How Can Policy Encourage Climate Adaptation?

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I. Introduction

This paper is about climate adaptation policy that relies on economic incentives. There are few discussions of incentive based instruments for adaption to climate change. Instead most of the literature focuses on the need for changes in the amount and mix of physical and natural infrastructure to respond to the changes in climate services at different locations.[1] These analyses implicitly assume people would continue to choose to live in the ways they currently do when climate changes. In this context, the implicit task of policy seems to be one that calls for the provision of services that substitute for natural climate services or, in the extreme, provides some mechanism to respond to inhospitable conditions with minimal change in the mix of production and consumption activities at these locations. My summary is an extreme characterization of the literature and this is deliberate. The point is to emphasize the relative absence of using incentives.

Certainly there is some literature that can be interpreted as considering the use of incentives for reducing the effects of climate change. The most easily cited would be models using spatial differences in agricultural activities, both cropping patterns and irrigation, to consider the impacts of climate change.[2] However, the link to adaptation policy in these cases is indirect.

Economic agents make commitments, usually associated with capital investments, as part of ongoing production and consumption activities. These decisions rely on the services these agents assume will be conveyed because they locate their activities in specific places. Changes in

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[1] For the purposes of discussions in this paper climate services in an area will be the typical weather pattern and its “usual” variability in that location.

[2] See Mendelsohn, Nordhaus and Shaw [1994]. Schlenker, Hanemann and Fisher [2006] [2005], and Deschênes and Greenstone [2007] as examples.

the natural services at a location alter what would be the best approach for producing goods or meeting household objectives. Attempts to continue with business as usual in a regime where many locations have different mixes of climate services will be more costly with these commitments than if one could “start fresh” without them. Static economic models represent this common sense with an envelope condition.

Incentive based adaptation policies would provide price schedules and allocation rules for the services that substitute for climate, describing how they change when the demands for these services exceed capacity. They do not assume changes in the current standards for reliable service are off the policy table. Instead reliability would be purchased as part of pricing contracts and its price would be expected to change year to year as expectations for natural conditions change. The examples envisioned in this paper are associated with pricing and capacity decisions for water (for consumptive uses) and electricity (for cooling). These resources serve as substitutes for climate related services for urban households in the arid Southwest.

My analysis “dusts off” and modifies an early framework used in considering peak load pricing problems with uncertain demand. After reviewing the basic model, a natural substitute is introduced to evaluate its role in optimal pricing and capacity for produced capacity. For example, in the Southwest water supply planning relies on meeting demands given a “typical” precipitation pattern. Changes in the typical regime will change water demand. Similarly, cooler temperatures in the evenings reduce the need for air conditioning (and thus electricity). The timing of transitions from Spring to Summer and from Summer to Fall is also important to these demands. These alternative natural conditions can be treated as offering imperfect substitutes for increases in the capacities to meet residential water or electricity demands.

Three conclusions follow from the analytical model. First, the pricing and capacity choices for substitute services depend on the level of natural capacity that contributes to the services supporting people’s activities. Decisions to augment produced capacity in response to a decline in natural capacity cannot be considered independent of the pricing policy. Second, and equally important, when produced capacity of the substitute is selected *ex ante* and its price is not easily adjusted, the evaluation of how much should be selected and the pricing 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 (including responses in reaction to reductions in natural supply) will not be rationed by prices. They translate into changes in the reliability of service. To my knowledge, the literature has not considered the pricing of reliability as incentive based climate adaptation policy.

The conclusion that *ex ante* decisions for both the price and capacity should consider how the limited capacity is allocated among “demanders” was an important lesson from the earlier literature on peak load pricing under uncertainty. It is also the first step in treating the reliability of service as an attribute of the substitutes for climate services that should be priced.

Finally, there is an indirect implication of incentive based adaptation for climate mitigation policy. Several studies have argued that in the long run adaptation and mitigation policies need to be evaluated jointly[3]. The terms of access to services that substitute for natural climate services 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 precisely because they can displace the highest cost substitute at exactly the times that power is needed. This analysis suggests that his point has general relevance – pricing and capacity policies designed to adapt to reduced climate services can alter our perspective on what might be “economic” climate mitigation investments.

