Borders, Geography, and Oligopoly: Evidence from the Wind Turbine Industry*

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Abstract

Using a micro-level dataset of Danish and German wind turbine installations, we estimate a structural oligopoly model with cross-border trade and heterogeneous firms. Our approach allows us to separately identify border-related variable costs from distance-related variable costs, and to put bounds on fixed costs of exporting. We find that the variable border costs are large, equivalent to 400 kilometers (250 miles) in transport costs. Counterfactual analysis shows that the fixed costs are also important; removal of fixed border costs would increase German market share in Denmark from 2 to 12 percent. Our analysis illustrates how border frictions affect firm profits and consumer surplus on each side of the border. The results indicate that a complete elimination of border frictions would increase total welfare in the wind turbine industry by 5 percent in Denmark and 10 percent in Germany.

1 Introduction

Since the seminal works of McCallum (1995) and Engel and Rogers (1996), an extensive literature has documented significant market segmentation across national boundaries. Obstfeld and Rogoff (2001) listed "home bias in trade" as one of the major puzzles in international macroeconomics. Estimated magnitudes of the border effect are so large that some researchers have suggested they are due to spatial and industry-level aggregation bias, a failure to account for within-country heterogeneity and geography, and cross-border changes in market structure.[1] To address these issues, we use spatial micro-data from the wind turbine industry in Denmark and Germany and estimate a structural model of oligopolistic competition with border frictions. Our main findings are: (1) The border effect persists and is large for

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[1]See Hillberry (2002), Hillberry and Hummels (2008), Broda and Weinstein (2008) and Gorodnichenko and Tesar (2009).

the particular industry that we study; (2) fixed and variable costs of exporting are both important in explaining overall border frictions; and (3) the costs associated with border frictions have a large impact on total welfare.

In contrast with studies that use aggregate trade measures to infer a border effect, we focus on an important but narrowly defined industry. In addition to being an interesting industry for study in its own right, the wind turbine industry in Europe offers a unique opportunity to examine the effects of national boundaries on market segmentation: First, this industry provides rich spatial information on the location of manufacturers and wind turbine installations. The data are much finer than previously used aggregate state or province level data. Next, we have plenty of observations on intra- and international trade. We observe active manufacturers on either side of the Danish-German border. Finally, due to the nature of energy output subsidies and wind electricity generation, foreign wind turbines should not prima facie be systematically less attractive to landowners than domestic turbines.

However, the data indicate substantial market segmentation between Denmark and Germany. When we examine sales of wind turbines in 1995 and 1996, we find that domestic turbine manufacturers enjoy a substantial market share advantage over foreign manufacturers. For example, the top five German wind turbine manufacturers possess a market share of 60 percent in Germany, but of only 2 percent in Denmark. When we sort wind farm projects by distance to the border, we find that the market share of Danish producers drops at the border by around 20 percentage points (see Figure 3). This is despite the fact that European Union (EU) has sought to minimize trade barriers between its member countries.[2]

What are the sources of cross-national market segmentation? A cursory glance at our data suggests that national borders affect both market entry decisions and variable costs of foreign firms. In particular, only one of the five large German firms exports to Denmark. On the other hand, all five large Danish firms are active in Germany, but their market share drops substantially at the border. To explain these discontinuities along extensive and intensive margins, we propose a two-stage model of cross-border oligopolistic competition. In the first stage, firms decide whether or not to export. If they choose to export, they must pay a *fixed border cost* to become active in the foreign market. In the second stage, firms observe the set of active firms in each market and engage in Bertrand-Nash competition. Firms are heterogeneous in production costs and in their proximity to project sites. In particular, we incorporate two types of variable costs which contribute to market segmentation: all firms face a variable *transport cost* which is increasing in the distance between the producer and the project. Exporting producers face

[2] All tariffs and quotas between former European Economic Community members were eliminated by 1968. The Single European Act came into force in 1987 with the objective of abolishing all remaining physical, technical and tax-related barriers to free movement of goods, services and capital within the EU until 1992. Between 1986-1992, EU adopted 280 pieces of legislation to achieve that goal.

additional *variable border cost* for supplying a project in the foreign market.

