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HOW CAN POLICY ENCOURAGE ECONOMICALLY SENSIBLE CLIMATE ADAPTATION?

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ABSTRACT

This paper considers the role of incentive based climate adaptation policies. It uses the early literature on pricing and capacity choices under demand uncertainty to describe how revised price structures for the substitutes for climate services can be treated as anticipatory adaptation. In many situations the policies determining the prices of these services make them difficult to adjust. Thus, excess demand will not be managed through price adjustment. This situation is important because it implies that the rationing rules determining who is served influence both capacity planning and pricing decisions. The lesson drawn from these models is that reform of pricing policy for climate substitutes offers a ready basis for incentive based adaptation policy. The last part of the paper offers some empirical evidence on how the price elasticity of the residential demand for water changes with variations in seasonal precipitation. The findings suggest marked differences between normal and dry conditions for the Phoenix metropolitan area. These results reinforce the need to co-ordinate changes in pricing policy with any capacity planning developed for water supplies as part of anticipatory climate adaptation. Similar relationships may well apply for other substitutes for climatic services.

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How Can Policy Encourage Economically Sensible Climate Adaptation?

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I. Introduction

There is broad consensus among scientists that the climatic services, such as what the public might associate with local weather patterns, will change due to the accumulation of greenhouse gases (GHGs). Action on a U.S. climate policy, regardless of what it turns out to be, will not stop it. As a result, adaptation is now viewed as an important focus for new policies along with those aimed at reducing GHGs.

In these discussions, adaptation is described as the adjustments in natural or human systems that exploit the beneficial opportunities and moderate the negative effects of any changes arising due to the altered climate system.[1] Several maintained assumptions are taken as given in nearly all discussions of climate adaptation. First, it is assumed there is a key role for government and that *anticipatory* action is essential. Second, the discussions maintain that the experts know what to do. A mix of physical and natural infrastructure investments, coordinated by government, is generally presented as the best adaptive responses to expected changes in the climate system. Finally, it is assumed that reliance on ex post responses, by either consumers or firms, will magnify the damages experienced from climate change. Numerous examples could be used to document this summary. The National Research Council's Adapting to the Climate Change, a newly released report that is likely to be influential, is one of them. It offers ten recommendations for adaptation. None of them considers using economic incentives as part of climate adaptation policy. There is nearly a complete reliance on information programs and government action.

This paper is about the design of adaptation policies that rely on economic incentives. It begins, following Mendelsohn [2000], by asking why anticipatory adaptation is believed to be an

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[1] This definition is consistent with what is used by the Intergovernmental Panel on Climate Change (IPCC).

efficient response. After that, it discusses current pricing policies for the private goods that households and firms can be expected to use as substitutes in adjusting to the natural services that are altered by climate change. Electricity for heating and cooling and water from public (and private) centralized water systems, are both examples of the types of substitutes used to respond to regional changes in temperature and precipitation. Changes in the price structure for these commodities may well make sense independent of anticipatory adaptation policy. Current pricing assumes changes in the service reliability standards with different levels of interruption and associated price discounts are not policy options.

My analysis "dusts off" an early framework used in considering pricing structures with uncertain demand. After reviewing the basic model, the analysis discusses alternative ways a natural substitute might be introduced. Four conclusions follow from the analytical model. First, the pricing and capacity choices for substitute services will depend on how the natural capacity is assumed to contribute to the services supporting people's activities. Second, decisions to augment the capacity for climate substitutes, in response to a decline in natural capacity or changes in demand uncertainty, cannot be considered independent of the pricing policy. Third, and equally important, when produced capacity of the substitute is selected *ex ante* and its price is not easily adjusted, the optimal decisions depend on the rationing rule for allocating the available supply during periods of excess demand. When prices do not adjust easily, short run variation in excess demand conditions must be managed. Rules defining who is served under these conditions translate into changes in the reliability of service. Thus, a practical implication of these simplified models is to suggest that policy consider pricing service reliability. These price schedules could be designed to change year to year as expectations for natural conditions that would affect demands for climate substitutes change.

Finally, there is an indirect implication of incentive based adaptation for climate mitigation policy. The terms of access to services that substitute for natural climate conditions affect the value of climate mitigation. Borenstein [2005] makes a related point using a specific example – suggesting that dynamic pricing can increase the value of investments in residential solar power in some regions. This conclusion follows because the renewable power can displace the highest cost substitute at exactly the times that power is needed.

