JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT 29, S-78–S-97 (1995)

Assessing the Economic Cost of Greenhouse-Induced Sea Level Rise: Methods and Application in Support of a National Survey*

GARY YOHE

John Andrus Center for Public Affairs, Wesleyan University, Middletown, Connecticut 06459

JAMES NEUMANN AND HOLLY AMEDEN

Industrial Economics, Incorporated, 2067 Massachusetts Avenue, Cambridge, Massachusetts 02140

Received March 29, 1994; revised July 14, 1994

The potential cost of sea level rise has dominated many of the recent estimates of the economic damage that greenhouse warming might inflict on the United States over the course of the next century. The cost of coastal protection and abandonment accounted for more than 80% of the early Nordhaus [14] estimate of likely damages—part of a review of the then-existing evidence which suggested that an effective doubling of atmospheric carbon concentrations might cost 0.26% of annual GDP.[1] The proportion of total cost attributed to sea level rise was a much smaller 11% in Cline [4], but the sea level rise costs that he quoted were among the most broadly accepted of his longer list of damages.[2] Both authors derived their cost estimates for future sea level rise from the work of Titus and others who contributed preliminary statistics to the EPA Report to Congress [21]; later publications by Titus *et al.* [20] and Yohe [25] converted the preliminary work into national estimates linked to specific sea level rise scenarios.

The relative importance of sea level rise in assessing the potential cost of greenhouse warming, and thus in evaluating the potential benefit of any mitigating strategy, has brought the original damage estimates under closer scrutiny. A series of integrated assessments of aggregate damages has begun.[3] Each has noted that the Titus estimates were based on the assumptions that all developed property would be protected and that all undeveloped property, including wetlands, would be abandoned. These assumptions were supported by comparisons of the economic

---

* This research was funded by the Electric Power Research Institute. The authors thank Tom Wilson and Rob Mendelsohn for their careful readings of an earlier draft. Two anonymous referees also gave a previous draft a thorough review, and this paper is much the better for their contribution. Their work notwithstanding, the opinions expressed here and any remaining errors reside with the authors.

[1] See Table 6 in Nordhaus [13, p. 932], where annual costs attributed to sea level rise for an effective doubling of atmospheric carbon dioxide concentrations were quoted as $5.29 billion out of a potential total of $6.23 billion; agricultural effects were taken as zero in this early calculation, because the range of uncertainty at the time straddled zero almost exactly.

[2] See Table 3.4 in Cline [4, p. 131], where annual costs attributed to sea level rise with a 2.5°C temperature increase associated with a concentration doubling were $7 billion out of a total of $61.6 billion.

[3] At least three comprehensive damage assessments are currently underway. One is housed at Carnegie Mellon University; a second is housed at MIT; a third, funded by the Electric Power Research Institute, has drawn its participants from across the country.

0095-0696/95 $12.00

vulnerability estimates produced by Yohe [25] and protection cost estimates produced by Weggel [22], but they are clearly too simplistic. Some of each type of property, developed and undeveloped, will be protected at least for a while, and so the cost of a more complicated pattern of protection must be reflected as part of the economic cost of rising seas. Some of each type of property will be abandoned, though, in which case the true (future) economic cost of sacrificed property (and not the Yohe vulnerability estimates) must also be added to the damage calculus across an equally diverse collection of coastal sites.[4] Moreover, the decision of when, whether, and for how long to protect any piece of property will involve accurately weighing the tradeoff between the cost of its protection and the economic cost of its abandonment—a balancing calculation which must be conducted on a site by site basis using estimates and projections of future costs and benefits. The key is to consider the world as it is likely to be and not necessarily as it is now.

This paper is written in support of a new round of sea level rise damage assessments which will more accurately portray the complication of including future development and adaptation along the U.S. coastline.[5] It describes a procedure that was designed to overcome the shortcomings of the earlier work on developed coastlines by producing more defensible estimates of the potential *economic cost* of greenhouse-induced sea level rise. Section 1 reviews some of the fundamental assumptions upon which the proposed long-term modeling of protection decisions and economic cost accounting was based. It argues that true economic cost can be represented most accurately (in most cases and given enough time to accommodate complete market adaptation) by the value of interior land—not by the value of shoreline land and not by the value of threatened structures.

Section 2 reports the stylized results of exercising a simple dynamic model which is designed to identify clearly the range of timing decisions that must be incorporated into any estimate of the prospective economic cost of sea level rise. The point will be to maximize the present value of the net benefits of protecting the coastline; equivalently, the objective will be to minimize the present value of the cost of rising seas. In the latter scheme, of course, the cost of rising seas is the cost of protecting some (or perhaps all) threatened property *plus* the cost of abandoning the rest *net* of efficient adaptation. Some additional structure, described in Section 3, is added to the simple model before the qualitative insights that it supports are applied in some detail to Charleston, South Carolina.

Section 4 highlights this application to five distinct subsites in the Charleston area and thereby exhibits the versatility of the underlying methodology. The reader will not, however, see a direct translation of the simple model to Charleston. Mapping technologies are employed to bring the lessons of the model to bear upon a more realistic and complicated depiction of the local geography and how it might

---

[4] Economic vulnerability estimates for the United States were published by Yohe [25], but they were never advertised as estimates of economic cost. They were, instead, simply the current (measured in 1989 dollars) economic values of properties which would eventually be lost to rising seas if it were not protected. They were, however, widely used either directly or indirectly in the absence of any other more appropriate measures to reflect economic cost.

[5] The methodology described and applied here should, in fact, be able to accommodate analyses of the cost of sea level rise within any country or region with well-developed real estate markets and organized coastal zone policy processes.

be threatened by rising seas. Section 5 concludes with some remarks which not only cast the analysis in the context of a broader, integrated damage assessment, but also suggest some of the potentially important ramifications of replacing the earlier estimates based upon vulnerability with more appropriate economic cost estimates in evaluating an efficient abatement response to the threat of global warming.

1. ACCOUNTING FOR THE ECONOMIC COST OF SEA LEVEL RISE

Economic damage that might be attributed to future sea level rise in the absence of any decision to protect threatened property must be calculated in terms of the value of that property at the (future) time of inundation and given any adaptation that might have occurred naturally and efficiently prior to flooding and abandonment. Portraits of both future development and efficient market adaptation are therefore required from the start.

Satisfactory descriptions of how future development might affect coastline real estate values can be derived from empirical market analyses of how property values might change as factors such as population and real income change. Planting scenarios of how these "driving socio-economic variables" might move as the future unfolds into accessible empirical studies produces historically based portraits of how real property values might change over the same time frame. Applied with care in the absence of any anticipated, fundamental structural change in the real estate marketplace, the resulting development trajectories offer representative portraits of the evolving context of the sea level rise problem.

Satisfactory descriptions of how real estate markets might respond on a more micro, local level in the face of threatened inundation from rising seas were more difficult to create. Yohe [24] provided some insight into how to proceed even in his preliminary construction of vulnerability estimates. He noted, first of all, that land and structures should be considered separately. The procedures that would account appropriately for the economic cost of losing one would not account accurately for the economic cost of losing the other.

