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Valuing the Visual Disamenity of Offshore Wind Projects at Varying Distances from the Shore

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Valuing the Visual Disamenity of Offshore Wind Power Projects at Varying Distances from the Shore: An Application on the Delaware Shoreline

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ABSTRACT. *Several offshore wind power projects are under consideration in the United States. A concern with any such project is the visual disamenity it may create. Using a stated preference choice model, we estimated the external costs to residents of the state of Delaware for offshore wind turbines located at different distances from the coast. The annual costs to inland residents was $19, $9, $1, and $0 (2006 dollars) per household for turbines located at 0.9, 3.6, 6, and 9 miles offshore. The cost to residents living near the ocean was $80, $69, $35, and $27 per household for the same increments.* (JEL Q42, Q51)

I. INTRODUCTION

The United States derives about 70% of its energy for electricity from fossil fuel sources.[1] As regulators look to address climate change concerns and reduce dependence on foreign sources of oil, alternative energy sources appear increasingly attractive as a way to reduce global carbon dioxide (CO_2) emissions and increase the domestic supply of energy. Currently, wind power is the only utility-scale, renewable, low-CO_2 energy resource that is large enough to become a significant fraction of electric supply (Kempton et al. 2005). Approximately 24,000 megawatts (MW) of new wind power capacity was installed over the past three years, breaking all previous records and increasing the nation's total wind power generating capacity to over 35,000 MW in 36 states and making the United States the world leader in installed capacity. The American Wind Energy Association (AWEA 2009) estimated that wind power generated about 1.5% of the U.S. electricity supply in 2008, powering the equivalent of 5.7 million homes.[2] The Department of Energy has set a goal of 20% wind generation by 2030, including 54 gigawatts (GW) of offshore wind power (DOE 2008).

Although no wind turbines have been installed offshore in the United States, there are a number of proposals under consideration.[3] States such as Texas, Rhode Island, Delaware, Massachusetts, Michigan, Ohio, Wisconsin, Maine, Maryland, New York, New Jersey, Virginia, and North Carolina are all considering wind power development off their coastlines, with some issuing requests for proposals and sponsoring competitions to select preferred developers. The Bureau of Ocean Energy Management, Regulation, and En-

[1] Nuclear accounts for 20%, hydro 6.5%, and renewables 3.5%. See the U.S. Energy Information Administration at www.eia.doe.gov/.

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[2] See the American Wind Energy Association (AWEA) reports for data on the United States at www.awea.org/publications/reports. An additional 10,000 MW was added in 2009, enough generation capacity for an additional 2.4 million homes, bringing U.S. generation to 35,000 MW (AWEA 2010). By comparison, in 2008, wind power in the European Union accounted for about 4.2% of all electricity, and there was approximately 65,000 MW of capacity installed. Germany at 24,000 MW and Spain at 17,000 MW accounted for most of this capacity. See the European Wind and Energy Association (EWEA) at www.ewea.org/.

[3] It is a different story in Europe, where as of the end of 2009 there are 30 offshore wind projects accounting for more than 2,000 MW of installed capacity, with an additional 1,000 MW of capacity expected to be installed in 2010 (EWEA 2010).

forcement (formerly Minerals Management Service), the federal agency in charge of regulating offshore wind power, finished its final environmental impact statement for the Cape Wind Energy Project off of Cape Cod, Massachusetts, and recently published its Record of Decision to issue a commercial lease for the United States' first offshore wind facility. Additionally, the first power purchase agreement in the United States has been reached for a proposed wind power project off the Delaware coastline.

The visual disamenity of and possible environmental impacts associated with wind power projects often raise concerns in local communities considering such developments. The well-publicized public opposition to the Cape Wind Energy Project off of Cape Cod, Massachusetts, is perhaps the most recognized example of this concern (Firestone and Kempton 2007).

From an economic standpoint, as the benefits and costs of offshore wind power are considered, one should account for the potential visual disamenity of wind turbines located in seascapes valued for their natural beauty. Like pollutants from the burning of fossil fuels, or fear of accidents from the storage of nuclear wastes, visual disamenities associated with energy projects, including wind power, are externalities missed in the calculus of markets. From an efficiency standpoint, these external effects should be brought into the social accounting. Interestingly, the economics of offshore wind power is such that disamenity costs are almost certain to decline with increased distance from the coast in the nearshore environment, while transmission, construction, and maintenance costs typically rise with distance.

In this paper we present the results of a choice experiment designed to value the visual disamenity associated with wind turbines in the waters off the Delaware coast. This area of study is particularly interesting because it is favorable for wind power from a purely physical standpoint and has recently witnessed the first power purchase agreement for offshore wind power in the Americas. We conducted a mail survey over a stratified random sample of Delaware residents in the fall of 2006. We analyzed the choice data using random utility theory and found that disamenity costs decline with distance from the coast, level off at approximately nine miles, and are significantly higher for people living nearer the coast. A broader discussion of the survey results has been presented by Firestone, Kempton, and Krueger (2008) and Krueger (2008). We begin with a brief review of valuation studies related to offshore wind power projects before presenting our model and results.

