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Economies of scale, learning effects and offshore wind development costs

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ABSTRACT

This paper presents a model of overnight development costs for offshore wind projects and tests for the presence of economies of scale and learning effects. Both industry-wide and country-specific learning effects are analyzed. Recently, "pilot projects" have been proposed in states such as Maine and New Jersey with the hope of inducing cost savings in future larger utility scale projects. Therefore the impact of country-specific learning effects are of particular importance.

The dataset used in the analysis consists of forty-one European offshore wind projects. Research findings do not suggest that the costs exhibit economies of scale, nor do we find robust evidence of either industry-wide or country-specific learning effects.

1. Introduction

The world's first offshore windfarm (OSW), Vindeby, was completed in 1991 in Ravnsborg, Denmark. Vindeby has a total capacity of five Mega Watts (MWs) and is composed of eleven turbines. Since 1991, forty additional OSWs have been constructed in eight different European countries including Denmark, Sweden, the Netherlands, the United Kingdom, Germany, Ireland, Belgium and Finland. Recently, there has been interest in developing offshore wind in the United States, as there are currently nine OSW projects totaling over 2,300 MW of total capacity in the permitting and development process in the United States [15]. These projects are all located in the northeast, specifically concentrated primarily in New Jersey, Deleware, Rhode Island, and Massachusetts. In particular, some of these proposed projects are considered "pilot projects" with relatively expensive price tags, in hopes that the lessons learned from these projects will lead to a decrease in the cost of future large utility scale projects.

While a great deal of interest in offshore wind exists, there are currently no OSWs in operation in the United States as all of the current projects are still absorbed in the approval and financing stages. It is still uncertain if any of these projects will be completed. Two reasons are cited for this holdup; (1) relatively high cost of offshore wind compared to other forms of energy, and (2) difficulty in receiving permitting [15]. These two issues are interrelated, though, as relatively expensive projects are less likely to receive approval than relatively less expensive projects [14].

Currently, there is no consistent methodology available for comparing the cost of a proposed off-shore wind project to other similar off-shore wind projects around the world as this is not straightforward for a variety of reasons. First, different areas have different physical characteristics, and these heterogenous conditions can have a potentially large impact on costs. For instance, sites with deeper water or sites that are further from shore might be inherently more expensive to develop. If these physical characteristics impact the cost, then they need to be taken into account when comparing windfarm costs.

The second reason that comparing costs across OSWs is especially difficult is because economic environments in which existing OSWs were built are heterogeneous. The forty-one OSWs that are currently in operation were built in seven different countries over a twenty year period. Not only does a country face changing costs over time, but also different countries might have vastly different costs in the same time period. Furthermore, some of these OSWs were built in a few months while others were under construction for multiple years. This heterogeneity also needs to be taken into account when comparing projects.

This paper will combine three different literature. First the paper will calculate the cost of each OSW on an "apples to apples" basis. This will be referred to as the "overnight cost," or the estimated cost if the OSW were to be built overnight. This overnight cost is a function of the interest rate, inflation rate and construction

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Table 1
Windfarm information.

Windfarm	Country	Year Completed	Capacity (MW)	Depth (m)	Distance to shore (km)
Vindeby	Denmark	1991	5	3.5	1.8
Lely	Netherlands	1994	2	7.5	0.8
Tuno Knob	Denmark	1995	5	4	5.5
Irene Vorrink	Netherlands	1996	17	2.5	0
Bockstigen	Sweden	1998	3	6	4
Utgunden	Sweden	2000	10	8.6	4.2
Blyth	United Kingdom	2000	4	8.5	1
Middlegruden	Denmark	2001	40	6	2
Yttre Stengrund	Sweden	2001	10	8	2
Horns Rev	Denmark	2002	160	10	14
Nysted	Denmark	2003	158	7.75	10
Samso	Denmark	2003	23	20	3.5
Arklow	Ireland	2004	25.2		11.7
North Hoyle	United Kingdom	2004	60	12	7
Scoby Sands	United Kingdom	2004	60	16.5	2.5
Kentish Flats	United Kingdom	2005	90	5	10
Barow	United Kingdom	2006	90	17.5	7.5
Kemi Ajos Phase I	Finland	2007	15	6	5
Egmond aan Zee	Netherlands	2007	108	18	10
Lillgrund	Sweden	2007	110	7	10
Beatrice	United Kingdom	2007	10	45	22
Burbo Bank	United Kingdom	2007	90	5	6.5
Prinses Amaliawindpark	Netherlands	2008	120	21.5	23
Lynn/Inner Downsing	United Kingdom	2008	97	9.5	5
Thronton Bank	Belgium	2009	30		28
Horns Rev 2	Denmark	2009	209	13	31.7
Rhyl Flats	United Kingdom	2009	90	7.5	10.7
Robin Rigg	United Kingdom	2009	180	5	9
Belwind Phase 1	Belgium	2010	165	22.5	46
Rodsand II	Denmark	2010	207	10	9
Alpha Ventus	Germany	2010	60	45	56
Gunfleet Sands	United Kingdom	2010	173	6.5	7
Thanet	United Kingdom	2010	300	18.5	12
Avedore Holme	Denmark	2011	10.8	2	0.4
EnBW Baltic I	Germany	2011	48	17.5	16
Greater Gabbard	United Kingdom	2011	504	20.5	36
Walney Phase 1	United Kingdom	2011	184	21	14
Bard	Germany	2012	400	40	111.9
Global Tech I	Germany	2012	400	41	109.4
Lincs	United Kingdom	2012	270	15	9.1
London Array	United Kingdom	2012	630	25	27.5
Mean			126.2	14.5	17.1
Min			2	2	0
Max			630	45	11.9
Std. Dev.			144.9	11.5	24.8

time. Once the overnight cost is calculated, it will be used as the dependent variable to test whether two economic principles apply to the offshore wind market; economies of scale and learning effects.[1] We will test for the presence of both industry-wide and country-specific learning effects. Such economic principles will be important when considering whether or not to approve the construction of an OSW. If economies of scale exist, then regulators might be interested in larger OSWs to decrease average costs. If industry-wide learning effects are present in the offshore wind market, then newly proposed projects should be more efficient, and therefore less costly per MW, than past projects. Conversely, if country-specific learning effects are present, then countries might be inclined to built an initial, more expensive, project in hopes to bring down costs of future projects. In fact, states like New Jersey and Maine are currently proposing such "pilot projects" citing these learning effects as justification.

[1] There are a variety of different terms used to describe learning effects in the literature. Some of these include "learning curves," "learning by doing," and "progress functions."

2. Model

2.1. Economies of scale

For well over half a century, economists have empirically tested for the presence of economies of scale in a variety of industries [12]. Economies of scale in electric power generation specifically has also been studied extensively both in the United States [2] as well in other countries around the world [4,5]. USDOE (2011) [15] discusses economies of scale in the on-shore wind market within the United States and finds that economies of scale are present in relatively small windfarms (less than 20MW), but economies of scale attenuate substantially after the 20 MW threshold is met.

There has, though, been very little empirical research on economies of scale in off-shore wind. Junginger et al. [8], for instance, find that for orders of over 100 turbines, there is approximately a 30 percent reduction in the list price. But this is based on a "bottoms-up" approach in which individual components of OSWs are analyzed. They provide no empirical evidence that economies of scale have actually been realized in OSWs to date. Snyder and Kaiser [13] find a positive relationship between total cost and total