of risk neutrality with the first derivative on S = 0, and an insistence for drought proofing with the first derivative on $S \rightarrow \infty$. Household heterogeneity with reference to differences in risk aversion can be represented by differences in the marginal rate of substitution, or relative marginal utilities, for Q and S.

Turning to businesses as water consumers, Hensher et al. (2006), using a choice modelling study find that businesses in the ACT have a similar willingness to pay as households to avoid water restrictions.

Allocation of available water for environmental flows has become a more explicit and important competing source of demand for water over time. In part this reflects a combination of higher incomes and environmental amenity as a normal if not a superior, good and the outwards shifts of demand for water by households and businesses with the growth of population and income. In part, also there is a better understanding of the public good property of water for the environment, and the need for government intervention to correct the market failure. In terms of

[2] These studies also point to the efficiency costs of multi-step tariffs by creating differences in marginal social costs across different users. Even a two-step tariff with a first step for "minimum essential water use" to meet an equity objective involves an efficiency loss, although with a low demand elasticity a small loss. But, there are more direct and explicit social security payments, including family allowances, which better target families of different sizes with low incomes.

environment needs and security of supply of water for consumptive uses, in one sense there is an important complementarity because many environmental needs are for variable supplies which mimic natural water flows. On the other hand, previous relegation of the environment as a residual consumer is being challenged.

In most Australian urban areas government owned corporations described as water utilities provide most of the services involved in the treatment and delivery of water to final consumers. Given the natural monopoly status of supply of most of these services, the water utilities are regulated by independent price setting bodies appointed by governments, and they are constrained in other ways by government legislated requirements regarding equity of access, water quality, and so forth. In general, ease of operations and public support for the utilities is facilitated if supply is more than enough to cover the quantity demanded. Then, by implication, the managers of water utilities also are risk averse to low stocks of water and for demand to exceed supply.

Governments in Australia have maintained a high level of both direct and indirect involvement in urban water. Indirect involvement includes ownership of most water utilities, the establishment of a regulatory system on water prices, and qualitative regulations on the time and form of use of water by households, businesses and local governments. Governments are directly involved in the supply of water in the form of and time of lumpy and infrequent investments in supply augmentation via new dams, interconnecting pipelines, desalination and recycling plants, stormwater capture and underground water, and investments in waste water treatment. There is anecdotal evidence that security of supply is one of the factors considered. Certainly politicians prefer not to have to impose regulations or other measures to ration what the public perceives as threats to security of supply. On the other hand, there is no public provided information on the weight attached to security of supply relative to other characteristics, and in particular the average cost.

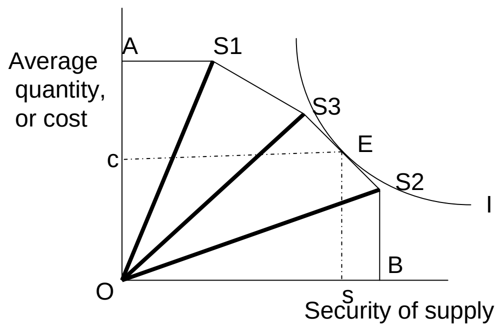
With this background, we turn next to possible formal models which explicitly include security of supply as a valued characteristic, but also a characteristic with costs of supply, in making decisions on the management of the current supply capital stock, potential gains in differentiated product characteristic packages to meet heterogeneous buyer preferences, and the form of and time of new investments to augment supply.

3. Multiple Product Characteristics Model

Figure 1 provides the essence of the Lancaster (1971) product characteristics model recast in the urban water context to analyse the implications of risk aversion for a number of different decisions regarding urban water. There are two product characteristics, average quantity of water, or the inverse of long run average price per unit supplied, and security of supply. Security of supply might be measured as the inverse of the probability of water restrictions and/or the severity of water restrictions, the stability of prices that equate supply and demand, or the ratio of the opening stock in storage relative to quantity demanded. Water buyers gain utility from the two product characteristics with (1) providing a formal view. From (1) a set of indifferences curves concave to the origin with the marginal rate of substitution (MRS) = ratio of marginal utilities of the two characteristics are drawn. One of the family of indifference curves, I, is shown in Figure 1. Preferences for greater security of supply or risk aversion steepen the indifference curves. Different buyers can have different preferences. As shown, initially it is assumed that there is homogeneity across all buyers or that I is an appropriate aggregation of heterogeneous preferences, and that there is some risk aversion.