II. VALUATION STUDIES RELATED TO LOCATION OF OFFSHORE WIND POWER PROJECTS

Ladenburg (2009) provides a nice review of the valuation literature, limited as it is, on the location of offshore wind power projects. This section draws heavily from his review. Table 1 is a list of the relevant studies. Three of these, by Aravena, Martinsson, and Scarpa (2006) in Chile, Ek (2006) in Sweden, and McCartney (2006) in Australia, are concerned only with the value of the location of wind power projects in the broad sense of whether they are located offshore or onshore. For example, in the context of choice experiments, Aravena, Martinsson, and Scarpa (2006) and Ek (2006) ask households to consider wind power projects in mountain versus inland versus offshore locations. Neither give respondents specific geographic areas or specific distances at which the wind power projects would be located offshore. Both find a preference, all else constant, for locating wind power projects offshore compared to onshore locations. McCartney's (2006) study is different in that she gives respondents a specific geographic area, which happens to be a marine park. Given that setting, she finds a preference for onshore versus offshore locations of wind power projects. So, as one might expect, whether households prefer wind power projects onshore or offshore is likely to depend on *where* onshore or offshore they are located. While useful for broader policy deliberations, none of these studies helps along the lines of establishing the size of the disamenity effect at different distances offshore and hence the optimal siting for offshore wind power projects. The studies by Ladenberg and

TABLE 1
Stated Preference Studies Addressing Location of Wind Power Projects Offshore

Author(s)	Year Conducted	Resource Studied	Number of Respondents	Method	How Offshore Distance Gradient Was Valued
Aravena, Martinsson, and Scarpa 2006	2005	Wind power projects in Chile	$N=300$ Random draw of residents from metropolitan area of Concepcion	Choice experiment, pictures not shown, payment with cost of electricity	Compared wind power projects in mountains, along coast, inland, and offshore
Ek 2006	2002	Wind power projects in Sweden	$N=547$ Random draw of Swedish population	Choice experiment, mail survey, pictures shown, payment with electricity bill	Compared wind power projects in mountains, inland, and offshore
McCartney 2006	2004	Wind power project in Jurien Bay Marine Park, Australia	$N=96$ Local residents and tourists on-site during holiday weekend	Contingent valuation, in-person survey, pictures shown, payment with electricity bill	Compared wind power projects inland, on beach, and offshore
Ladenburg and Dubgaard 2007, 2009	2003–2005	Wind power projects in Denmark	$N=362$ Stratified random sample of Danish population (with targeting of areas with offshore wind power projects)	Choice experiment, mail survey, pictures shown, payment with electricity bill	Compared wind power projects located at 8, 12, 18, and 50 km offshore

Dubgaard (2007, 2009) are the only ones to date that provided preference data on the value of that disamenity gradient.

Ladenburg and Dubgaard (2007, 2009) conducted a choice experiment in a mail survey of 362 Danish residents. They considered offshore wind projects only. Their experiment posed different-sized wind projects at varying distances from shore (8, 12, 18, or 50 km) and at varying annual costs per-household (€0, €12.5, €23, €40, €80, or €175). They found that residents were willing to pay approximately $58, $121, and $153 per household per year (2006 dollars) to have a wind project located at 12, 18, and 50 km from the coast versus a baseline of 8 km. Respondents living near the coast, having a summer home on the coast, or engaging in recreational activities on the coast reported significantly higher values. Our analysis builds directly on this work. We consider a location in the United States, consider distances closer to the coast (as near as 0.9 miles [1.5 km]), use specific geographic areas, and use a more flexible econometric model.

Before moving on to our analysis it is worth noting that there are some wind power valuation studies of onshore locations and some examining wind power in the broader context of its acceptability versus other renewable energy sources. Some of these consider distance to residential areas and are of interest to our application. Meyerhoff, Ohl, and Hartje (2010) in Germany, for example, consider distances of 750, 1,000, and 1,500 m from residential areas and find that people indeed prefer that wind power projects be located further from away from their homes. Fimereli, Mourato, and Pearson (2008) have a similar finding in the United Kingdom. A recent hedonic study examining the effect of wind projects on property values found no statistically significant difference in sales price among homes located less than 3,000 feet, 3,000 to 5,000 feet, 1 to 3 miles, or 3 to 5 miles from the project, as compared to the reference case of greater than 5 miles (Hoen et al. 2009).

Other studies that address preferences for wind power in various contexts, but do not address the distance-value gradient or even onshore versus offshore value, include those by Hanley and Nevin (1999), Alvarez-Farizo and Hanley (2002), Bergmann, Hanley, and Wright (2006), Groothuis, Groothuis, and Whitehead (2008), Borchers, Duke and Parsons (2007), Navrud and Braten (2007), Bergmann, Colombo, and Hanley (2008), Dimitropoulos and Kontoleon (2009), and Koundouri, Kountouris, and Remoundou (2009). As noted, most of these examine preferences for wind versus other sources of renewable energy.

III. SURVEY

Our survey began with 12 semistructured interviews of Delaware residents to help us understand knowledge and perception of, and attitudes toward, energy issues. A pilot version of the mail survey was tested in person at the Department of Motor Vehicles in Wilmington, Delaware, on June 29–30, 2006. The pilot test was used to refine wording and survey format, to ensure that respondents understood the questions, to test the layout and usefulness of a map and photo prop, to gather information on whether respondents perceived the survey instrument to be biased, and to see if the survey was appropriate in length. In particular, the test was critical to ensure that the choice experiment section was understandable and realistic, that the attributes chosen and the range of their corresponding levels were appropriate, that the respondents could understand and properly complete the choice experiment questions, and that the questions were producing usable data.

The final version of the survey has four sections. The first covers attitudes and opinions concerning wind power and the possibility of having offshore wind power in Delaware. The second contains the choice experiment in which respondents are asked to choose among two different offshore wind power scenarios and an opt-out fossil fuel power scenario. The choice experiment is described in detail in the next section. The third and fourth sections cover beach use and demographics. The protocol for survey construction, testing, and administration followed Dillman's tailored design method (Dillman 2000) as closely as possible, given time and budget constraints.