Our results indicate that there is a substantial border effect in wind turbine trade between Germany and Denmark. We find that the variable border effect is roughly equivalent to moving a manufacturer 400 kilometers (250 miles) further away from a project site. Given that the largest possible road distance from the northern tip of Denmark to the southern border of Germany is roughly 1400 kilometers (870 miles), this is a non-trivial cost for foreign firms. In addition, we find that removing fixed costs of foreign entry such that all firms compete on both sides of the border raises the market share of German firms in Denmark from 2 to 12 percent. An elimination of all border costs raises the market share of German firms in Denmark even further to 22 percent. Our counterfactual analysis provides further insights into the welfare effects of borders. A hypothetical elimination of all border frictions raises consumer surplus by 10.4 and 15.3 percent in Denmark and Germany, respectively. Removing border frictions increases profits of foreign firms while reducing those of domestic firms. The net effect is small in Denmark, reducing producer surplus by less than 1 percent, but large in Germany where producer surplus declines by over 6 percent. Overall, consumer gains outweigh producer loses in both countries. Total surplus increases by 5 percent in Denmark and 10 percent in Germany.

This paper adds to the border effect literature by estimating border costs within a structural oligopoly model of transactions within a specific industry while controlling for internal geography and firm heterogeneity. McCallum (1995) and Anderson and van Wincoop (2003) use data on interstate, interprovincial and international trade between the U.S. and Canada to document a disproportionately high level of *intranational* trade between U.S. states and Canadian provinces after controlling for income levels of regions and the distances between them. Engel and Rogers (1996) and Gopinath, Gourinchas, Hsieh, and Li (forthcoming) find a high level of market segmentation between the U.S. and Canada using price data on consumer goods. Goldberg and Verboven (2001, 2005) find considerable price dispersion in the European car market, and some evidence that the markets are becoming more integrated over time. Rather than examining trade flows or prices, our dependent variable is whether a particular firm is contracted to construct a wind turbine at a particular point in space.[3] By doing this, we addresses several critiques raised by the literature. Hillberry (2002) and Hillberry and Hummels (2008) show that sectoral and geographical aggregation lead to upward bias in the estimation of the border effect using trade flows. Similarly, Broda and Weinstein (2008) find that aggregation of individual goods' prices amplifies measured impact of borders on price. Holmes and Stevens (2010) emphasize the importance

[3]The first strand of papers described above use data on $x_{ij} = \sum_{n=1}^{N} q_{ij}^n p_{ij}^n$, trade volume between two regions i and j in N traded goods. The second strand uses information about p_{ij}^n for a set of tradable goods. This paper uses observation on q_{ij}^n for a particular tradable good.

of controlling for internal distances. Our data enables us to calculate project location-to-manufacturer distances for each potential supplier, which are used to separate the impact of distance from the impact of the border. Because we know the identity of manufacturers, we are able to control for firm-level heterogeneity. Our structural model of oligopoly competition controls for differences in market structure and competitor costs across space. This approach addresses Gorodnichenko and Tesar (2009)'s concern that model-free, reduced form estimates of the border effect that do not control for within country heterogeneity fail to identify the border effect. It also provides a framework that can be used to estimate oligopolistic industry models using spatial firm level data.

Of course, our empirical results are specific to the wind turbine industry, so they are meant to complement studies of the border effect based on multi-industry data. Nonetheless, we believe that our focus on a narrowly defined industry has three major advantages. First, the use of precise location data in a structural model allows a clean identification of transport and border costs. Second, unlike aggregate gravity models with CES preferences, we don't need to choose a parameter for the elasticity of substitution between goods/varieties. The magnitude of this parameter is an important determinant of estimates and welfare effects of border barriers in other work.[4] Finally, we gain a deeper insight into the sources of border frictions in business-to-business capital goods industries that constitute an important fraction of world trade.

Moreover, the wind turbine industry, a fast-growing industry at the forefront of the renewable energy market, is of interest in its own right. Our results suggest that border frictions play a surprisingly large role in the structure and development of this industry.

In the following section, we discuss our data source and provide some background to the Danish-German wind turbine industry. We also present some preliminary analysis that is indicative of a border effect. Section 3 introduces our model of the industry. We show how to estimate the model using maximum likelihood with equilibrium constraints and present the results in Section 4. In Section 5, we perform a counterfactual analysis of market shares and welfare by re-solving the model without fixed and variable border costs. We conclude in Section 6 with a discussion of policy implications.

2 Wind Turbine Industry and Data

Encouraged by generous subsidies for wind energy generation, Germany and Denmark have been at the forefront of what has become a world-wide boom in the construction of wind turbines. Owners of

[4] See Anderson and van Wincoop (2003) and Evans (2003).

wind turbine sites are paid for the electricity they produce and provide to the electric grid. In both countries, national governments regulate the price paid by grid operators to the site owners for each unit of electricity generated by wind energy. These price schemes ("feed-in-tariffs") are substantially higher than the market rate for other electricity sources. Public financial support for this industry is not tied to the nationality of the turbine manufacturer, which would have been against European single market policy.