On the one hand, Yohe argued the value of the land lost to rising seas should, in most cases, be estimated on the basis of the value of land located far inland from the ocean. Any price gradient which placed higher values on parcels of land in direct correlation with their proximity to the ocean would, in a very real sense, simply migrate inland as shoreline property disappeared under rising seas. Ignoring what could be significant transfers of wealth for the purpose of computing social cost, a case was made (and has been accepted as convention) that the true economic cost of inundation would be captured in most cases by the value of the land that was, in an economic sense, actually lost—interior land equal in area to the abandoned and inundated property.[6]

Yohe argued further that the economic value of structures would depreciate over time as the threat of impending inundation and abandonment became known. Structures would be lost at the moment of inundation, to be sure, but their true

---

[6] See Fig. 1 in Yohe [24, p. 240]. The exception to this procedure occurs when rising seas threaten a barrier island where the property value gradient encroaches from two sides. It is still possible to use the value of interior land to reflect costs, but care must be taken to note when interior values begin to reflect the higher values which define both gradients from the inside out.

economic value at that point could be zero with enough advanced warning and with a complete understanding that the property would, indeed, be abandoned when the time came to retreat from the sea. Despite stories of individuals' reluctance to abandon threatened property in, for example, flood plains, the literature which records the results of investigations into how markets react to low-probability–high-cost events strongly supports the assertion that market-clearing real estate prices do indeed decline over time in response to the pending cost of a growing threat.[7]

True economic depreciation (TED), modeled to start at some fixed time prior to inundation and to finish just when inundation would occur, is an appropriate representation of the maximally efficient market response to the (known) risk of future sea level rise.[8] Structures are thirty-year assets in the view of the Internal Revenue Service, so thirty years of (certain) advanced warning was deemed to be sufficient. TED is, by definition, a representation of how the value of an asset declines over time as it moves toward its retirement from service. Its application here supports the position that the true economic cost of structures lost to rising seas could be as low as zero.

Uncertain abandonment, caused by uncertainty about the rate of future sea level rise and/or a disbelief that existing property would actually be abandoned, would affect efficiency, of course. Either a source of imperfect information or an incomplete reaction to the threat of rising seas could, for example, shrink the time period over which markets could react to the threat of rising seas. The value of lost structures under these conditions would not be zero; it would, instead, equal the remaining value of (shoreline) structure at the time of inundation.[9] The worst case of imperfect information and uncertain abandonment would allow absolutely no warning and thus no time for any structural depreciation at all. Consideration of this case takes the lack of information to an extreme caused more by a sudden realization that the policy of abandonment would be followed than by a sudden realization that the oceans have risen. It would, however, capture the situation in which the cost attributed to rising seas would be maximized in either case.

[7] Brookshire *et al.* [3] examined the validity of the expected utility hypothesis as a model of homeowner behavior in the face of low-probability-high-severity risk, earthquakes in this case. They found evidence to support the hypothesis in peoples' response to expert and legal descriptions of risk even when the same people did not respond privately by purchasing disaster insurance. The Brookshire work reinforced similar conclusions offered by MacDonald *et al.* [12] after an analysis of homeowner behavior in the face of the threat of flooding. All of this work offers evidence to suggest that market values should accurately process information provided by experts on low probability natural hazards. The assumption made here extends that conclusion and argues that property prices should, over the very long term in the face of gradual manifestations of global warming, internalize the threat of rising seas given some validating informational authority (provided perhaps as informally as some loosely documented history of sea level rise).

[8] See Samuelson [19] or Stiglitz [20] for descriptions and derivation of true economic depreciation (TED), the rate at which the present value of an economic asset declines over time as it moves toward obsolescence. Yohe [23] contrasts TED with other alternative schedules, providing explicit portraits of their time trajectories.

[9] True economic depreciation takes a mirror-image trajectory over time when compared with the more familiar concept of accelerated depreciation. The actual trajectory depends upon the discount rate, but 10 (20) years of depreciation against a 30-year time horizon would, for all positive rates, mean that more than 67% (33%) of the true economic value of the structure would remain.

2. PLANNING TO CONFRONT SEA LEVEL RISE: A GENERAL MODELING APPROACH

Planning how to respond to rising seas along a developed coastline can be broken into two distinct decisions that are made in an effort to maximize discounted intertemporal welfare (i.e., the net benefits of any protection strategy minus the cost of its implementation). The first, a decision to protect the coastline starting at some time t_0, is reversible; it is always possible to decide at some later time T to abandon property that had previously been protected. The other decision, the decision not to protect shoreline property (or to stop protection at time T), is irreversible. Planning any heroic and expensive attempt at reclaiming previously abandoned property should always have been dominated in the planning process by the less-expensive option of protecting (or continuing to protect) that property all along.

The (net) benefit side of a decision to protect a shoreline from time t_0 through time T can be modeled as the true opportunity cost of abandoning coastal property, and calculation of that opportunity cost requires a time trajectory of the (future) value of property vulnerable to sea level rise along some specific scenario. To accommodate any set of circumstances, let $p(t)$ represent any time trajectory of property values that would be lost at time t if it were not somehow protected. What might $p(t)$ include? Assuming the efficiency of perfect anticipation, foresight, and adaptation involved in computing the true economic cost of sea level rise, the conventions outlined in Section 1 above suggest that it should reflect the value of parcels of interior land equal in area to inundated shoreline property. Efficiency conditions need not be satisfied in every case though. Protection decisions may indeed be made on the basis of second- or third-best behavior—behavior which might incorporate suboptimal decisions based on admittedly imperfect information. In such a case, $p(t)$ would include not only the value of interior land, but also some proportion of the value of threatened structure. Indeed, $p(t)$ would include 100% of the value of coastline structure if there were absolutely no foresight and property were lost suddenly and unexpectedly to rising seas.[10] In any case, it must be emphasized again that $p(t)$ is not a cumulative statistic; it is, quite simply, the value of (unprotected) property that would be lost at time t.

Notice that $p(t)$ is, tautologically, time dependent by virtue of its reliance on an underlying sea level rise trajectory. It should, therefore, incorporate appreciation in property values over time, where appropriate, regardless of the source of that appreciation (economic growth, property improvement, investment in infrastructure, etc.). As just noted, though, it should also reflect a judgement of exactly what land might be lost (interior land versus coastal property, for example) and any market-based depreciation of structure that might occur in anticipation of abandonment. If the analysis were applied to sites where real estate markets did not work well or where residents simply refused to believe that any property would ever be abandoned, in fact, then the $p(t)$ trajectory could reflect the full range of appreciated value measured right up to the time of abandonment.

[10] The case of no foresight might not be as far-fetched as it might seem, at first. While it is unlikely that people living near the ocean would be surprised to see water lapping at the foundations of their homes, they may be surprised to find that a policy of not protecting those foundations will, in fact, be enforced.