From September 9 to September 20, 2006, we mailed 2,000 surveys to a stratified random sample of Delaware households. The three strata are (1) households living in census block groups bordering the Atlantic Ocean, (2) households living in census block groups bordering Delaware Bay, and (3) all other households in the state. The initial sample from each of these strata was 400, 400, and 1,200, respectively. Each mailing included (1) a cover letter describing the survey and why the addressee's participation was important, (2) the survey booklet, (3) a map and photo simulations prop, and (4) a stamped return envelope. Three weeks after the initial mailing, reminder postcards were sent out to thank all respondents for their participation and to remind those respondents who had not yet completed their survey to promptly do so. Following the postcard reminder, a second mailing of 1,250 surveys was sent between October 28 and October 30, 2006, to those individuals who had not yet returned their original completed surveys. These packets contained a modified cover letter reaffirming the importance of the study, reminding respondents of the confidentiality of their answers, and asking respondents to take a few minutes to complete and mail back the survey.

A total of 949 returned surveys were used in our final analysis. After accounting for bad addresses and for deceased and otherwise incapacitated respondents (based on statements made by relatives), the response rate was 52%. Table 2 provides some descriptive data on the sample population. Survey respondents were more likely to be male, older, and wealthier than the overall Delaware population. For additional detail on survey development see Firestone, Kempton, and Krueger (2008, 2009) or Krueger (2008).[4]

IV. CHOICE EXPERIMENT

Each respondent faced three hypothetical referenda in our choice experiment. Figures 1

[4] The entire survey including the wind turbine visual is available at www.ceoe.udel.edu/windpower/docs/FinalDNRECOpinionReport.pdf.

TABLE 2
Sample Means over Key Respondent Characteristics

	Inland	Bay	Ocean
Sample Size	564	203	182
Age	57	61	61
Percent retired	33.7	42.4	48.4
Household income[a]	\$50,000–\$75,000	\$50,000–\$75,000	\$100,000–\$150,000
Gender (percent male)	68.1	69.5	69.7
Mean distance from nearest beach	35 miles	4 miles	0.6 miles
Average number of days per year spent at the beach	14	76	104
Percent who have seen a wind turbine	54.3	59.4	72.9

[a] Median values.

Offshore Wind Power in Delaware

Assume Delaware needs to increase its energy supply by 20% and that you have the opportunity to vote on energy development options. One way to meet the energy demand would be to place a 500-turbine wind farm offshore. Another option would be to continue Delaware's current energy policy and obtain additional energy from a new plant that burns coal or natural gas.

Because wind energy uses no fuel, your electric bill would not increase over time due to higher fuel cost; however, like other sources of electricity, it could increase for other reasons. To offset the initial costs of providing wind energy to Delaware residents, assume that there would be a **"Renewable Energy Fee"** added **each month** to your electric bill, for the first **three years** only.

We are now going to ask you three questions where you get to vote on wind power development. For each question, assume the option that receives the most votes will be carried out.

Continue on and vote→→→

FIGURE 1
Preamble to Choice Experiment Section

and 2 show the preamble and an example question. Respondents were asked to consider a scenario in which Delaware would be expanding its power capacity to meet future energy needs. Respondents were then asked to consider three development scenarios: two offshore wind options and a status quo option of expanding natural gas or coal power. The attributes for the two wind options and their levels are shown in Table 3. These were selected based on a review of current regulatory policy and pertinent literature and from insight gained during semistructured interviews. People were told in the preamble leading up to the choice questions that 500 turbines would be placed offshore. This was held constant throughout the experiment and was consistent with the size of the wind power project actually being considered. The project size is 450 MW.

The first attribute is the location of the wind power project. In Delaware, there are three logical areas: Delaware Bay, the northern Atlantic coast (adjacent to the town of Rehoboth Beach), or the southern Atlantic coast (adjacent to the town of Fenwick Island). We used these three areas for candidate locations and provided respondents with the map shown in Figure 3.

The second attribute is distance from shore. We provided a range of realistic distances based on current technological limitations and on existing proposals for offshore wind power projects off other parts of the U.S. Atlantic

18. Now, for which option would you vote?

Refer to the Delaware map insert for the "wind farm location." Refer to the ocean photo insert for simulated views of the wind farm at different distances.

	Option A	Option B	Option C
Wind farm location	Ocean (South)	Ocean (North)	No wind power Expansion of coal or natural gas power
Distance from shore	0.9 miles	6 miles	
Annual rent/royalty	$1 million to Beach Nourishment Fund	$8 million to Beach Nourishment Fund	
Renewable energy fee on your monthly electricity bill for 3 years	$1	$20	

I would vote for …

- □ Option A
- □ Option B
- □ Option C

FIGURE 2
Sample Choice Experiment Question

coast. A page with photo simulations was included to help respondents visualize changes that would occur to the seascape if wind turbines were to be placed at different distances from shore. The unusual increments (e.g., 0.9 instead of 1.0 miles) correspond to actual distances under consideration. In all cases the wind turbines shown were 440 feet high. The nacelle was 258 feet high and the blades extended that to 440 feet. These were also the turbines actually being considered for the Delaware project.