The next section outlines an economic perspective on the reasons for intervention to promote climate adaptation and summarizes Carlton's [1977] version of a model to describe optimal pricing and capacity decisions with stochastic demand. The model is used as a template to consider two issues: (a) the effects of the conditions of access on the "ideal" pricing and capacity choices; and (b) the implications of alternative ways of characterizing climate services in models of the demands for substitutes.

II. Climate Adaptation Policies and Substitutes

A. Context

If the external conditions governing temperature and precipitation in a location change exogenously, we usually assume the people and firms affected by the change will adjust when it makes sense for them to do so. Of course, those involved have to be able to distinguish a permanent change from "normal" variability in their local environment. In the climate adaptation literature these types of actions are labeled as autonomous adaptations (see Fankhauser et al [1999]). Most of climate policy recommendations call for *anticipatory* adaptation which amounts to doing things in advance of the changes that are expected. Mendelsohn [2000] has questioned the need for these advance interventions. His arguments are the traditional ones we expect from economists. That is, if there is a market failure or incomplete information, then the first best response is usually to correct the source of the failure. Actions taken assuming the failures will persist may be inefficient.

In the real world some market failures are the result of practical compromises. Pricing policies for electricity and water reflect past metering technologies (and are changing slowly) as well as the regulations governing the reliability of these services. For example, we realize that the incremental costs of delivering another kilowatt hour of power depends on the overall demands imposed from the full system of users at each time. These total demands vary with the location, the season, the days of the week, and hours of the day. Initially it was impractical to have residential electric meters that provided this temporal resolution. In addition, meters had to be read by people.

Today it is not only possible to vary the recording systems for power, but the readings can be collected remotely. Usage could also be controlled remotely. Residential devices with these controls may well be cost effective in many areas independent of whether the price schedules are changed or service is controlled remotely. The savings in manpower reading meters may be sufficient to justify the change.

This example helps to explain the source of a failure in pricing schemes. Initially metering technology could not accommodate prices that adjusted to changes in the costs of service. In addition, the firms providing the service were regulated. To adjust prices in many areas these firms must seek permission from a regulatory commission. This is broadly true for electricity and true in many areas for residential water supplies as well.

Firms providing these goods face uncertain demands and varying costs of meeting a reliability mandate. Current practice imposes the risks created by the differential costs of meeting varying system demands (and prices that don't readily adjust) on the suppliers. Significant changes in either the variability of demand or the costs of providing service will alter the nature of these risks. Changes in local weather conditions due to climate change could be one source for such a shift. As a result, it may be efficient to reconsider the pre-defined pricing contracts and reliability mandates. To illustrate the economic rationale for this suggestion, the next section reviews a class of models that has been used to describe socially optimal pricing and capacity decisions under demand uncertainty. These models assume the social objective function is to maximize the expected consumer surplus from the service.

B. Pricing and Capacity Planning

Over forty years ago, a series of papers considered situations where firms (or a stylized description of a policy maker) faced a stochastic demand and had to select the production capacity and a single price for output.[2] The intended application was to motivate a reconsideration pricing policies for resources with these attributes. An important byproduct of the research was a conclusion that these choices can depend on the conditions of access to the resource when demand exceeds capacity and prices do not adjust. My analysis begins with the last paper in this sequence by Carlton [1977]. His model assumes the random component of demand scales the quantity demanded at each price. This paper finds that selecting a price and capacity to maximize expected consumer surplus would, under some conditions of access to the service, imply an "optimal" price *above* long run marginal costs. The assumed terms of access

[2] The initial research was developed by Brown and Johnson [1969]. A subsequent comment by Visscher [1973] raised the issue of how the excess demand would be allocated among different demanders.

when demand exceeds available capacity also affect the prospects for profits (or losses). Thus, they affect the need for taxes or subsidies to assure reliable provision of service.

Demand is a function of prices and defined as the product of two terms, $x(p)$ and u. $x(p)$ could be considered a per capita demand; p is the price of service; and u a positive, random variable with distribution function $F(u)$. u could be interpreted as a measure of the number of customers. Capacity is planned as multiples of unit demand under "normal" conditions. Capacity is given by $k = s \cdot x(p)$. So when $u > s$, then with a fixed price that is set in advance, not all customers can be served. Assuming p and s are selected before the size of u is known, then the policy maker must also consider rules to determine who will have their demand satisfied.