Turning now to a generic representation of the present value of the net benefit to society from protecting property from time t_0 through time T, it is convenient to the accounting to let $\rho(t)$ represent a time trajectory of appropriate property values (per unit of area) and $A(t)$ represent the incremental area of land threatened at time t. The $\rho(t)$ series therefore captures all of the complication caused by appreciation and adaptation while the $A(t)$ series reflects an inundation trajectory. In this case, $p(t) = \rho(t)A(t)$; and the present value net benefits can be expressed:

$$PV\{B[t_0,T]\} = \int_{t_0}^{T} p(t)e^{-rt}\,dt - e^{-rT}A(t)\int_{t_0}^{T}\rho(t)\,dt. \tag{1}$$

The first term in Eq. (1) represents the value of protection, expressed in terms of the sum of the value of property that was not lost, incrementally over time, because of the protection (discounted from the time when protection became necessary for each increment at some discount rate r). The second term represents the value of all of the property that had been protected but then abandoned at time T. All of this property is valued through $\rho(t)$ in time T—the time of abandonment—but its loss is also fully discounted.[11] Note that neither term includes the cost of protection.

The cost of protection from time t_0 through time T is easier to frame. Let $c(t)$ represent the time trajectory of protection costs along the same specified sea level rise scenario. The present value of those costs is then, simply

$$PV\{C[t_0,T]\} = \int_{t_0}^{T} c(t)e^{-rt}\,dt. \tag{2}$$

The planning problem described above is thereby reduced to one of picking (t_0^*, T^*) which maximized the present value of the net benefit of protection,

$$PV\{B[t_0,T]\} - PV\{C[t_0,T]\}. \tag{3}$$

The functional constraint that $t_0^* < T^*$ is imposed by the irreversibility of the decision to abandon, not to mention common sense.

3. AN ILLUSTRATIVE SPECIAL CASE

To see how the general model described in Section 2 might work, it is instructive to add some structure to Eqs. (1) through (3). The benefit side construction described here will turn out to be too simple to be applied in reality; the irregularities which typify most coastlines required the more complicated framework to be outlined in Section 4. The cost-side construction described here will, by way of contrast, adopt a variant of the usual fixed and variable cost structure of standard microeconomic theory; and so it will prove to be more generally applicable.

Adopting the EPA convention (EPA [21], Yohe [24, 25]), let the seas rise along a quadratic time trajectory given by

---

[11] These benefits—costs which are avoided, actually—are net of any adjustment, efficient or otherwise, which may occur in response to rising seas; they do not, therefore, reflect transfers of wealth and income which might also be driven by abandoning property.

$$SLR(t) = at + bt^2,$$

where the linear term captured local subsidence and the quadratic term reflects the likely physical impact of greenhouse-induced sea level rise. For simplicity only, let $a = 0$ and assume that $b > 0$. Assume, again for the sake of simplicity only, that the relationship between sea level rise and the area of land threatened by that rise is linear.[12] The value of threatened land can therefore be taken to be proportional to the rate of sea level rise. Assuming efficient depreciation of structures, then

$$p(t) = A_0[d(SLR(t))] = 2bA_0t,$$

where $A_0 > 0$ is the constant of proportionality; and the present value of the benefit side of protection is

$$\begin{aligned} PV\{B[t_0,T]\} &= \int_{t_0}^{T} 2bA_0te^{-rt}\,dt - e^{-rT}\int_{t_0}^{T} 2bA_0t\,dt. \\ &= \int_{t_0}^{T} 2bA_0te^{-rt}\,dt - A_0b\left[T^2 - t_0^2\right]e^{-rT}. \qquad (4) \\ &= -\left\{2bA_0\left[rte^{-rt} + e^{-rt}\right]/r^2\right\}\Big|_{t_0}^{T} - A_0b\left[T^2 - t_0^2\right]e^{-rT}. \end{aligned}$$

Turning now to costs, let the cost of protection be divided into an initial fixed-cost component P_0 (e.g., the initial cost of building a dike) and a variable-cost component (covering ongoing maintenance expenses and required extension) which depends on the rate of sea level rise. Assuming that variable costs are proportional (with constant P_v) to the rate of sea level rise, variable costs are

$$c_v(t) = P_v[d(SLR(t))] = 2bP_vt$$

and

$$\begin{aligned} PV\{C[t_0,T]\} &= P_0e^{-rt_0} + \int_{t_0}^{T} 2btP_ve^{-rt}\,dt \\ &= P_0e^{-rt_0} - \left\{2bP_v\left[rte^{-rt} + e^{-rt}\right]/r^2\right\}\Big|_{t_0}^{T}. \end{aligned} \qquad (5)$$

The planning problem characterized most generally in Eq. (3) is thus given some explicit structure by Eqs. (4) and (5).[13]

The appropriate first-order conditions emerge most easily by application of the fundamental theorem of calculus applied to the first representations of the right-hand sides of Eqs. (4) and (5):

$$t_0\colon rP_0e^{-rt_0} - 2b[A_0 - P_v]t_0e^{-rt_0} + 2A_0bt_0e^{-rT} = 0 \qquad (6a)$$

$$T\colon -2bP_vTe^{-rT} + rA_0be^{-rT}\left[T^2 - t_0^2\right] = 0. \qquad (6b)$$

---

[12] Linearity is clearly a bad assumption for large amounts of sea level rise along an irregular coastline. It is more defensible for smaller sea level rise trajectories aggregated over many sites; but it is employed here only in an illustrative framing of the planning and cost computation problems. Subsequent empirical application will recognize any monotonic pattern of inundation over time.

[13] The cost structure portrayed in this illustrative model is consistent with the results of Weggel [22] and the work of the Coastal Zone Management Working Group in support of the IPCC Scientific Assessment [10], particularly in reference to fixed defensive structures. The cost of other protection strategies, like the nourishment of open beaches, may be quadratic in sea level rise.

Equation (6b) requires either that $T^* \to \infty$ or that T^* solves a quadratic equation which also includes t_0^*. In the latter case, $T^* < 0$ (which must be constrained to $T^* = 0$, so that $t_0 = 0$, or $T^* \approx \{t_0^* + k\}$, so that Eq. (6a) can be satisfied only by $t_0^* \to \infty$, in which case $T^* \to \infty$ as well). In the former case, Eq. (6a) reduces immediately to

$$rP_0 e^{-rt_0} - 2b[A_0 - P_v]t_0 e^{-rt_0} = 0.$$

Again, $t_0^* \to \infty$ is a possible solution; but so, too, is

$$t_0^* = \{rP_0/2b(A_0 - P_v)\}. \tag{7}$$

Note in passing that the solution defined in Eq. (7) is positive only if $A_0 > P_v$; i.e., only if the linear value parameter is greater than the linear variable cost parameter. The second-order conditions for maximization guarantee that this condition is satisfied in cases in which the decision to protect might be in doubt.[14]

Even the simplistic model presented here therefore accommodates the possibility that planning for the protection of vulnerable property may optimally involve an implementation delay with $t_0^* > 0$. This delay would expand, according to Eq. (7), with an increase in either the initial cost of protection, P_0, or the variable cost of protection, P_v. These sorts of positive correlations should have been expected, though, because extended delays would ameliorate the effect of higher costs through discounting. Discounting would be even more effective with higher discount rates (parameter r), of course. Equation (7) therefore shows that the optimal delay in the protection decision would increase with the discount rate so that the planning process can take greater advantage of its "discounting" power.