The third and fourth attributes are the type of royalty fund and the amount of payment in the fund. We used Delaware's existing Green Energy Fund (which subsidizes home solar

TABLE 3
Attributes and Levels for the Choice Experiment

Attribute	Levels
Location of wind farm	Delaware Bay; Rehoboth Beach; Fenwick Island
Distance from shore (miles)	0.9; 3.6; 6; 9; too far out to see
Royalty fund	Beach nourishment fund; Delaware green energy fund; Delaware general fund
Renewable payment	$1 million; $2 million; $8 million
Renewable energy fee	$0; $1; $5; $10; $20; $30

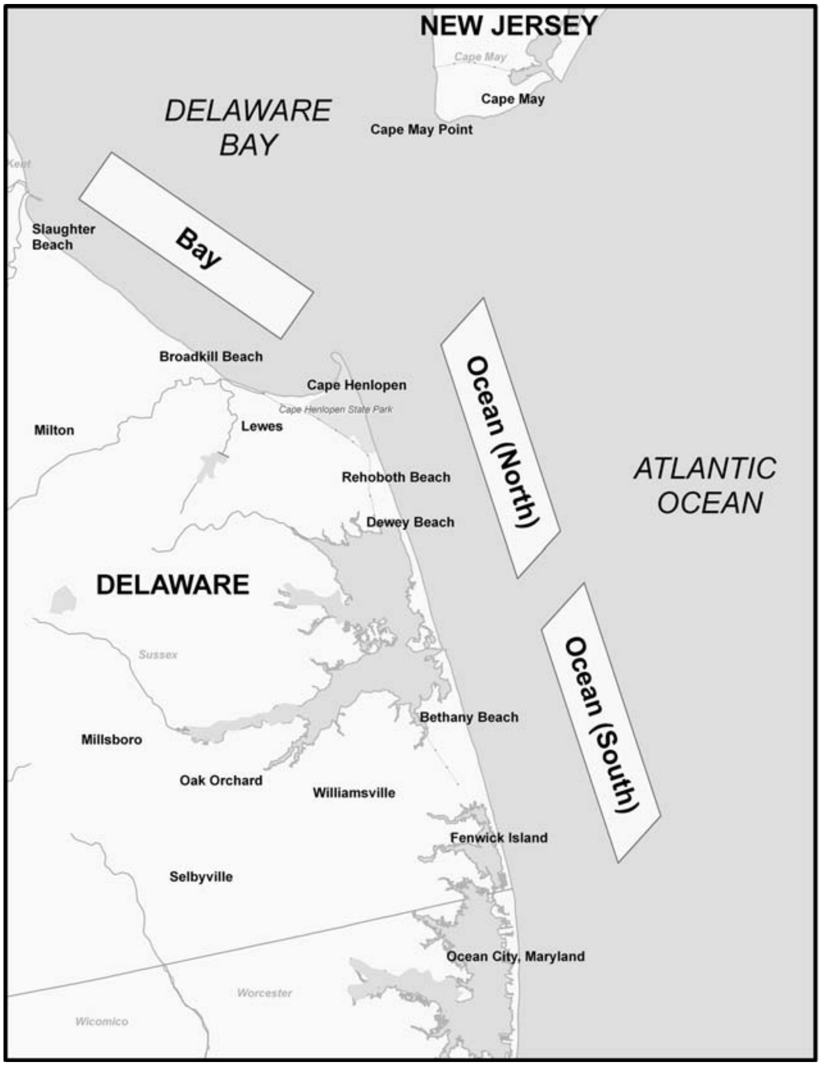

FIGURE 3
Delaware Map Depicting Hypothetical Offshore Wind Development Areas

and wind power, among other things), the State General Fund, and a hypothetical Beach Nourishment Fund. We included the latter to test whether individuals living near the coastline would be more willing to accept a visual disamenity from wind turbines if a nearby beach benefits from the collected revenues. The range of royalty revenues to be collected by the state was based on low and high estimates of other onshore and offshore wind project royalty payments.

The final attribute is a renewable energy fee, which was used as the payment vehicle. It was chosen because it is related to the delivery of the electricity, was believable in our pretests, and is easily understood. We used a monthly payment period of 3 years. The ranges were determined based on the pretest.

The five attributes and their corresponding levels, presented in Table 3, result in 810 possible treatment combinations. We used an orthogonal main effects only design to generate

TABLE 4
Twenty-Five Choice Combinations Used in the "Tailored" Choice Question

Survey Version	Option A		Option B		Options A and B	
	Distance	Fee	Distance	Fee	Royalty	Fund
1	0.9 miles	$0	TFTS	$5	Green	$2 M
2	0.9 miles	$1	9 miles	$10	Beach	$8 M
3	0.9 miles	$5	6 miles	$20	Green	$8 M
4	0.9 miles	$10	3.6 miles	$30	Beach	$2 M
5	0.9 miles	$20	TFTS	$30	General	$1 M
6	3.6 miles	$0	6 miles	$10	Green	$1 M
7	3.6 miles	$1	9 miles	$20	Beach	$1 M
8	3.6 miles	$5	TFTS	$10	General	$8 M
9	3.6 miles	$10	6 miles	$20	General	$2 M
10	3.6 miles	$20	9 miles	$30	Green	$2 M
11	6 miles	$0	9 miles	$1	Beach	$8 M
12	6 miles	$1	TFTS	$30	Green	$1 M
13	6 miles	$5	9 miles	$30	Green	$8 M
14	6 miles	$10	TFTS	$30	Beach	$1 M
15	6 miles	$20	9 miles	$30	Beach	$2 M
16	9 miles	$0	TFTS	$20	General	$1 M
17	9 miles	$1	TFTS	$5	General	$2 M
18	9 miles	$5	TFTS	$20	General	$8 M
19	9 miles	$10	TFTS	$20	Beach	$2 M
20	9 miles	$20	TFTS	$30	Beach	$8 M
21	0.9 miles	$5	3.6 miles	$10	Green	$8 M
22	3.6 miles	$10	6 miles	$30	Beach	$1 M
23	6 miles	$5	9 miles	$20	Green	$1 M
24	0.9 miles	$10	TFTS	$20	General	$2 M
25	3.6 miles	$1	9 miles	$10	Green	$2 M

Note: M, million; TFTS, too far out to see.