The next section outlines an extension to the Carlton [1977] version of the pricing and capacity model with stochastic demand. It describes how natural supply of substitutes and uncertainty in their availability can be introduced into the analysis. The two are treated as independent sources of uncertainty. Section three summarizes results in Klaiber et al. [2010] suggesting the assumption of independence needs to be reconsidered even for short run analyses. In the long run, the pattern of demand for substitutes will be the result of the mix of adaption and mitigation policies as well as the behavioral responses to them. The paper closes by discussing how this simple analysis might be related to more general, dynamic models.

II. Climate Adaptation Policies for Substitutes

A. Context

Over forty years ago, a series of papers considered situations where firms (or the social planner) faced a stochastic demand and had to select capacity as well as a single price for

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[3] See Hanemann [2000] and Mendelsohn[2000]

output.[4] The intended application was peak load pricing of electricity. 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. My analysis begins with the last paper in this sequence by Carlton [1977] which assumes multiplicative uncertainty and finds, in contrast to the earlier models, that selecting a price and capacity to maximize expected consumer surplus would imply an "optimal" price *above* long run marginal costs. The assumed terms of access when demand exceeds available capacity affect the prospects for profits (or losses) and thus the need for taxes or subsidies to assure reliable provision of service.

My extension here considers more directly the effects of term of access and the presence of uncertain natural supplies on the capacity and pricing choices under private and social objectives. The application envisioned is a water provider that cannot be assured of a wholesale market to purchase water in the event demand exceeds capacity. In the short run, demand is uncertain, perhaps due to variation in seasonal weather conditions and there is both storage (produced capacity) and natural sources (precipitation). A large portion of the variation in demand is due to outdoor uses, so the context is an urban setting in the arid Southwest.[5] An important component of the expected effects of climate change is on summer temperature and natural availability of water.[6] The model is intended to follow directly from this stylized example.

Demand is a function of prices $x(p) \cdot u$ where $x(p)$ could be considered a per capita demand, p is the price and u a positive random variable with distribution function $F(u)$. u could be considered the number of customers. Capacity is planned as multiples of unit demand under "normal" conditions $k = s \cdot x(p)$. So when $u > s$ then one must consider who will have their demand satisfied. Notice the price is not allowed to adjust. It is set in advance. The conditions of access (or rationing schemes) will influence what "counts" in defining the expected profit and consumer surplus that are realized with each ex ante selection of a capacity and price pair. Equations (1) and (2) specify the objective functions for maximizing expected consumer surplus

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

[5] A comparable argument could be developed with electricity supporting air conditioning as a response to increased temperatures.

[6] The U.S. Global Change Research Program (Karl et.al. [2009]) suggests the evidence is for a warmer and drier set of conditions in the Southwest. By end of the century temperatures are projected to be 4°F to 10°F above historical baseline and Spring precipitation could change by thirty percent over the 1961-1979 baseline conditions in the same time span.

with expected consumer surplus defined assuming with efficient (S_E) and random rationing (S_R) of access when $u > s$ respectively.

$$S_E = \int_0^s u\left[\int_0^{x(p)} x^{-1}(q)dq - bx(p)\right]dF(u) - \beta\, sx(p) \tag{1}$$

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

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. $q = x(p)$). b is the constant (per unit), variable cost of producing q; and β is the constant, long run cost of capacity. There are comparable objective functions describing how the capacity and price would be selected if the goals were to maximize expected profits with these two added rationing conditions when demand exceeds capacity.