Increases in both the rate of sea level rise (parameter b) and the value of property, A_0, would have the opposite effect on the optimal planning delay. To see why, note that the pace of inundation would be accelerated by more rapidly rising seas; and so unprotected property would be lost to those rising seas more quickly and the discounted value of those losses would necessarily climb. Higher property values have the same effect, of course—an upward shift in the time trajectory of the value of unprotected and thus abandoned land. In either case, therefore, the discounted value of a decision to avoid losing that land would rise and weigh more heavily against the discounted value of the cost of protection, and the optimal delay in implementing a protection strategy could shrink accordingly.

The linear structure of the benefit side of this simple illustration does great violence to the reality as a model for predicting the future value of potential inundation losses along almost any threatened coastline. Coastlines are far too irregular and coastal contours are far too rugged for linearity to serve very well. A linear structure was employed here only as a first step in the construction of a more applicable model. Indeed, the intuition developed around the two parts of Eq. (1) and the precise formulation of Eq. (3) will inform the construction of a more realistic benefit side in Section 4. The news is even more encouraging on the cost side of the calculation. The fixed- and variable-cost structures which characterized the protection response through Eq. (4) are, given limited information, sufficiently general to accommodate more realistic analyses of various options designed to protect a wide range of vulnerable shoreline topographies.

---

[14] Variable costs alone would exceed the potential benefits of protection if $P_v > A_0$, and protection could not be the better decision.

4. APPLICATION TO CHARLESTON

Turning now to reporting the results of a careful consideration of the economic cost of future sea level rise at a specific site—Charleston, South Carolina—the mechanics of how to apply the general structure of the benefit side of protection presented in Section 2 and the specifics of the cost side presented in Section 3 should become clear. Charleston was chosen because it was part of the sample which supported earlier estimates of national vulnerability to sea level rise, so producing a time series of potential economic cost along a given sea level rise trajectory will allow a direct comparison with those vulnerability estimates.[15] Moreover, the local geography of the Charleston site allowed this application to consider five distinct and qualitatively diverse "subsites," downtown Charleston, Mount Pleasant, Avondale, Dorcester, and Sullivan's Island. The versatility of the model and its applicability across a range of sites and options was therefore adequately tested.

Subsection 4.1 begins with a description of the data and assumptions which frame both the Charleston site and the sea level trajectory to be considered. A second subsection presents results for each of the subsites; protection decisions, including their timing, which minimize the discounted value of anticipated costs are identified and supported. The ultimate result—a time profile of these costs along the given trajectory—is finally presented in Subsection 4.3.

4.1. Background Data and Assumptions

For the sake of illustration, let a quadratic sea level rise scenario which would produce 100 cm in total elevation from 1990 through the year 2100 reflect the potential natural impact of greenhouse warming; i.e., let the greenhouse-induced component of future sea level rise be characterized by

$$SLR(t) = bt^2 = (0.0081)t^2. \tag{8}$$

This trajectory certainly lies on the high side of the best IPCC estimates [11], but it serves here to support a diverse set of protection responses—and thus economic cost profiles—across the five Charleston subsites.[16] It is also the middle trajectory in the national sample of vulnerability completed in 1989 by Yohe [25]. Any

---

[15] Yohe [25] reports the results of the sample. The reader should note once again that cost and vulnerability estimates should not be comparable—the former reflect land values appreciated over future time and incorporate impact mitigation through adaptation while the latter reflect only 1989 values of land and structure. The vulnerability statistics have, however, been used to support damage estimates on the benefit sides of integrated assessments designed to compute efficient abatement of carbon emissions through, e.g., carbon taxes. Comparisons of cost and vulnerability estimates can thus be useful in examining the sorts of errors that using vulnerability data might have created and/or the adjustments which might be required to reflect the more appropriate inclusion of cost-based damage statistics in the efficiency calculus.

[16] The middle IPCC [10] trajectory still shows 67 cm through the year 2100. It is surrounded by two other cases, a low trajectory that sees 31 cm through 2100 and a high trajectory that sees 110 cm. Recognizing this, and more recent work which has suggested that even 67 cm might be too high, subsequent application of the methods described here to a national sample will consider 33 cm and 67 cm. It would not be prudent, though, to ignore higher trajectories completely. On the one hand, surprises and nonlinearities in the problem will only be uncovered if higher scenarios are examined; on the other, comparability with the previous vulnerability statistics can only be achieved if the 100-cm scenario (the middle case in the earlier work) is considered.

comparison that might be attempted between the economic cost of sea level rise along this trajectory and the corresponding estimate of economic vulnerability would therefore be immediate and transparent.

Inundation profiles over time for each subsite of Charleston along the 100-cm scenario are available from the computer-based mapping capability developed by Richard Park and his colleagues at the Holcomb Research Institute for the 1989 EPA Report to Congress [14]. Each site in the Park sample, of which roughly one-third were used in the Yohe sample, represented a 30-minute cell provided by the U.S. Geological Survey.[17] The maps divide each site into 500-m-square partitions; and the mapping technology looks at how each partition changed over time for a specified sea level rise trajectory. If the seas were assumed to rise along, for example, the 100-cm scenario reflected in Eq. (8), then the Park maps would show snapshots of seawater inundation and other land changes across all of the partitions in five-year increments along that trajectory. Table I records, in decadal increments, the resulting time series of inundated partitions for each of the five Charleston subsites.

Applying estimates of how the value of the properties located in these threatened partitions might appreciate over time to these dynamic portraits of the physical impact of sea level rise produces estimates of (1) the potential benefit of protection, (2) the potential cost of abandonment, and/or (3) the cost of protection —the statistics required to discover the solutions to Eq. (3). Table I also records the initial values of land and structure (per 500-m partition) that were employed to anchor the appreciation of property values in each subsite over time.[18] To preserve comparability, and in the absence of any other reasonable set of estimates, the average values for land and structures which supported the earlier Yohe vulnerability estimates are employed.

Appreciation in the value of threatened property reflects the likely effect of future development—development that will be driven by future changes in real income and population. Note, in passing, that income and population also represent the best potential coordinating links between this coastal zone analysis and other impact studies in larger integrated assessments of the cost of global warming.[19] Abraham and Hendershott [1] provide a reasonably applicable regression result for housing prices which could be interpolated for land value assuming only that real construction costs and after-tax interest rates will be roughly stable over the very long term.[20] Given this assumed stability of relative prices, in fact, the best-fit regression over their full sample is

$$d[\ln(p(t))] = -0.006 + 0.313g_{\mathrm{L}} + 0.565g_{\mathrm{Y}} + 0.402[\ln(p(t-1))], \quad (9)$$

---

[17] See Park and Trehan [14]. Ten percent of all of the 30-minute USGS cells which contain any coastline at all were captured by the Park sample; he traversed the coastline, choosing to include every tenth cell.