25 choice experiments for two of the three choice questions using standard SAS macros and following Hensher, Rose, and Greene (2005). The other choice question was designed to focus specifically on the trade-off between distance from shore and willingness to pay. In this question, the respondent was presented with two offshore wind power development options that were identical in every respect except that they were at two different distances from shore, with the further distance always having a higher fee. The levels of the other attributes varied across respondents but were held constant in each choice experiment. We tailored one choice question in this way because of our focus on estimating the value of the distance gradient. This question gave respondents a choice that focused on that trade-off. The question also did well in discussions with respondents following the pretests. The pairings used for our tailored question are shown in Table 4. While there is no doubt room for added statistical efficiency in the design, our format introduces no bias and, given the standard errors on our estimates, which we discuss shortly, there appears to be adequate statistical efficiency.[5]

V. RUM MODEL

We modeled the choices made by respondents using a conventional random utility maximization (RUM) model. In the model each individual n faces a decision among a set of three alternatives: two wind projects (i = 1,2) and the status quo expansion of fossil fuel power (i = 0). Random utilities are given as

$$\begin{aligned} U_{ni} &= \boldsymbol{\beta}\mathbf{x}_{ni} + \boldsymbol{\alpha}\mathbf{y}_n + \varepsilon_{ni} \qquad (i = 1,2) \\ U_{n0} &= \varepsilon_{n0} \end{aligned}, \qquad [1]$$

[5] See Ferrini and Scarpa (2007) for more on design strategies that might be used in further research along these lines.

where the first expression is the utility for individual n for one of the two wind projects i, and the second is the utility for the status quo option (coal or natural gas). $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}$ are parameter vectors to be estimated, $\mathbf{x}_{ni}$ is a vector of project attributes, $\mathbf{y}_n$ is a vector of individual attributes, and ε_{ni} is a random error term. An individual is assumed to choose the alternative i that gives the highest utility. In a RUM model that choice can be explained only up to the *probability* of alternative i being chosen. We used mixed logit in estimation to allow for a fairly general pattern of correlation among the error terms in equation [1]. We considered normal and triangular mixing distributions over most parameters, but ended up employing normal distributions in all cases. The results were not sensitive to this choice. We used Halton draws in our simulation and found that the parameters stabilized around 500 draws. We allowed for correlation among each respondent's error terms (one for each question) by making the Halton draws person specific instead of choice specific. Separate models were estimated for the inland, bay, and ocean populations. The theory and approach are well known and fully developed by Train (2003) and Louviere, Hensher, and Swait (2000).

In our application, the wind power project disamenity is measured using a set of four dummy variables representing the different distances offered in the choice experiment: 3.6 miles, 6 miles, 9 miles, and too far away to see under any lighting conditions (estimated at 20 miles). Because the nearest distance offered (0.9 miles) is the excluded variable, these coefficients capture a utility increase for having the wind power project at each distance relative to that nearshore location.

The external cost of wind turbines at any location d versus having them out of sight is

$$v_d = \frac{1}{R}\sum_{r=1}^{R}\frac{\beta^r_{\mathrm{TFTS}} - \beta^r_d}{-\beta_{\mathrm{fee}}}, \quad [2]$$

where β^r_{TFTS} is the coefficient on distance at "too far to see" and β^r_d is a coefficient on a distance dummy variable (d = 0.9, 3.6, 6, 9) in the $\mathbf{x}_{ni}$ vector; $\beta^r_{0.9} = 0$ since it is the excluded variable in estimation. β_{fee} is the estimated coefficient on the fee variable, which is fixed in estimation and is a measure of the marginal utility of income. Because the distance coefficients are estimated as random parameters, the ratios also are random and are thus calculated as simulated means. The superscript r on β^r_{TFTS} and β^r_d signifies that the coefficient is one of R draws from the estimated distribution of β^r_{TFTS} and β^r_d. We use $R = 5{,}000$ in our application.

VI. ESTIMATION RESULTS

Estimation results are shown in Table 5. As noted earlier, separate models were estimated for the inland, bay, and ocean populations.[6] The results are more or less as expected. The coefficient on fee is negative and statistically significant in all three models, so the likelihood of choosing one of the wind alternatives declines as the fee increases. There also is a clear preference for the wind power project being located further from the coast. The coefficients on all of the distance variables are positive and statistically significant. Generally, the sizes of the coefficients rise at a declining rate as you move away from the coast in all three models, although the distance coefficient in the inland model peaks at 9 miles and then drops somewhat at "too far to see." The relative size of these coefficients is significantly larger in the bay and ocean models, implying, as expected, greater disutility for those living near the coast. We discuss implicit values from these coefficients in the next section.

Model results indicate no clear preference for the location of a wind power project at the two ocean and one bay locations offered. The coefficients on Rehoboth Beach, Fenwick Island, and Delaware Bay are not statistically significantly different from one another in any of the models. In one section of the survey, respondents were asked directly to choose whether they preferred a certain location for offshore wind development. Descriptive sta-

[6] When tested against a pooled model that constrained parameters to be constant across these three groups, the pooled model was easily rejected in favor of the split models.