Once decisions about capacity and price are made, the conditions of access (or rationing schemes) will influence what "counts" in defining the expected consumer surplus. Price does not play a role in clearing the market. Few markets allow instantaneous price adjustment. However, the assumption of no price adjustment is especially relevant to the issue of climate adaptation. This conclusion follows because climate's substitute services have historically been provided in situations with limited price adjustment. Even when there is time of use pricing for electricity or increasing block structures for water, these structures amount to replacing constant *prices* with constant *price schedules.* The schedules are not designed to be altered based on market conditions or natural supply changes.

To illustrate the logic of the model, consider the simple graph presented in Figure 1. Price is measured on the vertical axis and total quantity demanded on the horizontal. With multiplicative uncertainty, the variability in u pivots the demand function about the choke price, given by the point A. At the time s and p must be selected, the planner does not know what the aggregate demand will be. To begin this summary, consider first the case of planning when efficient rationing is assumed to govern situations when demand exceeds available capacity. Three cases need to be distinguished to describe all possibilities: (a) demand matches exactly the planned capacity; in this case the diagram represents demand as $s^* \cdot x(p)$; (b) demand is less than planned capacity or $x(p) \cdot u^L$ in the figure, and (c) demand exceeds the planned capacity, given by $x(p) \cdot u^h$ in the figure. If the value for the capacity that maximizes the expected surplus is s^* multiples of demand at the optimal price of $\overline{p}$, or $s^* x(\overline{p})$, then the realized consumer surplus is $AD\overline{p}$. The need for a subsidy will depend on how revenue $(\overline{p}s^* x(\overline{p}))$ compares with $bs^* x(\overline{p})$ in the short run and $(b+\beta)s^*x(\bar{p})$ in the long run. b is the constant (per unit), variable cost of producing the output, and β is the constant (per unit), long run cost of capacity. The demand possibilities in Figure 1, aside from the exact match with planned capacity, represent two (i.e. $x(p)\cdot u^L$ and $x(p)\cdot u^h$) of an infinite array of possible demands. Thus, the model assumes the policy maker focuses on the expected value of the aggregate consumer surplus net of costs. If demand is less than capacity (i.e. $x(\bar{p})\cdot u^L$), at $\bar{p}$, then consumer surplus will be $AB\bar{p}$ and we consider $bx(\bar{p})\cdot u^L$ versus $\bar{p}\,x(\bar{p})u^L$ to determine the need for subsidies in the short run. The contribution to net benefits is $A\bar{p}B+\bar{p}\,x(\bar{p})u^L$ less the variable ($bx(\bar{p})u^L$) and fixed costs ($\beta sx(\bar{p})$). At $\bar{p}$ all consumers with willingness to pay represented along the demand curve from A to B want to consume the service and there is sufficient capacity to accommodate them. Indeed, if the price could be adjusted, more users could be accommodated because aggregate demand is less than the capacity. When price effectively rations use, as it does in this example, then benefits are defined assuming those with highest willingness to pay are served. Other consumers are not "counted". At the selected price, $\bar{p}$, they would not purchase the good.

The issue of other rationing schemes arises when the aggregate demand at the price, $\bar{p}$, exceeds capacity. This is case (c). All the consumers represented along the demand curve $x(p)\cdot u^h$ from A to E would be willing to pay at least $\bar{p}$. However, only $s^*x(\bar{p})$ of this total demand can be served. Price does not screen out users consistent with the pre-defined capacity of $s^*x(\bar{p})$. If price cannot be raised, then someone must decide who among the consumers represented from A to E gets access to the service. Efficient rationing assumes those with the highest willingness to pay, or the segment from A to C, are the customers to be served. Random rationing assumes anyone from A to E has an equal chance of service.