[18] Structure values were taken to equal three times the value of land—slightly more than IRS convention, but more in line with results offered by Poterba [17].

[19] Consistent assumptions about the rates of growth of population and per capita income are, in fact, two of the major ways in which the various components of the Electric Power Research Institute damages assessment for the United States will be integrated. They were chosen from the most recent IPCC Scientific Assessment [10] to preserve comparability with the state of the art.

[20] The Poterba [17] correlation, combined with the IRS convention of a fixed proportional relationship between land and structure values supports the application of the Abraham and Hendershott [1] results to land and structure taken separately.

TABLE I

Characteristics of the Charleston-cell Subsites[a]

	Charleston	Dorcester	Avondale	Mt. Pleasant	Sullivan's Island
			A. Inundation		
Year					
2000	0	0.5	0	0.5	0
2010	0	1.0	0	1.0	0
2020	0	1.5	0	0.5	0
2030	0	2	0	0.5	0
2040	0	0	0	0.5	0
2050	0	0	0	1.0	0
2060	0.5	0	0	1.0	0
2070	0.5	0	0	0	0
2080	0	0	0	0	0
2090	1.0	2.0	1.0	1.0	1.0
2100	0.5	1.0	0.5	0.5	2.0
			B. Economic parameters		
Initial Land Value[b]	8.6	0.8	1.9	6.0	10.3
Initial value of structure[b]	25.9	2.5	6.0	18.1	30.8
Fixed cost of protection[c]	11.6	23.2	7.7	27.1	0.3
Variable cost of protection[d]	0.05	0.10	0.03	0.12	0.024

[a] The number of 500 m by 500 m partitions deemed lost to rising seas along the 100-cm trajectory during the decade ending in the year noted. These values were judged from the Park mapping technology according to the following convention. Newly inundated partitions were noted for both of the 5-year intervals which comprised the period between one decade and the next; a partition is taken as inundated when more than 50% of its area would be under water during mean spring high tide. Any partition seen inundated in the first 5-year interval (say between 2040 and 2045) was assigned to the decade in question (the decade ending in 2050). Any partition disappearing in the second 5-year interval (say between 2045 and 2050) was shared 50–50 with the next decade (one-half to 2050 and one-half to 2060).

[b] Denominated in millions of dollars (1989) per 500 m by 500 m partition.

[c] Denominated in millions of dollars (1989); P_0 is in the notation of Eq. (5).

[d] Denominated in millions of dollars (1989) per centimeter of sea level rise; P_v is in the notation of Eq. (5).

where g_L and g_Y represented the rates of growth of population and real percapita income, respectively.[21] Equation (9) provides a means of proposing the $p(t)$ trajectory required to quantify Eq. (1) given anticipated population and (per capita) income scenarios. Table II defines the scenarios employed for both; they were taken to reflect the expectations for the United States of the most recent IPCC Scientific Assessment [10].

---

[21] The income elasticity reflected here might appear high, but note that it is a long-run (cumulative effect) elasticity and represents a response to changes in real income per working-age adult. The corresponding short-run elasticity corresponds well to the lower estimates offered by Peek and Wilcox [16], Mankiw and Weil [11], and Hendershott [9].

TABLE II

Assumed Annual Growth Rates for Population and Real per Capita Income[a]

Interval	Population growth	Real per capita income growth
1990–2000	0.8	3.2
2000–2025	0.5	2.2
2025–2050	−0.1	1.5
2050–2100	0.0	1.0

[a] *Source.* IPCC (10).

Note. These projections were used to drive land and structure values into the future.

The literature on property values offers only limited and somewhat contradictory evidence that coastal values might change at a different rate from noncoastal properties. On the one hand, Frech and Lafferty [6] and East [5] have argued that policy factors, such as development moratoria, could constrain the future "supply" of coastal properties relative to other locations and thereby inflate their relative price. Parsons [15] and Beaton [2] note, however, that the data seem to suggest that rates of growth over time for coastal and noncoastal property values are not significantly different. Rates of change were most important in drawing moving portraits of future development, though; so the apparent coincidence of property value trends is reassuring, assuming that the initial valuations were correct.

Table III records the current values of property that would be lost to inundation in the absence of any protection along the trajectories described in Table I for each subsite. There are two columns for each subsite. The first, in part A, reflects the value of (interior) land equal in area to the coastal property which would be lost over succeeding decades beginning in the year 2010. The decadal statistics recorded for the years 2000 and 2010 include the value of any remaining, undepreciated structure which would be located on inundated property with 10 and 20 years' notice, respectively. Applying true economic depreciation to both cases with an assumed real discount rate of 3% shows that 78% of the initial value of a structure would remain in 2000 and 48% of the initial value of a structure would remain in 2010.

The second columns for each subsite, recorded in part B, reflect the potential cost that could be attributable to sea level rise if there were absolutely no anticipation of impending loss. They therefore include the value of an appreciated and a totally undepreciated structure on the threatened land at the time of inundation. These estimates therefore reflect the cost of abandoning property to rising sea level if the market did not believe that the seas were rising and/or that the plan to abandon threatened property would actually be implemented.

The P_0 and P_t parameters of Eq. (5) define the cost side of the protection decision calculus. Table I records, in its bottom two rows, estimates for both at each of the five Charleston subsites. They are derived from Weggel [22], extrapolating from the detailed estimates he offered for building dikes and nourishing beaches (raising a barrier island) in preparation for a detailed study of Long Beach Island, New Jersey, and a few other sites scattered around the country.

TABLE III

Current Value of Potential Loss to Sea Level Rise[a]

Year	Charleston	Dorcester	Avondale	Mt. Pleasant	Sullivan's Island
		A. With perfect foresight[b]			
2000	0	1.6	0	17.5	0
2010	0	1.5	0	14.7	0
2020	0	1.3	0	3.3	0
2030	0	1.5	0	2.8	0
2040	0	0	0	7.4	0
2050	0	0	0	7.6	0
2060	7.6	0	0	6.3	0
2070	7.6	0	0	0	0
2080	0	0	0	0	0
2090	10.7	4.1	2.6	7.7	12.8
2100	11.7	1.6	2.8	8.4	31.7
		B. With absolutely no foresight[c]			
2000	0	1.7	0	24.5	0
2010	0	1.9	0	28.9	0
2020	0	5.1	0	12.5	0
2030	0	6.2	0	11.3	0
2040	0	0	0	28.9	0
2050	0	0	0	29.8	0
2060	30.3	0	0	30.3	0
2070	30.2	0	0	0	0
2080	0	0	0	0	0
2090	42.8	16.2	10.2	29.9	51.0
2030	46.9	6.5	11.2	32.7	126.9

[a] In millions of dollars, the value of land (A) or land plus structure (B) that would be lost in the decade ending in the year indicated with and without foresight.