The project owner's choice of manufacturer is our primary focus. In the period we study, purchasers of wind turbines were primarily independent producers, most often farmers or other small investors.[5] The turbine manufacturing industry is dominated by a small number of manufacturing firms who both manufacture turbines and construct them on the project owner's land. It is in the best interest of the wind farm owner to purchase the turbine that maximizes her profits independent of the nationality of the manufacturer.

Manufacturers usually have a portfolio of turbines available with various generating capacities. Overall, their portfolios are relatively homogeneous.[6] However, the perceived quality and reliability of the turbines differs across manufacturers. The proximity of manufacturers' production locations to the project site is an important driver of cost differences. The cost of transporting turbine parts from manufacturing plant to project location is substantial, often necessitating road closures along the delivery route (see Figure 1). In addition, the manufacturers usually include maintenance contracts as part of the turbine sale so they must revisit turbine sites after construction is completed.

2.1 Data

We have constructed a unique dataset from several sources that contains information on every wind energy project developed in Denmark and Germany from 1978 to 2005.[7] The data include the location of each

[5]Small purchasers were encouraged by the financial incentive scheme that gave larger remuneration to small, independent producers such as cooperative investment groups, farmers, and private owners. The German Electricity Feed Law of 1991 explicitly ruled out price support for installations in which the Federal Republic of Germany, a federal state, a public electricity utility or one of its subsidiaries held shares of more than 25 percent. The Danish support scheme provided an about 30% higher financial compensation for independent producers of renewable electricity Sijm (2002). A new law passed in Germany in 2000 eliminated the restrictions for public electricity companies to benefit from above market price renumeration of renewable energy.

[6]The main observable turbine characteristics are tower height, generation capacity, and rotor diameter. One explanation for cross border differences in market shares would be that projects in Denmark and Germany are qualitatively different and firms naturally specialize in turbine types that work best at home. The distribution of number of turbines per project look very similar in either country, as do the distributions of turbine size and rotor diameters. The tower heights are larger in Germany on average, which can be explained by lower wind velocity in Southern Germany. Manufacturers explicitly offer a variety of turbine heights in their marketing documentation. Histograms of project characteristics in each country are available from the authors.

[7]The data on Danish installations comes from the Danish Energy Agency. The data on German installations comes from the private consulting company Betreiber-Datenbasis. Data on manufacturer locations was hand-collected from manufacturers websites and contacts in the industry.

Figure 1: **A convoy of wind turbine blades passing through the village of Edenfield, England.** Photo Credit: Anderson (2007)

project, the number of turbines, the total megawatt capacity, the date of grid-connection, manufacturer identity and other turbine characteristics such as rotor diameter and tower heights. A key missing variable in our data set is the transaction price of the turbine.[8] We match the project data with the location of each manufacturer's primary production facility, enabling the calculation of road-distance from each manufacturer to each project. This provides us with a spatial source of variation in manufacturer costs which aids in identifying the sources of market segmentation.[9]

In this paper, we concentrate on the period from 1995 to 1996. The focus on this time period has several advantages. First, the set of firms was stable during this time period. There are several medium-to-large firms competing in the market. In 1997, a merger and acquisition wave began, which lasted until 2005. The industry merger wave, including cross-border mergers, would complicate our analysis of the border effect. Second, site owners in this period were typically independent producers. This contrasts with later periods when utility companies became significant purchasers of wind turbines, leading to

[8] As in most business to business industries, transaction level prices are confidential. Some firms do publish list prices, which we have collected from the industry publication Interessenverband Windkraft Binnenland (various years). These prices, however, do not correspond to relevant final transaction prices due to site-specific delivery and installation costs.

[9] Road distances were calculated using the Google Maps API (`http://code.google.com/apis/maps/`), accessed on June 30, 2011. Therefore, they reflect the most recent road network. For developed countries such as Germany and Denmark, we believe the error introduced by the change in road networks over time is negligible.

Table 1: **Major Danish and German Manufacturers.**

Manufacturer	Nationality	Market share in Denmark (%)	Market share in Germany (%)
Bonus	(DK)	12.12	5.05
Micon	(DK)	19.19	8.17
Nordtank	(DK)	11.45	4.73
Vestas	(DK)	45.45	12.04
Wind World	(DK)	4.38	2.73
Enercon	(DE)		32.58
Fuhrlaender	(DE)		2.15
Nordex	(DE)	1.68	7.53
Suedwind	(DE)		2.37
Tacke	(DE)		14.95

more concerns about repeated interaction between purchasers and manufacturers.[10] Finally, this period contains several well-established firms and the national price schemes were well understood. Prior to the mid-1990s, the market could be considered an "infant industry" with substantial uncertainty about the viability of firms and subsidies.