The point of this earlier literature is to recognize that the definition for the access conditions, or the rationing rule when demand exceeds capacity, influences how the policy maker would select both the ex ante price and the amount of capacity. The rationing rules define who "counts" in the objective function. Equations (1) and (2) specify the objective functions for these two cases (S_E for the expected surplus with efficient rationing and S_R for random rationing).

$$S_E = \int_0^s u\left[\int_0^{x(p)} x^{-1}(q)dq - bx(p)\right]dF(u)$$
$$+\int_s^\infty u\left[\int_0^{x(p)} x^{-1}(q)dq - bx(p)\right]dF(u) \qquad (1)$$
$$-\int_s^\infty u\left[\int_{\frac{s}{u}x(p)}^{x(p)} x^{-1}(q)dq - (1-\frac{s}{u})bx(p)\right]dF(u) - \beta sx(p)$$

$$S_R = \int_0^s u\left[\int_0^{x(p)} x^{-1}(q)dq - bx(p)\right]dF(u)$$
$$+\int_s^\infty u \bullet \frac{s}{u}\left[\int_0^{x(p)} x^{-1}(q)dq - bx(p)\right]dF(u) - \beta sx(p) \qquad (2)$$

In these specifications $x^{-1}(q)$ is the inverse demand function for $x(p)$ with q the quantity demanded at a price of p (i.e. $q = x(p)$). Both objective functions describe ex ante choices of p and s. As such, they describe what counts when demand is less than $sx(p)$ and when it exceeds $sx(p)$ for every possible value of p and s, the choice variables. Equation (1) could be written more compactly. This more detailed form is used because it helps to illustrate the issues to be considered in extending the model to include a natural supply.

The first term in (1) provides the contribution to expected surplus if demand is less than selected capacity at any selected price. The second term overstates the contribution to expected surplus for demand in excess of capacity. In terms of Figure 1 it would count all of the surplus along the demand to point E. In fact, at $\overline{p}$ only $s^*x(\overline{p})$ units of demand can be served. So we need *two* corrections that are represented in the third term. First we remove the extra surplus (illustrated by $s^*x(\overline{p})CEx(\overline{p})u^h$ in Figure 1) and correct the variable cost embedded in the second term. The term, $(1-\frac{s}{u})bx(p)$, removes the cost used in the second term and includes variable cost for only those units actually sold, $bsx(p)$. As the more compact version of the objective function in equation (2) illustrates, this amount is all that can be counted for a capacity price selection with random rationing. Moreover in this case we attach to each unit of consumption the "average" surplus over the full range of users that would "like to" use the service at price $\overline{p}$. The last term in equations (1) and (2) is the cost of a selected capacity. This long run cost does not change with the rationing schemes.

Table 1 summarizes the implications for capacity and price selections under the two objective functions and rationing schemes. The capacity/price pair for the objective function associated with efficient rationing summarizes the results from Brown and Johnson (with a somewhat different specification for capacity) and those for random rationing are taken from Carlton. Clearly, the selection of an "optimal" price (*p*) and capacity (*s*) pair depends on how access conditions are determined in periods of excess demand.

It is not easy to compare the capacity choices under efficient and random rationing. Direct results depend on what we assume for *x(p)* and *F(u)*. *s* is defined implicitly by equality between the truncated expected consumer surplus of the marginal user who is not served, (less corresponding operating costs), $(\int_s^\infty \tilde{p}\, dF(u) - b(1-F(s)))$ and the marginal capacity cost. With random rationing, capacity depends on the relative size of consumer surplus per unit demanded net of both unit variable and capacity costs compared to consumer surplus per unit net of the variable cost. With efficient rationing, prices would be set below long run marginal costs while with random rationing they would be greater than long run marginal costs.

Table 1: Capacity and Pricing with Demand Uncertainty [a]

	Pricing	Capacity Choice
Efficient Rationing	$p=b$	$\int_s^\infty \tilde{p}(u)dF(u) = \beta + b(1-F(s))$
Random Rationing	$p = b + \dfrac{\beta}{\frac{1}{s}\int_0^s u dF(u) + (1-F(s))}$	$s = F^{-1}\left(\dfrac{\frac{cs}{x(p)} - b - \beta}{\frac{cs}{x(p)} - b}\right)$

[a] These results are derived maximizing expected consumer surplus using equations (1) and (2) in the text. $F^{-1}(.)$ refers to the inverse of the distribution function *F(u)*.
$\tilde{p}$ is defined implicitly based as the price required to assure the unit quantity demand would equal the proportional reduction required so that $ux(\tilde{p}) = sx(p)$. Thus $\tilde{p} = x^{-1}(\frac{s}{u}x(p)) = x^{-1}(\frac{s}{u}x(b))$ when *p* is set equal to *b*.