[b] The statistics recorded here are, essentially, the values of lost land, appreciated up to 30 years short of the point of inundation. The 2000 and 2010 values included 20 and 10 years of undepreciated structure; true economic depreciation with a 3% discount rate was applied.

[c] No foresight implied no market reaction until the date of inundation. This is the worst case of bad information—disbelief in sea level traiectory and/or plan to abandon property. The statistics recorded here included the value of land and structure appreciated up to the date of inundation.

The relatively low fixed cost for Sullivan's Island corresponds to the small initial cost of preparing to raise the island and nourish its beaches. Diking is simply not an option there, so variable costs reflect an ongoing and, given the acceleration in sea level rise along a quadratic trajectory, increasing investment in sand along its entire length over a potentially long period of time. A decision to protect the island would, in fact, really be a decision to begin protection in 1990 because delay is not possible. Irreversible (or at least problematical) erosion and inundation of beaches and dunes would begin immediately along a sea level rise trajectory unless some protective strategy were adopted. As a result, the only real timing decision involved in considering what to do for Sullivan's Island is planning when to stop; the default option is, in a very real sense, to stop immediately and plan never to protect the island at all.

Dikes emerge as the (potential) option of choice in the other four subsites, and the lists of protection decisions for each are more complete and more complicated. Dikes can be constructed at any time, of course, so questions of when to start construction must be confronted directly. The fixed cost of the initial construction plays a critical role here, of course, but it should be noted explicitly that a dike would be constructed only along the limited coastline that merits protection. Dikes must be maintained and enlarged over time, though, so variable costs which depend upon the rate of sea level rise create the possibility that even limited protection might not be continued indefinitely. The question of when, if ever, to stop protection and to sacrifice previously protected land as well as property that would be threatened subsequently thus comes into play as well.

4.2. Some Representative Results

Table IV displays an array of results for the downtown Charleston subsite—the present values of deciding to begin protecting the threatened partitions at the t_0 values recorded down the leftmost column and ending that protection at the T values recorded across the top row. Positive values appear only in the last column in which the property is never abandoned, at least not through the year 2100; and a present value of slightly more than $900,000 emerges as the highest value on the entire table. Notice that this maximum value corresponds to (1) planning to build the requisite protective dike in 2050, just before inundation losses would be felt, and (2) maintaining it beyond 2100. In the notation of Section 3 then, $t_0^* = 2050$ and $T^* > 2100$ for downtown Charleston.

A similar array of potential start and stop dates was produced for the Mount Pleasant subsite, and $t_0^* = 1990$ and $T^* > 2100$ emerged as the best choices. The qualitative result from downtown Charleston—that protection should begin just before valued property was threatened by inundation—carries over, but for a slightly different reason. Table I shows that inundation would start almost immediately in Mount Pleasant; and Table III shows relatively high potential losses. This is not because land would be more valuable in Mount Pleasant than it would be in downtown Charleston. It is, instead, because there would be insufficient time to depreciate the value of structures in Mount Pleasant in the face of the threat of higher seas. Structure values have to be included in the decision calculus, therefore, and drive the starting date forward to the present.

The decision arrays for Dorcester and Sullivan's Island both revealed that threatened property should not be protected; but again, the reasons are different. Building protective dikes would have been the correct option for Dorcester, but the present value of their cost exceeds their value primarily because prospective losses would be felt so far into the future that only interior land values support the benefit side of the calculations. Even discounting the cost of building a dike equally far into the future is not enough to support a positive difference between discounted benefits and costs.

By way of contrast, beach nourishment (in effect, raising the island) would have been the correct option for Sullivan's Island; but any nourishment strategy must begin in 1990 even though the potential losses to sea level rise occur far in the future. Unfortunately for those whose relatively valuable properties are located on this barrier island, protection never displays a positive present value through the year 2100 given a real discount rate of 3%. The trajectory of net benefits climb

TABLE IV

Decision Array, Downtown Charleston: The Present Value of the Net Benefits of Protection Alternatives with Perfect Foresight[a]

T:	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	< 2100
t_0													
1990	−11.61	−11.62	−11.69	−11.79	−11.89	−11.99	−12.08	−12.08	−11.70	−11.39	−11.01	−10.64	−9.26
2000		−8.60	−8.68	−8.78	−8.88	−8.97	−9.06	−9.07	−8.68	−8.38	−7.99	−7.63	−6.24
2010			−6.37	−6.47	−6.57	−6.67	−6.75	−6.76	−6.37	−6.07	−5.68	−5.32	−3.93
2020				−4.72	−4.82	−4.92	−5.00	−5.01	−4.63	−4.32	−3.94	−3.57	−2.18
2030					−3.50	−3.59	−3.68	−3.69	−3.30	−3.00	−2.61	−2.25	−0.86
2040						−2.59	−2.68	−2.68	−2.30	−2.00	−1.61	−1.24	0.14
2050							−1.92	−1.93	−1.54	−1.24	−0.85	−0.49	0.90
2060								−1.42	−1.28	−1.15	−0.90	−0.63	0.48
2070									−1.05	−1.11	−0.99	−0.82	0.01
2080										−0.78	−0.66	−0.49	0.34
2090											−0.58	−0.55	−0.12
2100												−0.43	−0.43

[a] Each figure recorded here represents the present value of the benefit of beginning protection at the time t_0 (indicated in the first column) and stopping at the time T (indicated in the top row) net of the present value of the cost of that protection and the loss involved in abandoning previously protected property at time T. These values have been measured along a quadratic trajectory which attributes 100 cm of sea level rise to greenhouse warming through the year 2100. A discount rate of 3% was employed both in the present value calculations and in the definition of the time traiectory of structure depreciation.

TABLE V

Decision Array, Avondale: The Present Value of the Net Benefits of Protection Alternatives with No Foresight[a]

T:	2080	2090	2100	> 2100
t_0				
2080	−0.52	−0.26	0.15	0.47
2090		−0.39	0.03	0.35
2100			−0.29	−0.29

[a] Each figure recorded here represents the present value of the benefit of beginning protection at the time t_0 (indicated in the first column) and stopping at the time T (indicated in the top row) net of the present value of the cost of that protection and the loss involved in abandoning previously protected property at time T. These values have been measured along a quadratic trajectory which attributes 100 cm of sea level rise to greenhouse warming through the year 2100. A discount rate of 3% was employed both in the present value calculations, but structure was not depreciated.

toward zero as prospective stopping dates rise to 2100, though; so perhaps a longer time horizon would bring better news.

Avondale is yet another subsite for which protection fails the net welfare test when threatened structures efficiently depreciate to worthlessness just before they fall into the rising water. The present values of all of the protection options are negative. If foresight were not perfect so that undepreciated structures would be lost to inundation as well as land, however, a different decision could be made. If, for example, residents (and thus real estate markets) simply did not believe that their property would be abandoned, then structures and land might continue to appreciate right up to the very end. The cost of abandonment would then be exaggerated by the resulting disregard of the threat of sea level rise and any planned retreat in its wake. Using the resulting inflated property values, derived under the assumption of absolutely no market foresight, the decision calculus shows that a decision to begin protection in 2080 and to continue past 2100 would be (suboptimally) best. Table V highlights the part of the decision matrix that changes with the lack of foresight and indicates that the maximum present value of almost $475,000 identified $t_0^* = 2080$ and $T^* > 2100$ dominates.