Panel A in Table 1 summarizes the implications for capacity and price selections under the two objective functions and rationing schemes. The capacity/price pairs for the objective function based on expected surplus summarize the results in Carlton (using a slightly different format). Before turning to the extensions, it is clear the selection of an "optimal" price (p) based on each criteria and these constraints, depends on the capacity (s). Similarly the "optimal" capacity depends on the selected price. Changes in the access conditions affect the selection of an optimal capacity. From the perspective of social criteria for selecting a pricing scheme, the treatment of excess demand determines the extent of markup over long run marginal costs. For efficient rationing (those with greatest willingness to pay are served first) $\frac{1}{s}\int_0^s udF(u) < 1$, so we expect that $p > b + \beta$ (the sum of incremental variable and incremental capacity costs). For random rationing, the difference between a condition where price equals long run marginal cost (i.e. $p = b + \beta$) and the pricing condition that results with this type of access may be more pronounced.

Table 1-Panel A: Capacity and Pricing with Demand Uncertainty

	Pricing	Capacity Choice
Efficient Rationing	A. All Produced Capacity	
Social	$p = b + \dfrac{\beta}{\frac{1}{s}\int_0^s u dF(u)}$	$s = \dfrac{\beta}{\left[\dfrac{cs}{x(p)} - b\right] dF(s)}$
Monopoly	$MR = b + \dfrac{\beta}{\frac{1}{s}\int_0^s u dF(u)}$	$s = \dfrac{\beta}{(p-b) dF(s)}$
Random Rationing		
Social	$p = b + \dfrac{\beta}{\frac{1}{s}\int_0^s u dF(u) + \left(1 - F(s)\right)}$	$s = F^{-1}\left(\dfrac{\dfrac{cs}{x(p)} - b - \beta}{\dfrac{cs}{x(p)} - b}\right)$
Monopoly	$MR = b + \dfrac{\beta}{\frac{1}{s}\int_0^s u dF(u) + \left(1 - F(s)\right)}$	$s = F^{-1}\left(\dfrac{p - b - \beta}{p - b}\right)$

The differential depends on the likelihood of exceeding capacity as well as the average rate of utilization. Capacity choices depend on long and short run markups over per capita consumer surplus. With random rationing the decisions depend on the relative size of long run relative to short run differences. More specific results require more specific assumptions. However, the first conclusion is no surprise – pricing structures and capacity planning go hand in hand. This seems to have been forgotten in the literature on climate adaptation policies.

B. Adding Natural Supply

One direct way to introduce natural supply includes an exogenous contribution to *s* in determining how demand is met. The reality of natural supply is that it is not a perfect substitute for the capacity being represented by *s*. Variability in the amount as well as the inability to synchronize the timing of precipitation with needs is what motivates developing increased capacity in the water supplies usually intended for people's consumption to meet some of these other needs. In the arid Southwest these are generally outdoor uses (e.g. landscape). As a result, we would replace *s* in (1) and (2) with a function of *s* and effective water available naturally. This function would not be replaced in all aspects of (1) and (2) – only for the limits of integration and in determining the likelihood of being served (i.e. $\frac{s}{u}$) in the random rationing case. Reductions in natural supply would, based on its ability to substitute for *s*, increase the need to raise prices over long run incremental costs. They also add a new consideration into the elements affecting pricing and capacity choices.

Panel B in Table 1 describes the results when there is natural supply and the objective is to maximize expected consumer surplus. The value of the function ϕ designates the effective capacity to supply equivalent services when natural sources of water (*n*) are included with produced capacity (*s*), $\phi = \phi(s,n)$. This function is intended to imply that substitution is only available for some uses. The results in panel B (reported only for the social objective function) are broadly similar to those under this criterion in Panel A. The marginal conditions for produced capacity choices depend on the marginal cost of capacity as a source for "effective" water, considering the level of the natural supply (i.e. $\beta / \phi^{'}$, with $\phi^{'} = \partial\phi / \partial s$).