C. Adding Natural Supply

To relate these results to incentive based policies for climate adaptation I need to describe how the private goods substitute for climate services. Assume, for simplicity, that *x* is a perfect substitute for some climate service. If the level of natural service provided by climate is initially η, then each person's demand for a substitute is conditional to the amount of η available. If η represents the aggregate services to everyone, and climate change eliminates these natural services, then the market demand for the substitute would shift out by η (parallel to $x(p) \cdot u$). If we assume natural services are specific to each individual user then $(x(p) - \eta)u$ is the market demand. In this case natural supply reduces needs for *x* but could accentuate the variability in the aggregate demand for *x*. The introduction of these natural services into the formal model in the simplest case (where natural supply affects aggregate demand) is similar to adding natural capacity. It influences how we define excess demand (the upper limits of the first integral and the lower limit of the second and third in equation (1) and in a similar fashion the two integrals in equation (2)). As a result, it influences the effects of assumptions about rationing.[3] The natural supply would not influence the cost of the substitutes. Nonetheless, the comparison of price and capacity choices with the two rationing schemes would be altered.

Relaxing the assumption of perfect substitution between *x* and η is another variation that would further change the results. Alternatively, we could also assume the amount natural services affect the unit demands for *x*. This formulation would change the slope and position of *x(p).* Finally, we could assume that *u* and for η are not independent random variables. In this case a joint distribution for these two random variables needs to be defined and the problem becomes more complex.

One does not need to display all the algebra for these cases to conclude that pricing and capacity decisions would change in all of them. Thus, regardless of how we treat natural supply, anticipatory adaptation must consider both the pricing and the conditions of access to services provided by the planned substitutes for climate services at the same time as capacity planning takes place.

The incremental value of policies that would alter natural capacity also depends on adaptation policy. Access conditions determine the value of capacity as demonstrated in Table 1.

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[3] For random rationing it could influence how we average consumer surplus but not the costs of capacity produced.

The lesson from this algebra is adaptation planning will implicitly (or explicitly) incorporate rules for allocating supply when all cannot be served. With a permanent change in the climate regime at some locations, these allocation rules serve to redefine reliability conditions for the substitute services. A more direct way of providing incentives to substitute for productive capacity would be by using pricing schemes that share the risks between suppliers and demands of these substitutes. These price structures can also be described as methods for including the reliability of service as part of a nonlinear price schedule. In the model these possibilities are represented through the rationing alternatives. In a more realistic setting, consumers would select among plans for service that define prices and the ability of a centralized control to remove service at particular intervals. These terms could vary with season, time of day, or whatever. They might be more complex for some substitutes than others.

They are feasible policy alternatives today due to the changes in our ability to meter and inform consumers of their patterns of use. It is certainly possible to envision a consumer friendly device that would switch off electric appliances (i.e. heat pumps, refrigerators and so forth for short periods) and track the changes in usage. It is also possible to envision remote systems a consumer might use to monitor home usage and conditions. In the case of water as a substitute for climate services this type of continuous adjustment seems unlikely. Nonetheless, price signals that varied by season and year based on climate along with decentralized storage could be options that policy makers and customers might consider.

III. Weather and Water

Climate change will alter local weather conditions. People and firms adjust by using substitutes. This paper's analysis of this process envisioned changes to a system that already acknowledged stochastic demand for these substitutes and pricing conventions that do not allow markets to alter prices as the demand supply imbalance changes. As a result, the effects of new uncertainties on this system and the design of revised policies depend upon what is assumed about the interrelationships between uncertainties in the supplies of climate services and the stochastic demand for substitutes. Can we treat the two as approximately independent? Or are there reasons to believe the demand for substitutes changes when the natural services they displace are also more variable? The pervious section posed these as alternative model specifications.

A detailed answer for the cases of electricity and water is not possible. It is difficult to estimate the demands for these substitute goods under any set of conditions. This task is confounded by a variety of issues: inverted block rate pricing structures, limited price variation, incomplete metering of use (especially for outdoor uses in the case of water), and a variety of other challenges. Instead this section summarizes some recent empirical research on residential water demand in the urban Southwest that suggests independence would not be a good assumption. It suggests that the nature of the residential demand for water changes with seasonal levels of precipitation. As a result, models that treat the uncertainty in water demand and the response of water consumed to price as independent of the uncertainty in the climate system would understate the complexity of the problem.