4.3. An Intertemporal Cost Profile for Charleston

The middle five columns of Table VI record the undiscounted incremental costs that are attributable in successive decades to sea level rise with perfect foresight and market adaptation (i.e., structure depreciation) along the 100-cm trajectory for each of the five subsites in the Charleston cell; the last column collects the subsite costs across the entire cell. The statistics displayed there are expressed in current dollars, and they include the optimal decisions described in Section 4.2. More specifically, they include the cost of protection, when protection is deemed to be appropriate; and they include the cost of abandoned property when retreat from the rising seas is the better response. The present value of all of these costs,

TABLE VI

Decadal Economic Cost Estimates: The Charleston Site[a]

Year	Dorcester	Avondale	Mount Pleasant	Sullivan's Island	Charleston	Total
2000	1.6	0	27.1	0	0	28.7
2010	1.5	0	0.1	0	0	1.6
2020	1.3	0	0.1	0	0	1.4
2030	1.5	0	0.2	0	0	1.7
2040	0	0	0.4	0	0	0.4
2050	0	0	0.6	0	14.4	15
2060	0	0	1	0	16.1	17.1
2070	0	0	1.5	0	18.3	19.8
2080	0	0	2.2	0	21.5	23.7
2090	4.1	2.6	3.2	12.8	25.8	48.5
2100	1.6	2.8	4.5	31.7	31.8	72.4

[a] Current values denominated in millions of (1989) dollars. These costs include the cost of protection for Mount Pleasant (beginning in 1990) and Charleston (beginning in 2050) as well as the value of lost property where abandoned (taken from Table III). Optimal protection decisions and efficient adaptation with perfect information are both assumed given a 3% discount rate.

discounted at 3%, is nearly 37 million dollars—a sizable sum, to be sure, but certainly a small fraction of the total value of the metropolitan Charleston area.[22]

Notice that the current value cost statistics start high, fall quickly, and then gradually climb over time. There are several reasons why this shape makes sense. First of all, economic costs can be high early because the cost of deciding not to protect property in the near term must include a significant proportion of the value of structures that cannot be depreciated to zero, even assuming efficient markets and perfect foresight; there is simply insufficient time for complete adaptation before, say, the year 2020. Perfect foresight would allow all threatened structures to be depreciated to zero after 2020, though, so this initial cost-inflating effect eventually disappears. Eventually, though, it can be expected that either the cost of protection will rise (because higher seas threaten to inundate more property and so the cost of protecting that property climbs) or the cost of deciding not to protect certain property rises (because the current value of abandoned property probably

---

[22] Indeed, the only subsite in Charleston that faces a significant threat from sea level rise, measured in terms of total value, is Sullivan's Island; that threat materializes only after more than 100 cm of net sea level rise. Indeed, there is no noticeable loss of land on the island (given a square grid of 500 m) until roughly 75 cm of sea level rise. Conversely, though, the island is breached by a 150-cm rise, and more than 50% of its developed area would be inundated by a 2-m rise.

Gibbs [7, 8] provided early glimpses into the potential cost of sea level rise in the Charleston area—an area that is somewhat larger than the site studied here. Most of his results are not comparable because all but his lowest sea level trajectory ran far above even the 100-cm case considered here. His first publication focused primarily on a high trajectory that proposed 231.6 cm in sea level rise through the year 2075. His second recorded some estimates along a low trajectory that produced 87.6 cm in sea level rise through 2075—an amount that is almost 50% higher than the 2075 level proposed here. Combined with his assumption about slow adaptation (to more rapid sea level rise), his coverage of a larger area, his inclusion of storm damage, and his omission of protection investment when warranted, it is not surprising that he produces higher estimates of economic impact through 2075, a present value of between $285 and $375 million (1980) dollars given a comparable 3% discount rate.

climbs over time, and because more of it may be abandoned). In either case, the incremental economic cost of sea level rise climbs in the more distant future.

It is interesting to note that including the inefficient, no-foresight response for Avondale increases the present value of costs by less than 1%—something on the order of $250,000. This is a small effect, to be sure; but it is a number derived from planning to undertake an incorrect (inefficient) reaction nine decades into the future. It remains to be seen if similar effects might occur across a national sample with enough frequency and perhaps a bit earlier in the planning horizon to exaggerate the extra cost of this sort of inefficiency and thereby increase the value of (1) good information about future sea level rise and (2) certainty about any plans to retreat from the sea.

5. CONCLUDING REMARKS

The results reported here are only the first step in one component of a project designed to assess the potential economic damage that might result across the United States from climate change. The methods described here will be applied to each of the sites included in the Yohe vulnerability sample for a variety of sea level rise scenarios (33 cm, 67 cm, and 100 cm through the year 2100, at the very least). At least two discount rates (3% and 5%) will be employed, the sensitivity of the protection decisions and the cost estimates to a range of property value appreciation relationships will be explored, and the value of information (about future sea level rise *and* anticipated policy responses) will be assessed. It is expected that national estimates of the potential economic cost of greenhouse-induced sea level rise, expressed in terms of damage functions associated with specific sea level scenarios, will result.

Turning, finally, to Table VII, note that the cost schedules (expressed in current values for the decades noted) captured there support the notion that moving beyond estimates of economic vulnerability might have some direct effect on the debate about the degree of mitigation which might be supported in the United States on efficiency grounds. The second column there repeats the last column of Table VI; the next column records the corresponding cumulative damage estimates. The vulnerability estimates prepared for Charleston along the 100-cm sea level rise scenario in Yohe [25] are reported in the last two columns. Cumulative cost statistics are portrayed as functions of sea level rise in Fig. 1 in direct contrast with their comparable vulnerability estimates. The data reflected there are specific to the 100-cm scenario, but note that cumulative costs show a more gradual curvature once the thirty-year limitation for efficient depreciation of structure has been accommodated by the passage of time. It would appear that the ability of market-based adaptation to reduce the abandonment cost of future sea level rise might combine with essentially quadratic costs of protection to reduce the curvature of the damage schedule.

If this observation were to hold more generally across many sites, then national cost estimates would show similarly reduced curvature when compared with national vulnerability estimates. Any risk premium that policymakers might chose to include in their calculation of an efficient, intertemporal shadow price of carbon emissions (i.e., an efficient carbon tax) in response to curvature on the damage side

TABLE VII

Contrasting Economic Damage and Vulnerability Estimates

Year	Economic Damage[a]		Economic Vulnerability[b]	
	Decadal[c]	Cumulative[d]	Decadal[c]	Cumulative[d]
2000	28.7	28.7	30	30
2010	1.6	30.3	11	41
2020	1.4	31.7	18	59
2030	1.7	33.4	24	83
2040	0.4	33.8	12	95
2050	15	48.8	6	101
2060	17.1	65.9	5	106
2070	19.8	85.7	12	118
2080	23.7	109.40	36	154
2090	48.5	157.90	59	213
2100	72.4	230.30	47	260

[a] Source: Table VI.