TABLE 5
Mixed Logit Estimation Results

	Inland		Bay		Ocean	
Variable	Parameter	p-Value	Parameter	p-Value	Parameter	p-Value
Random parameters (means)						
Bay	6.25****	0.000	5.60	0.112	− 3.91**	0.050
Rehoboth Beach	6.22****	0.000	6.57*	0.080	− 4.64**	0.024
Fenwick Island	6.37****	0.000	7.17*	0.066	− 4.78**	0.019
Distance 3.6	1.05****	0.000	2.58***	0.006	0.62	0.780
Distance 6	1.90****	0.000	3.28**	0.010	2.29****	0.000
Distance 9	2.39****	0.000	3.60***	0.004	2.72****	0.000
Distance too far to see	1.93****	0.000	4.00***	0.009	4.14****	0.000
Green Energy Fund	0.53**	0.024	1.35	0.166	0.12	0.835
Beach Nourishment Fund	0.78***	0.001	0.22	0.729	0.76	0.106
Royalty $2 million	− 0.54***	0.010	− 0.21	0.754	0.26	0.560
Royalty $8 million	− 0.57**	0.030	− 0.12	0.856	− 0.56	0.295
Fixed parameters						
Fee	− 0.11****	0.000	− 0.12***	0.005	− 0.05***	0.005
Income	0.002	0.492	− 0.01	0.110	0.002	0.495
Some college education	0.59	0.193	− 1.31	0.503	0.36	0.765
Four-year college degree	− 0.60	0.139	− 5.51**	0.021	− 0.19	0.858
Post grad degree	− 1.93****	0.000	− 2.79	0.180	− 0.44	0.678
Age	− 0.07****	0.000	− 0.04	0.423	0.03	0.258
Male	− 0.14	0.640	0.26	0.799	− 0.78*	0.089
Retired	0.52	0.246	0.92	0.520	0.72	0.200
Delmarva	− 0.45	0.172	4.96**	0.019	NA	NA
See ocean	3.39***	0.007	− 0.24	0.884	0.56	0.459
Distance from beach	0.01**	0.046	− 0.11*	0.069	2.49***	0.001
Beach days	0.003	0.650	0.001	0.833	0.003	0.150
Seen a turbine	0.46	0.130	3.05**	0.034	1.48***	0.007
Beach house	− 0.47	0.443	NA	NA	NA	NA
Random parameters (dispersion)						
Bay	1.85**	0.010	0.25	0.872	5.14*	0.057
Rehoboth Beach	0.76	0.373	6.89**	0.011	3.85***	0.0010
Fenwick Island	1.14**	0.046	4.45**	0.015	0.04	0.975
Distance 3.6	1.66**	0.044	0.26	0.840	10.35	0.283
Distance 6	2.19***	0.002	5.26	0.101	0.33	0.899
Distance 9	1.49**	0.024	1.26	0.461	0.81	0.554
Distance Too Far To See	0.01	0.994	5.41**	0.043	1.99	0.189
Green Energy Fund	1.25*	0.098	3.44	0.226	1.13	0.340
Beach Nourishment Fund	1.65***	0.001	2.08	0.176	0.01	0.985
Royalty $2 million	0.78	0.202	0.17	0.921	0.09	0.947
Royalty $8 million	1.58***	0.004	0.78	0.626	0.05	0.953
Number of observations (respondents)	1,692 (564)		609 (203)		546 (182)	
Log likelihood value	− 1,401.152		− 454.8983		− 442.3946	

Note: NA, not applicable.
* Significant at the $\alpha = 0.1$ level of confidence; ** significant at the $\alpha = 0.05$ level of confidence; *** significant at the $\alpha = 0.01$ level of confidence; **** significant at the $\alpha = 0.001$ level of confidence.

tistics show that significantly more respondents prefer wind power development in the ocean (40%) than in Delaware Bay (16%); although a plurality (45%) expresses no preference (Firestone, Kempton, and Krueger 2008).

Respondents prefer that royalty funds from wind power go to targeted funds rather than to general revenues: the coefficients on the beach nourishment and green energy funds are positive in all three models (the general state fund being the excluded category). The coefficients show significance only in the inland model. The implied willingness to pay by inland residents to have funds distributed to the beach nourishment and green energy funds versus the state's general fund is about $7 and $5 per month for 3 years. At the same time, the variables for the amount of the royalties give counterintuitive results: negative and significant coefficients in the inland model and negative but insignificant coefficients in the other models in three of the possible four cases. Because a $1 million royalty is the excluded category, the $2 million and $8 million royalty variables represent higher payments and would presumably be utility enhancing. The insignificant results in the bay and ocean models suggest that the amount of royalties collected is not important to individuals. For the inland model, the negative coefficients suggest a dislike for royalty payments to the state. Perhaps respondents perceive that royalty payments might increase the actual cost of delivered energy, or that such payments might hamper development of offshore wind power, or they distrust the state with such funds.

We estimated all of the parameters on the individual characteristics as fixed. Initially we experimented by interacting individual characteristics with the distance variables to see if there might be preference variation along these lines, but detected none. Even as simple shifters of preferences for wind over fossil fuel power, which the parameters in Table 5 show, the demographic variables have only modest explanatory power.

Consider the variables that show some statistical significance. The distance one lives from the coast is the only variable that is significant or borderline significant in all three models, but the results across models are inconsistent. The probability of choosing offshore wind over fossil fuel power sources increases with the distance one lives from the coast for the inland and ocean samples, but decreases for the bay sample. Distance away from the beach in the ocean sample is a large predictor of voting in favor of wind power. With each additional *quarter* mile away from the coast that a household is, we find that willingness to pay increases by about $12. Although significant for the inland sample as well, that value is only about 90 cents per *10 miles*. For these models, then, value increases by either moving the turbines away from people or moving people away from turbines. The bay sample willingness to pay decreases with distance from the coast by about $1 per mile with statistical significance.

We also wanted to test whether preferences differed between households that had an ocean or bay view and those that did not. One might expect the parameter (*See ocean*) to be negative and statistically significant, but such was not the case in our results. Indeed, for the small population of residents living inland but having a view (7%) of the ocean or bay, they showed a preference in favor of wind.

Having seen a wind turbine at some time in one's life increases the probability of voting for an offshore wind option in all three models and with significance in the bay and ocean models. Braunholtz (2003) found that those who most frequently saw wind power projects on their day-to-day routine were most favorable toward them. Our results may imply that those who have not seen turbines before may envision a far more objectionable visual impact than is actually the case. Or, they may imply that those who favor this type of technology are more likely to have made an effort to view turbines in some setting.