Table 2 summarizes some of the estimates for the price elasticity of demand for water by residential users in Phoenix taken from Klaiber et al [2010]. These results were developed by exploiting two types of changes in water prices for Phoenix households. In each of these years the Phoenix water department varied residential water customers' rates between winter and summer. There was also a gradual transition in marginal prices and a change in the threshold consumption level (in the block structure) for higher marginal prices from 600 to 1000 cubic feet between winter and summer. Finally, over time, the level of the marginal prices by block and month also changed to reflect cost increases.

Table 2: Price Elasticity for Residential Water Demand[a]

	2003-2000 (Normal / Normal)			2002-2000 (Normal / Dry)		
Percentile	Overall	Winter	Summer	Overall	Winter	Summer
10	-1.068	-0.528	-0.959	-0.296	-0.758	-0.362
	(-27.78)	(-3.9)	(-15.22)	(-7.37)	(-7.92)	(-4.54)
25	-0.899	-0.215	-0.823	-0.143	-0.627	-0.335
	(-37.19)	(-2.17)	(-20.34)	(-5.54)	(-10.03)	(-6.28)
50	-0.743	-0.061	-0.652	-0.99	-0.524	-0.307
	(-40.13)	(-0.71)	(-22.25)	(-5.16)	(-11.05)	(-7.87)
75	-0.625	-0.075	-0.537	-0.003	-0.438	-0.195
	(-35.21)	(-0.91)	(-19.42)	(-0.15)	(-9.67)	(-4.71)
90	-0.528	*	-0.437	*	-0.428	-0.138
	(-27.38)		(-14.94)		(-6.27)	(-2.99)

[a]The numbers in parentheses are asymptotic Z statistics, treating the price difference, price and quantity at their sample means as constants for estimating the variance of the estimated price elasticity.

[*]Positive and statistically insignificant

Source: Klaiber et al [2010].

The estimation strategy matched records by month for years experiencing cost increases and evaluated the *change* in the quantity thresholds that define the 10, 25, 50, 75 and 90 percentiles for residential customers in each census block group served by the Phoenix water department. Summer and winter months were considered separately. As a result, each consumption group did not move between the blocks associated with different marginal prices. Thus, the endogeneity of price due to "choosing" a consumption block does not need to be considered. The customers in each consumption group experienced the same price change due to changes in the rates for each block over time.[4]

The effects of natural supply variability can be seen thru the difference in price elasticity estimates implied for different pairings of the years used in the models. Consumption in 2000 is compared with 2002 and 2003 in forming the quantity differences used to estimate the first difference model. The average annual precipitation (as well as in average days with measurable rain) in 2002 was less than half the level experienced in 2000 and 2003. The estimates for price elasticities in winter and summer indicate quite distinct changes when pairing two normal years as compared to the pairing of a normal and a dry year.[5] For the normal / dry combination, summer demand is much <u>less</u> responsive to price changes compared to the estimates derived using changes between two normal years. By contrast, the winter demand for a normal/dry combination is <u>more</u> responsive to price than when two normal years are used to estimate the price response.

While these results are for residential water demand in one city, it is important to note that it is the first evidence of a response in monthly demand to differences in seasonal conditions, after controlling for differences in both the monthly temperatures and the monthly precipitation in the two years. It is consistent with an early stated preference study by Howe et al [1994]. This study offered a change in the likelihood, on an annual basis, of a standard annual shortage event.[6] They found that the level of baseline reliability of the water system and average water

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[4] Erin Mansur noted that the increasing block pricing structure implies that all marginal prices enter demand under uncertainty. Our analysis is a short run model that examines changes in matched months for the typical household as the marginal price for a pricing block changes over time. This change is separate from the seasonal change winter to summer and is not part of the block structure. It reflects increases over time in marginal prices due to cost increases and would not be anticipated by households. The Olmstead et al [2007] result relates to a given increasing block structure and the movements within that block structure that take place due to uncertain needs for water. Our analysis holds constant the price block for consumption and considers how use changes over time as marginal price for <u>that</u> block changes.

[5] By pairing the consumption at a block group level we control for demographics, and landscape conditions. The models include temperature and precipitation controls for changes in minimum temperature and precipitation in the months paired to estimate the differences in quantity demanded for the paired years.