[b] Source: Yohe (1990), Table 1, page 406.

[c] Current value denominated in millions of (1989) dollars.

[d] Current values through the year noted in millions of (1989) dollars.

of their expected value calculus would also fall. Incorporating the more appropriate economic cost trajectory data in lieu of relying on vulnerability trajectories might, in other words, work to ameliorate the effect of uncertainty and thereby reduce both the applicable risk premium that should be reflected in the carbon tax and the targeted level of emissions reduction.

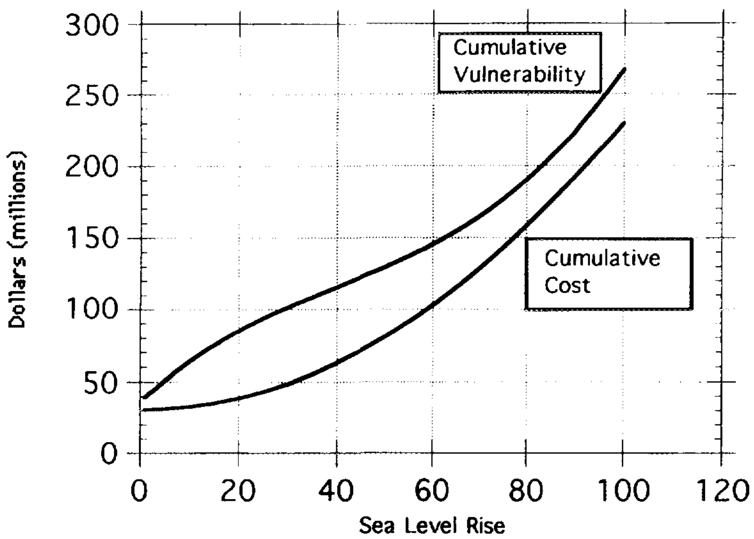

FIG. 1. Cumulative vulnerability and cumulative cost are plotted as functions of sea level rise along a quadratic trajectory which produces 100 cm of sea level rise through the year 2100. Source: the third and fifth columns of Table 7.

REFERENCES

1. J. Abraham and P. Hendershott, Patterns and determinants of metropolitan house prices, 1977 to 1991, *in* "Real Estate and the Credit Crunch, Proceedings" (Browne and Rosengren, Eds.), Federal Reserve Bank of Boston, Boston (1993).
2. P. Beaton, "The Cost of Government Regulations. A Baseline Study for the Chesapeake Bay Critical Area," Vol. II, Rutgers University, New Brunswick, NJ (1988).
3. D. Brookshire, M. Thayer, J. Tschirhart, and W. Schulze, A test of the expected utility model: Evidence from earthquake risks, *J. Polit. Econom.* **93**, 369–389 (1985).
4. W. Cline, "The Economics of Global Warming," Institute for International Economics, Washington, DC (1992).
5. B. East, Paradise lost: California house prices are slumping, *Barron's*, July, p. 15 (1990).
6. H. Frech and R. Lafferty, The effect of the California Coastal Commission on housing prices, *J. Urban Econom.* **16**, 105–123 (1984).
7. M. Gibbs, Economic analysis of sea level rise: Methods and results, *in* "Greenhouse Effect and Seal Level Rise: A Challenge for This Generation" (M. Barth and J. Titus, Eds.), pp. 224–251, Van Nostrand–Reinhold, New York (1984).
8. M. Gibbs, Planning for sea level rise under uncertainty: A case study of Charleston, South Carolina *in* "Effects of Changes in Stratospheric Ozone and Global Climate," Vol. 4, United Nations Environment Program and the United States Environmental Protection Agency (1986).
9. P. Hendershott, Are real housing prices likely to decline by 47 percent?, *Regional Sci. Urban Econom.* **21**, 553–563 (1991).
10. Intergovernmental Panel on Climate Change, "Climate Change: The IPCC Second Scientific Assessment," Cambridge Univ. Press, Cambridge, MA (1992).
11. N. Mankiw and D. Weil, The baby boom, the baby bust, and the housing market, *Regional Sci. Urban Econom.* **19**, 235–258 (1989).
12. D. MacDonald, J. Murdoch, and H. White, Uncertain hazards, insurance, and consumer choice: Evidence from housing markets, *Land Econom.* **63**, 361–371 (1987).
13. W. Nordhaus, To slow or not to slow, *Econom. J.* **101**, 920–937 (1991).
14. R. Park, J. Trahan, P. Mausel, and R. Howe, The effects of sea level rise on U.S. coastal wetlands, Appendix B to "The Potential Effects of Global Climate Change on the United States," U.S. Environmental Protection Agency Report to Congress (1989).
15. G. Parsons, The effect of coastal land use restrictions on housing prices: A repeat sales analysis, *J. Environ. Econom. Management* **22**, 25–37 (1992).
16. J. Peek and J. Wilcox, The measurement and determinants of single-family house prices, *AREUEA J.* **19**, 353–382 (1991).
17. J. Poterba, Tax subsidies to owner-occupied housing: An asset-market approach, *Quar. J. Econom.* **99**, 729–752 (1984).
18. P. Samuelson, Tax deductibility of economic depreciation to insure invariant valuations, *J. Polit. Econom.* **72**, 604–606 (1964).
19. J. Stiglitz, "Economics of the Public Sector," Norton, New York (1986).
20. J. Titus, R. Park, S. Leatherman, J. Weggel, M. Greene, S. Brown, C. Gaunt, M. Trehan, and G. Yohe, Greenhouse effect and sea level rise: The cost of holding back the sea, *Coastal Management* **19**, 219–233 (1992).
21. U.S. Environmental Protection Agency, "The Potential Effects of Global Climate Change on the United States," Report to Congress (1989).
22. J. Weggel, The cost of defending developed shoreline along sheltered waters of the United States from a two meter rise in mean sea level, Appendix B to "The Potential Effects of Global Climate Change on the United States," U.S. Environmental Protection Agency Report to Congress (1989).
23. G. Yohe, Depreciation and the conservation of energy, *Econom. Lett.* **2**, 275–279 (1976).
24. G. Yohe, The cost of not holding back the sea—economic vulnerability, *Ocean Shoreline Management* **15**, 233–255 (1989).
25. G. Yohe, The cost of not holding back the sea—toward a national sample of economic vulnerability, *Coastal Management* **18**, 403–431 (1990).
26. G. Yohe, Sorting out facts and uncertainties in economic response to the physical effects of global climate change, *in* "Assessing Surprises and Nonlinearities in Greenhouse Warming" (J. Darmstadter and M. Toman, Eds.), Resources for the Future, Washington, DC (1993).