Finally, over the inland sample, whose numbers dominate Delaware's population, the probability of favoring wind over fossil fuel sources of power decreases with education and age. The education result holds weakly in the bay and ocean models, and the age result does not hold. For the most part, then, our results show only modest observed heterogeneity along the lines noted above and suggest that people's preferences for offshore wind versus fossil fuel sources are not easily classified demographically. Perhaps most interesting among the variables with little significance is the coefficient on number of days an individual spent at the beach over the last year. It is positive but insignificant in all models, suggesting the impact on in-state visitors to the shore may not be significantly larger than on the general population.

While there is limited observed heterogeneity, there is a reasonable degree of unobserved heterogeneity realized through the dispersion measures on the random parameters. This is most evident in the inland model, as one might expect, since this is the most diverse of the sampled populations. Eight of the 11 estimated standard errors are signifi-

TABLE 6
External Cost per Household for Wind Turbines Located a Different Distances Offshore

	External Costs Annually in Perpetuity			External Costs Monthly for 3 Years		
Distance	Inland	Bay	Ocean	Inland	Bay	Ocean
0.9	$18.86	$34.39	$80.03	$17.99	$32.78	$76.30
3.6	8.74	11.17	68.79	8.34	10.64	65.59
6	0.78	5.83	35.10	0.75	5.55	33.47
9	0[a]	2.06	26.65	0[a]	1.96	25.41

[a] Value is slightly negative in estimation.

cant for this model. There is strong evidence of variation in the preferences of inland residents for the view disamenity, the allocation of royalty funds, and the size of the royalty funds. The sizes of the standard errors, relative to their means, on the royalty funds and the royalty amounts suggest particularly wide variation in preferences for these attributes, with some residents favoring, and some opposing, targeted funds. And finally, the size of the dispersion terms for the location variables in the bay and ocean models stand out, showing strong variability in the wind power preference and for the location of turbines among the coastal samples.

VII. THE EXTERNAL COST OF TURBINES AT DIFFERENT DISTANCES OFFSHORE

Table 6 shows the estimated external cost of wind turbines located at different distances from the coastline. The values are shown separately for the inland, bay, and ocean samples. All estimates are per household in 2006 dollars and are shown in annual values in perpetuity and monthly values for 3 years. The estimates were calculated using equation [2]. The annual values in perpetuity were converted from the 3-year monthly values using a discount rate of 3%.

The external cost for each of the three population groups decreases with distance from the coast. The further a wind project is located from the shore, the lower the disamenity effect. The values for the ocean sample are largest, followed by the bay and inland samples. The external costs per household per year for the inland population are $19, $9, $1, and $0 at 0.9, 3.6, 6, and 9 miles. The external costs for the bay residents for the same distances are $34, $11, $6, and $2, and the values for the ocean residents are highest at $80, $69, $35, and $27. The external costs captured in our estimates may include more than visual disamenity. In some cases people may be expressing, for example, a concern over the conflict of turbines with recreational boaters and fishers in the nearshore area.

As we noted earlier, Ladenburg and Dubgaard (2007, 2009) provide the only other published estimate of willingness to pay to move wind turbines further offshore. Figure 4 overlays their estimated values with ours.[7] Their values are higher and persist at greater distances from shore. One explanation might be the size of the wind turbines. We use simulations of wind turbines with the nacelle at 258 feet, and blades extending to 440 feet above the ocean; they use larger, next-generation wind turbines, with the nacelle at 328 feet, and blades extending to 520 feet.[8] At the

[7] Note: The value for Inland sample at 9 miles actually goes slightly negative in estimation. The distance "too far to see" is shown at 20 miles, which seems to be the greatest distances at which a modern offshore wind turbine could be visible from shore under even the clearest of conditions. Our project has 500 turbines each 440 feet high and is located in Delaware. Ladenberg and Dubgaard's project has approximately 700 turbines each 520 feet high and is located in Denmark. Ladenburg and Dubgaard's estimates are for a random sample of all residents (after adjustment for stratification), including some with and some without a view of the coast. Also, the closest view in our experimental design was 0.9 miles; Ladenburg and Dubgaard's was 8 km (about 5 miles).

[8] They also use a larger wind project—700 versus 500 wind turbines—but each simulated project is very large, so large in fact that they are each significantly larger than any