Table 1-Panel B: Capacity and Pricing with Demand Uncertainty

	Pricing	**Capacity Choice**
	B. Produced and Natural Capacity (where $\phi = \phi(s,n)$)	
Efficient Rationing	$p = b + \dfrac{\beta}{\frac{1}{s}\int_0^{\phi(s,n)} u\,dF(u)}$	$\phi = \dfrac{\beta / \phi^{'}}{\left[\dfrac{cs}{x(p)} - b\right] dF(\phi)}$
Random Rationing	$p = b + \dfrac{\beta s}{\frac{1}{\phi}\int_0^{\phi(s,n)} u\,dF(u) + \left(1 - F(\phi)\right)}$	$\phi = F^{-1}\left[\dfrac{\frac{cs}{x} - b - \left(\beta / \phi^{'}\right)}{\frac{cs}{x} - b}\right]$

The importance of access conditions depends on both produced capacity and natural conditions, as reflected in the computation of expected demand, given there is the possibility of exceeding the available total capacity.

The task of recognizing that climate may change the variability in natural supply is more challenging. To illustrate why, consider an ad hoc strategy for introducing this variability. Assume water (or power) providers treat variability in climate services that alter the demands for their services as independent, in the short run, from the processes giving rise to variability in their demands. Under these conditions assume they might consider including a type of risk premium in assessing how to adjust natural supplies for this natural supply uncertainty. Suppose the “typical” or average natural supply was replaced by a certainty equivalent with the risk premium based on their aversion to variability in natural supply. This strategy allows a simple comparison of the importance of risk aversion versus the substitution between natural and produced capacity in influencing the selected capacity.

My example uses a constant elasticity of substitution function to represent the effective supply from produced and natural sources (i.e. the ϕ function). In this context the assumptions about the extent of substitution between produced and natural capacity are more important than what is assumed about aversion to variability in natural supply. The ratio of total effective capacity (ϕ) to produced capacity (s) is used to display the effects of variations in the coefficient of relative risk aversion versus the elasticity of substitution indicates assumptions about the later (from σ =0.5 to σ =2.0) cause the ratio to vary by over 600 percent (with low initial values of natural capacity). Variation in the coefficient of risk aversion leads to at most a 19 percent (at the low initial values) change in the ratio.

Of course, this result separates the effects of the various components of uncertainty contributing to the decision problem and does not allow them to have cascading effects. It assumes the importance of variability in natural supply is evaluated separately from the importance of water to people.[7] The numerical example illustrates how the uncertainty influences the problem *within* the function we have used to describe how produced and natural capacity substitute for each other. As a result, it is straight forward to see that the treatment of uncertainty,

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[7] While in a conceptual analysis this may seem an especially serious criticism, the decisions about managing supply and those associated with how water is used are made by different agents. In the case of water, the providers currently use simple rules of thumb to decide margins for water supply to meet demand variations.

the attitudes decision makers have toward it, and the nature of the substitution together influence how these simplifications affect the model's conclusions.

C. Mitigation and Adaptation Policy

Equations (1) and (2) can be used to derive a measure of the marginal value of climate mitigation implied by adaptation policy. Each equation describes the expected aggregate consumer surplus from a pricing / capacity selection, given different assumptions about the conditions of access when demand exceeds capacity. $x(p)$ is assumed to correspond to a unit demand and u a (random) measure of the number of customers. When we include average income (m) into the unit demand, a type of marginal value of additions to natural capacity can be defined by considering the equivalent increase to income that could be requested of each customer for an increase in the natural supply (n) without altering the expected consumer surplus.[8] Equations (3) and (4) provide these results for this thought experiment with the access conditions implied by (1) and (2) respectively.

$$\frac{dm}{dn} = -\frac{\dfrac{\partial\phi}{\partial n}\left[\dfrac{cs}{x(p)} - b\right]dF(\phi)}{(\tilde{p} - b)\dfrac{x_m}{x(p)}\displaystyle\int_0^{\phi(s,n)} u\,dF(u) - \beta s\left(\dfrac{x_m}{x(p)}\right)} \tag{3}$$

$$\frac{dm}{dn} = -\frac{\dfrac{\partial\phi}{\partial n}\left[\dfrac{cs}{x(p)} - b\right]\bigl(1 - F(\phi)\bigr)}{(\tilde{p} - b)\left(\dfrac{x_m}{x(p)}\right)\left(\displaystyle\int_0^{\phi(s,n)} u\,dF(u) - \phi(1 - F(\phi))\right) - \beta s\left(\dfrac{x_m}{x(p)}\right)} \tag{4}$$

where $\tilde{p} = p^c - p^*$

p^c is the choke price

p^* is the optimal price selected under one of the two objective functions ((1) or (2)).[9]

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[8] This formulation assumes everyone has the same income. It would be possible following the logic outlined in a different context by Williams [2009] to provide a more general treatment of the effects of heterogeneity in income.