A production possibility frontier (PPF) represents a general framework for expressing the opportunity costs of providing the two water characteristics with different decision choice options. Figure 1 shows the specific example of three different water storage management strategies given the existing investments in infrastructure. By way of illustration, strategy 1, S1, involves very little inter-year carry over storage; as a result it provides a relatively insecure supply, but with very small storage losses to evaporation and seepage and a low risk of a spill, which, collectively, mean a relatively low average cost per unit of supply. Strategy 2, S2, is roughly the opposite with a high inter-year carry over storage; as a result there is a relatively high security of supply, but at a higher cost per unit due to greater storage losses associated with evaporation and seepage and a higher probability of spills. An in-between strategy 3, S3, completes the available options. The PPF combines the offerings of the three strategies is shown as AS1S3S2B in Figure 1. It has a quasi-concave shape, and if the number of strategies were to be increased it would approach a continuous smooth function.

Figure 1 Evaluating Water Storage Strategy Options



Given the aggregate preferences represented by the indifference curve I and the production PPF represented by AS1S3S2B in Figure 1, the welfare maximising strategy for storage rules to provide the urban water attributes of average cost of water and security of supply is given at point E. This involves a linear combination of the two water storage management strategies of S2 and S3, yielding an average cost of c and a security of supply of s. In practice, this suggests further investment in a strategy between S2 and S3, and in particular one that extends the PPF beyond the S3-S2 approximation.

The special case decision problem shown in Figure 1 for choosing the water storage strategy given the current infrastructure capital stock to maximise buyer utility can be used to illustrate the effect of risk aversion on decisions. The greater is risk aversion to demand exceeding available supply, the steeper the indifference curve and the larger the MRS and willingness to pay for water security, the more conservative the chosen water storage strategy. In the extreme, S2 would be chosen.

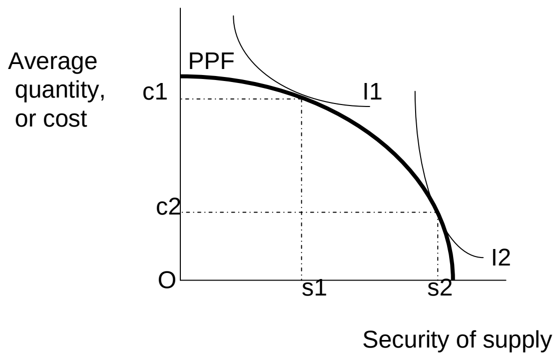
By contrast, a risk neutral model solution, with an implicit horizontal indifference curve in Figure 1, would choose S1. Note that if preferences are represented by I with some risk aversion, a choice of S1 would place buyers on a lower indifference curve and loss of welfare. The magnitude of this loss could be measured in the usual ways as a compensating or equivalent variation.

Choice of a very conservative storage strategy with the objective of drought proofing implies the indifference curve in Figure 1 is close to vertical.

Figure 1 also illustrates that different urban areas and the same area overtime likely will choose different storage management strategies (and mixes of the water characteristics). Almost certainly the position and shape of the PPF will vary with topography, climate and other factors from one city to another. For any specific urban area with population growth, it is most unlikely that the sequence of PPF will be a homothetic. Preferences driving the relative marginal utilities of the different water characteristics are likely to vary across different urban areas, and they will vary overtime with changes in income, urban density and lifestyles.