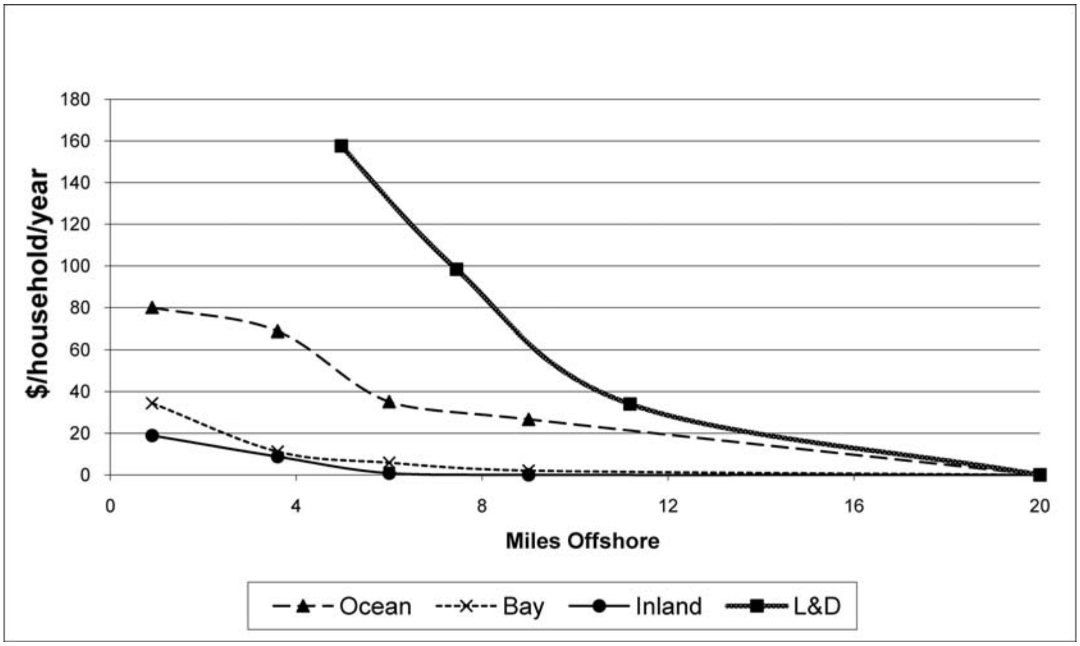

FIGURE 4
External Cost per Household for Wind Turbines Located at Different Distances Offshore with Ladenburg and Dubgaard (L&D) Results Overlaid, in 2006 Dollars

same time, the differences may be due simply to differences in the Danish and U.S. populations, differences in the timing of the studies relative to development (their study occurred after the installation of a large offshore wind power project of approximately 70 wind turbines), or differences in study design. On the last point, for example, we use a monthly payment period over 3 years and they use an annual payment that continues indefinitely. Also, we include an opt-out alternative that allows a respondent to choose neither wind project; their design includes no opt-out alternative.

One caveat worth noting in our findings is that the maximum monthly fee offered in our choice experiment ($30) was well below our predicted values in monthly terms for the ocean population. While our parameter estimates on the distance variable are significant in the ocean model and the stepwise values have the order one would expect, we are predicting values outside the range of our data and hence have somewhat lower confidence in these numbers. All of our pretests were done on inland populations, which led us to a range of prices that worked in the bay and inland samples but were on the low side for the ocean population. This was simply a mistake in our pretest design.

Aggregate values for the state of Delaware at 0.9, 3.6, 6, and 9 miles are $7.6 million, $4.2 million, $1.1 million, and $870,000 annually in perpetuity. This is the external cost to all Delaware residents at each distance. The number of households for each area (inland 282,691, ocean 22,579, and bay 12,369) was obtained using 2007 U.S Census Bureau statistics.

The estimated values, of course, ignore the effects on visitors to the shore, many of whom are out-of-state visitors from New Jersey, Maryland, Virginia, Pennsylvania, and the Washington, D.C., area (Lilley, Firestone, and Kempton 2010). Because there are about 1.3

project now in existence. We do not feel this difference explains the disparity in results.

million out-of-state visitors each year to the Delaware shore (DEDO 2007), this value is potentially large. Ladenberg and Dubgaard (2009), for example, find that recreational boaters and anglers have higher external costs than other populations. But, there is also evidence that wind turbines may attract more tourists than they dissuade, so there may be positive amenity effects to account for as well (Lilley, Firestone, and Kempton 2010).

VIII. CONCLUSIONS

Offshore wind power is a promising alternative energy source that has gained considerable attention recently given the size of the resource, concern over climate change, health impacts of air pollutants from conventional energy sources, and degree of domestic control over global fossil fuel stocks. While nearly free of the textbook external effects of pollution (NAS 2010), offshore wind power, like any other energy facility or transmission line, has external effects in the form of a visual disamenity.

Using stated preference data over households in the state of Delaware, we estimated the economic value associated with the visual disamenity from wind turbines at various distances off the coast. Our results pertain to a wind power project with 500 turbines each 440 feet high (about 450 MW). The results are shown in Figure 4. We estimate that inland residents have an external cost of $19, $9, $1, and $0 annually in perpetuity (2006 U.S. dollars) for wind turbines located at 0.9, 3.6, 6, and 9 miles offshore. Respondents living on the ocean have external costs of $80, $69, $35, and $27 at the same distances. Aggregated statewide, the external costs at these distances are $7.6, $4.2, $1.1, and $0.9 million per year. Keep in mind that these costs exclude the disamenity (and amenity) effects on out-of-state visitors to the Delaware coast and residents from nearby states such as Maryland.

Looking back at Figure 4, perhaps the most striking finding of this study is the descent of disamenity values after 6 to 9 miles offshore. The conventional wisdom, without much information on external costs, has been that turbines should be located outside the viewshed. Given the sizable cost savings associated with moving turbines closer to shore, our results may call this conventional wisdom into question. For example, based on rough estimates for other projects in the United States, the cost savings of moving the wind project currently under consideration in Delaware from outside the viewshed to 9 miles is likely to range between $7 to $20 million per mile. By comparison the external costs of moving the project over the same range is about $8 to $10 million per mile. So, the numbers are close. The external costs exclude tourists and residents in nearby states, so these numbers will be larger. At the same time, our estimates for the cost of moving turbines closer are based on projections for past projects and may decline with technological advancement. Taken together these adjustments would lower transmission cost and raise visibility costs, suggesting that moving turbines outside the viewshed or perhaps nearer the proposed distance of 13 miles may make sense. But again, these numbers are rough, and getting sharper estimates on both sides would be useful for policy.[9]

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[9] The cost estimates are derived from Wright et al. (2002), who reported costs for projects in Rhode Island and Maine. Their numbers are per megawatt. Our estimates for disamenity values convert annual losses to discounted present values (to be compared with Wright et al.'s numbers) using a 3% discount rate.

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