[9] $(p^c - p^*)x_m$ is an approximation. It is exact for the case of a linear demand. I selected it to highlight the separation between a "price" effect that would reflect optimal pricing policy and the income effect for the amount demanded.

The incremental value of policies that would alter natural capacity depends on adaptation. It is important to acknowledge that this marginal value is not the traditional definition of incremental willingness to pay. It simply asks about the implications of changes in the baseline conditions for the objective functions used to define different specifications for the socially optimal price and capacity. It is used here to suggest that the evaluation of mitigation depends on how we decide adaptation rules and vice versa.

The key elements in this relationship are instructive. Access conditions determine whether we focus on the conditional expected demand or a type of lower bound mean. The extent to which natural capacity meets the needs represented by these demands also matters. The elements align with economic intuition. What may be the most interesting aspect of these relationships follows from the influence of rationing conditions, when demand exceeds capacity, on the value of augmenting natural sources of simply (or in the context of mitigation policy avoiding climate change).

Large disruptions in the supply systems for power or water due to storms or system failures (e.g. water main breaks) often require that the recovery process establish a priority system for who is served. 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 should not be considered incidental or associated with infrequent events. Rather they may redefine reliability conditions as an attribute that should be a more direct part of pricing schemes. These rules also alter the implicit value of mitigation as it is perceived through the lens of the objective function for planning adaptation.

III. Weather and Water

To this point the analysis acknowledged two sources of uncertainty for decision making. The first was the uncertain demand that motivated the need to consider how any excess demand would be allocated to a limited capacity. While the analysis acknowledged that climate change could alter the nature of this demand uncertainty, the model also speculated on the effects of a second type of uncertainty associated with natural capacity. In the numerical example cited in the previous section I used a simple fix – assume planners replace the average or typical value for natural capacity with a certainty equivalent. This strategy allows recognition of their attitudes toward risk and avoids the difficult questions of how should the social objective function consider the full dimensions of uncertainty. For short term planning, this approach allows me to compare the effects of substitution between produced and natural capacity and extent of risk aversion to gauge which was more important to selections of the resources needed to meet uncertain demand.

Thus, the analysis relies on the assumption that the two uncertainties are independent. In the case of water supply it amounts to saying that uncertainty in precipitation means we don’t know whether existing reservoirs will be at their capacity each year. There may be shortfalls. Added capacity would allow smoothing these variations over several years. Of course, reduced precipitation may also alter the nature of the variability in water demand (or in the case of temperature, power demand). No doubt it does change the nature of the demand uncertainty, but are these changes large enough to warrant altering my simplifying assumptions?

This question is hard to answer because it is difficult to estimate the demands for these substitute goods (i.e. electricity and water) under any set of conditions. Pricing policies (i.e. inverted block rate structures), limited price variation, incomplete metering of use (especially for outdoor uses in the case of water), and a variety of issues confound the task. As a result, a detailed answer seems unlikely. Instead I will summarize some recent empirical research on residential water demand that suggests my simplifying assumption needs to be revisited. I suspect the same conclusion would also hold for electricity.

Table 2 reports estimates for the price elasticity of demand for water by residential users in Phoenix. The estimates are taken from Klaiber et al. [2010] and were developed by exploiting two types of changes in water prices for Phoenix households. In each of these years the residential water customers’ rates are varied 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].

Our 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. By considering summer and winter months separately, each consumption group did not move between the blocks associated with different marginal prices so the endogeneity of price due to “choosing” a consumption block do not need to be considered. The customers in each consumption group experienced a constant price change due to rate changes over time.