Consider next the implications of heterogeneous preferences, and in particular where some buyers are more risk averse or willing to pay a higher premium to ensure supply exceeds demand more often than not. Figure 2, as for Figure 1, shows the case of urban water with the two characteristics of average quantity supplied (or the inverse of average cost) and security of supply (or lower probability of water restrictions and/or high scarcity prices to balance supply and demand in times of low opening storage and inflow). A smooth convex to the origin PPF shows the feasible options associated with, for example, more conservative storage rules and higher proportions of more stable manufactured to rain fed water supplies. The indifference curves across the average cost and security of supply water product characteristics for buyers with different preferences are shown as I1 for the relatively risk neutral buyer and I2 for the relatively risk averse buyer. Relative to a one size fits all treatment of all consumers having homogeneous preferences, say product characteristic input mix E of Figure 1, offering buyers the choice of retail packages with different mixes of the characteristics, c1s1 and c2s2, would raise the welfare of both sets of buyers, a point made by the Productivity Commission (2008) and others.

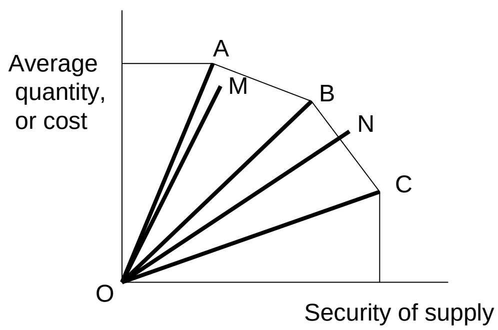
Figure 2 Heterogeneous Buyer Preferences



A potentially important application of the product characteristics model is to assist the choice of supply augmentation investment options with different mixes of water product characteristics. Of current relevance around Australia is the choice between relatively high cost and secure supply desalination plant verses relatively lower cost but variable rainfall dependent dams. Other potential supply augmentation investment options include inter-connections to link dams with imperfect correlations of inflows, storm water capture and treatment, more- and less-aggressive storage carry-over strategies, and underground water. Suppose there is an available sum of $X billion to invest, with a choice of supply augmentation options to meet projected increases in demand with population growth and/or lower supply from existing investments with climate change, and there are a number of investment options providing different mixes of the consumer desired water product characteristics, average cost and security of supply.

Figure 3 shows the preliminary offerings of the different investment options in terms of their mix of the average quantity and security of supply characteristics. Option A might be a new dam with relatively low average cost and relatively low security of supply. Option C is a desalination plant, and it has the opposite characteristic mix. Option B might be a smaller dam plus inter-connection pipelines. Together, these options would provide a PPF ABC. How might other supply augmentation options be considered? Suppose option M involves the new dam of A, but with a more proactive inter-season storage strategy (resulting in greater security but at a loss of water to evaporation, seepage and spills). As shown, this option falls within the PPF, it is dominated by a combination of A and B (unless economies of scale are very important), and it can be ignored from further analysis. Option N, for example the catchment of storm water and storage underground, provides a ray of water product characteristics outside the ABC PPF, and it becomes a worthy addition to the choice set; and, while not illustrated in Figure 3, it could dominate one or more of the A, B and C investment options.

Figure 3 Evaluating New Investment Options to Provide Water



Following this early ranking of investment options, and retaining only those on the PPF, the choice of investment option, or combination of options, requires bringing into Figure 3 a measure of the aggregate indifference curve for decision makers. The analysis finds the combination for the highest feasible indifference curve. The society efficient choice equates the marginal willingness to pay for additional supply security with the marginal cost of its supply. The more risk averse the decision makers, and ultimately this should refer back to urban water users, the higher the proportion of the available funds allocated to the more security of supply investment options.

Analyses assuming risk neutrality as an approximation when risk aversion is important will dismiss desalination more often and relegate the option to a smaller share of investment in supply augmentation than is consistent with society optimisation. Also, as illustrated in Hughes et al. (2009), desalination can have a higher option value than a rain-fed dam, because the former guarantees supply when completed whereas a dam depends on uncertain rainfall.