[6] This was defined as a draught of sufficient severity and duration that residential outdoor water use would be restricted to three hours every third day for the months of July, August, and September.

expenditure in each of three Colorado towns influenced the choices their respondents from those towns would make to policies explained as being intended to enhance reliability.

If the demand results reported here hold up in other studies, they suggest that the stochastic nature of water demand itself may change with factors influencing natural sources of climate related services. That is, one might speculate that climate change would not only alter the amount of water demanded as a substitute for natural sources but the price responsiveness might also change. This finding would imply larger price changes may be needed to induce greater conservation and that prices might need to depend on seasonal conditions. This conclusion parallels the Howe et al finding that the value of reliability depends both on the costs of water and the extent to which natural supply makes water shortfalls a more common event. Changing prices as these conditions are anticipated would offer a parallel to the more complex pricing systems described earlier for electricity.

IV. Implications

Climate adaptation is not synonymous with augmenting the capacities of systems that provide substitutes for the climate services. Changes in pricing can reduce the demands for the services of substitutes (especially during times when demand is high) and can signal the potential for higher, long term end user costs for those with higher levels of use. Household commitments to power and water using devices change both the level of demand and the ability of the overall system to respond to climate changes that may require different uses for power and water. To the extent new price systems change the incentives households face as they make such power and water using commitments, and alter the level or the efficiency of these commitments, we might describe them as altering effective capacity of the system to meet households' needs with variation in long run natural conditions.[7] Some types of demand are reduced or displaced. As a result, a smaller capacity can meet the revised demand pattern with less likelihood of shortfalls. This interpretation is commonly used in the demand response literature associated with pricing schemes for electricity. It has not been connected in formal models with discussions of climate adaptation.[8]

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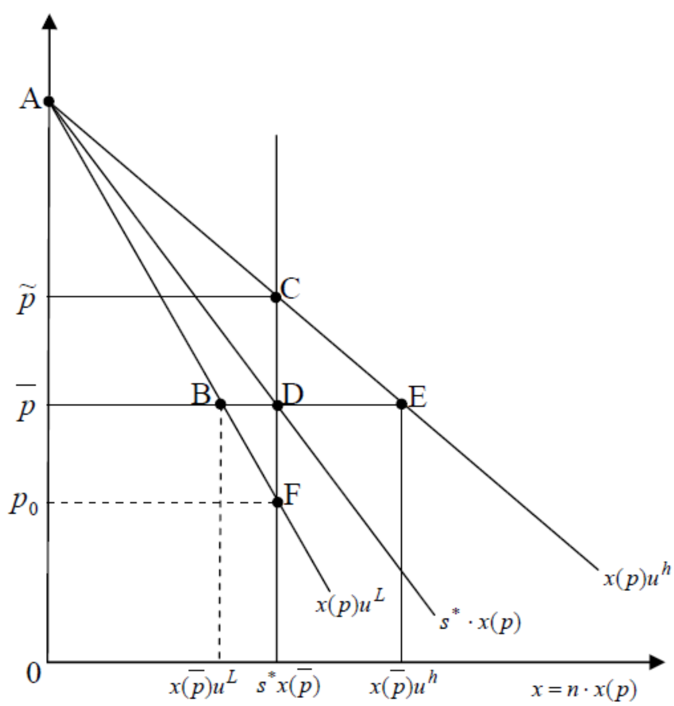
[7] Price schedules that smooth demand reduce the need for capacity to meet a peak and in this sense function like added capacity. See Earle et al [2009].

[8] Smith [2009] discusses this connection but does not attempt to show a formal analysis.

This paper has used the early literature on pricing and capacity decisions in the presence of demand uncertainty to describe how an economic analysis of capacity planning, as a response to climate change, cannot be undertaken independent of considering how substitute services are priced. In addition, with inflexible prices, the rules used to determine who is served when demand exceeds supply will be important to both capacity and price choices. Considering the design of price schedules as part of anticipatory adaptation would imply that prices for a wide range of activities serving as substitutes for climate services might be considered. These types of changes offer the potential to create incentives that can feedback to influence both the pace of climate change and the demands for the services facilitating adaptation.

Figure 1:

Illustration of the Effects of Stochastic
Demand with Ex Ante Price and Capacity Decisions



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