What is relevant to the issue of the effect of natural supply variability is the distinction in price elasticities estimates implied for different pairing of the years used in the first difference models. Consumption in 2000 is compared with 2002 and 2003 in forming the quantity differences used to estimate the model. Average annual precipitation (as well as in average days with measurable rain) across the block groups 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 two normal years are paired as compared to the pairing of a normal and a dry year.[10] For the normal / dry combination summer demand is much less responsive to price changes relative to the estimates derived using changes between two normal years. By contrast, the winter demand for a normal/dry combination is more responsive to price than when two

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[10] 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.

normal years are used to estimate the price response. These findings would suggest the nature of the patterns of demand reflect an effort to smooth water usage over the year under dry conditions saving on water expenditures in the winter to provide for the summer. Most of this water is used for outdoor purposes. Larger differences are found with larger users, consistent with the adjustment coming through outdoor use and reinforcing the importance of household commitments for adjustment to climate change.

These findings would suggest the uncertainty in natural conditions is likely to affect price responsiveness as well as to contribute to the uncertainty patterns characterizing demand. Thus, these empirical results call into question my independence assumption and suggest a more complex treatment of uncertainty may well be needed to describe the price and capacity decisions. However, this limitation does not detract from the main objective of my simple analysis. It was intended to argue that augmenting the capacity of substitutes for the natural climate services cannot be considered separately from pricing policies for those substitutes or from the rules expected for allocating access to these substitutes in periods when demands exceed available capacity.

IV. Implications

Climate adaptation is not synonymous with augmenting the capacities of systems that provide substitutes for the climate services. Changes in pricing that reduce the demands for these services (especially during times when demand is high) and that signal the potential for higher user costs associated with capital investments that require long term commitments to a pattern of use can be described as indirect ways to augment effective capacity.[11] Demands are reduced or displaced. As a result, the existing capacity can meet the revised demand pattern with less likelihood of shortfalls. This interpretation is common place in the demand response literature associated with pricing schemes for electricity. It has not been connected in formal models with discussions of climate adaptation.[12]

This paper has used the early literature on peak load pricing in the presence of demand uncertainty to show that an economic analysis of capacity planning as a response to climate change cannot be undertaken independent of consideration of how these substitute services are

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[11] 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].

[12] In other papers Smith [2009, 2010] I have discussed this connection but not attempted to show a formal analysis.

priced and the rules used to determine who is served when demand exceeds supply. The analysis has also proposed one way of linking the framework to an implicit value for climate mitigation. That is, within a system for deciding pricing and capacity for substitutes for climate services as short run adaptations to climate change, it is possible to also define a type of implicit value for climate mitigation.

It is useful to consider how the value implied by this envelop condition aligns with the shadow value of climate services that are implied by long term climate policy. While this analysis is static, the incremental values of natural capacity and their comparison across different social objective functions offers a way to relate the implications of these short term analysis to more dynamic considerations. Some analysts have expressed concern that ready adaptation reduces the incentive to engage in mitigation. These effects are clearly outside this simple model. Nonetheless, this type of conclusion relies primarily on viewing adaptation as incrementing capacity to provide substitute services.[13] Once pricing and access conditions are included in the analysis the results are not as clear cut. Considering the design of price schedules as part of adaptation can change the prices for a wide range of activities serving as substitutes for climate services and creates dynamic incentives that can feedback to influence both the pace of climate change and the demands for the services facilitating adaptation.

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[13] It also relies on the assumption that clean and dirty (CO_2) producing inputs are not good substitutes in producing output. Acemoglu et al. [2010] have shown in a dynamic model with induced innovation, if these inputs are highly substitutable the optimal response will be low emission taxes and R+D subsidies to "jump start" innovations in the clean technologies. It is only when clean and dirty goods are limited substitutes and discount rates high that adaptation might reduce the costs of delayed interventions. See their Table 2, (p. 30).

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