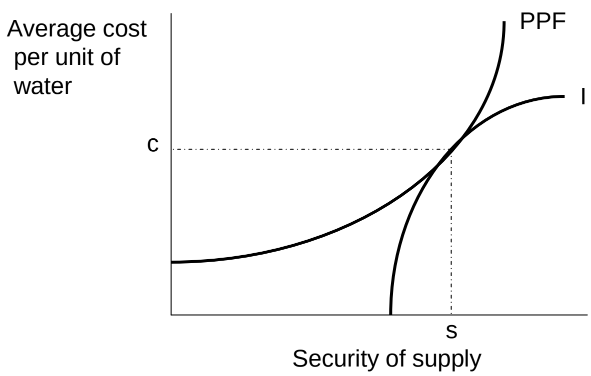
There are conflicting logical arguments on whether greater risk aversion brings forward the time of supply augmentation investments, and it is likely the answer will require empirical assessment. A preference for greater security of supply with risk aversion would, ceteris paribus, bring forward a supply increase investment (to reduce the probability of demand exceeding supply). Working in the opposite direction, the more conservative management strategy with existing supply infrastructure results in less demand per year, but also higher on average carry-over storage and more losses to evaporation and spills. Also, to the extent risk aversion favours desalination and perhaps later investment compared with the lower average cost but more risky new dam option, the supply augmenting investment might be delayed. Potentially important empirical factors driving the net outcome include the elasticity of demand to higher prices, the magnitude of losses associated with more aggressive carry-over storage, and relative costs and reliability characteristics of the different supply augmentation options.

Again, it is important to note that the position and shape of the investment PPF will vary across one urban area to another, and for each urban area over time. And, it is likely that preferences will vary from one urban area to another and over time. As a result, the social efficient mix of investment choice options and resulting mixes of water product characteristics will vary by urban area and over time.

4. A Portfolio Model

A variant of the expected value-variance model of portfolio choice of the finance literature provides another option for assessing the effect of risk aversion on urban water decisions. Figure 4 illustrates. Here the vertical axis represents the average cost per unit of water supplied and the horizontal axis represents the security of supply (or inverse of the variance or standard deviation of supply each year). A PPF is upward sloping and convex to indicate that security of supply of urban water can be achieved, but at a rising marginal cost, for example with more aggressive storage carry-over management or with a higher proportion of supply augmentation in desalination plants. A set of concave indifference curves representing a decline in marginal utility for additional security and rising marginal utility for a smaller average quantity (purchased at a higher average price). I is shown as the highest attainable indifference curve resulting in a welfare maximising portfolio choice with urban water product characteristics c and s.

Figure 4 Portfolio Choice Model



Different levels of risk aversion have important effects on choice decisions for the urban water market. In Figure 4, the more risk averse the water decision maker, the steeper the indifference curve, and the choice shifts to a higher average cost and higher security of water supply option. This result is similar to that reported with the product attributes model.

5. Conclusions

The paper argues that risk aversion to demand running ahead of supply (a) is an important aspect of the objectives of decision makers in urban water markets and (b) that risk aversion leads to quite different decisions if society is to choose welfare maximising decisions about the management of existing water supply infrastructure and in making decisions to augment supply with population growth and the likelihood of climate change. Choice modelling studies of willingness to pay to avoid water restrictions and the costs of water restrictions in a household production model indicate high levels of risk aversion by households, and also heterogeneity of preferences.

A product characteristics model is used to assess the effects of risk aversion on some key decisions in urban water markets; a portfolio model would generate similar results. Relative to a risk neutral model, risk aversion would involve a more aggressive storage carry-over management strategy, and it would increase the share of augmented supply provided by more costly but also more reliable supply augments such as desalination and recycled plants. The heterogeneity of attitudes to risk warrants investigation of the benefits of offering buyers different security of supply and average cost water packages. The decision answers will vary across different urban water markets with differences in choice options and preferences, and over time.

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