In focusing on a two-year time period, we abstract away from some dynamic considerations. While this greatly simplifies the analysis, it comes with some drawbacks. Probably most important, we are unable to distinguish sunk costs from fixed costs of entering the foreign export market (Roberts and Tybout (1997)). Because of the small number of firms, we would be unable to reliably estimate sunk costs and fixed costs separately in any case. Instead, we model the decision to enter a foreign market as a one-shot game. This decision does not affect the consistency of our variable cost estimates, while our counterfactuals removing fixed costs should be interpreted as removing both sunk and fixed costs. We also abstract away from dynamic effects on production technologies such as learning-by-doing (see Benkard (2004)). Learning-by-doing would provide firms with an incentive to lower prices below a static profit maximizing level to account for the efficiency gains that will be discovered in producing the turbine.[11] We feel that learning-by-doing is probably more of a concern earlier in the data period. By 1995, the industry has matured to the extent that the assumption that firms set prices to maximize expected profits from the sale seems like a reasonable assumption.

Table 1 displays the market shares or the largest five Danish and German firms in Denmark and

[10] Also, professional project developing companies became a frequently used middlemen from the late 1990s onwards. One would need to take into account repeated interaction between turbine manufacturers and the middlemen.

[11] In some cases, this could even lead firms to sell products below cost. See Besanko, Doraszelski, Kryukov, and Satterthwaite (2010) for a fully dynamic computational model of price-setting under learning-by-doing.

Germany. We take these firms to be the set of manufacturers in our study. All other firms had domestic market shares below 2 percent, no long-term presence in their respective markets, and did not export. In our model, we treat these small turbine producers as a competitive fringe. The German and Danish wind turbine markets were relatively independent from the rest of the world. There is only one firm exporting from outside Germany and Denmark: A Dutch firm, Lagerwey, which sold to 21 projects in Germany (2.26 percent market share) and did not have a long term presence in the German market. We include Lagerwey as part of the competitive fringe.

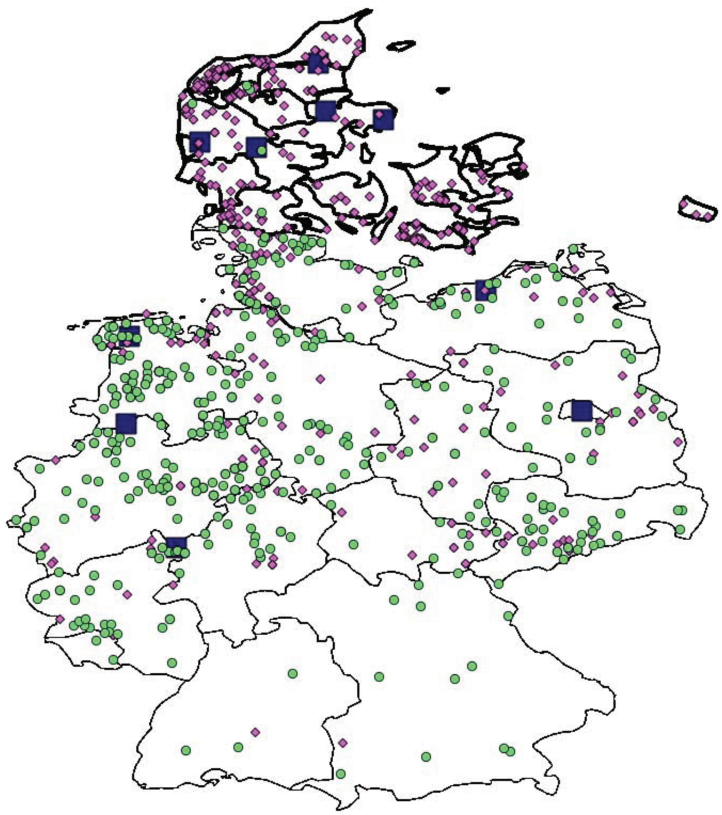

Figure 2: **Wind farm installations in Denmark and Germany in 1995 and 1996.**
Large squares are the location of manufacturers' facilities. Smaller symbols illustrate projects constructed by Danish (purple diamond) and German (green circle) manufacturers.

2.2 Preliminary Analysis of the Border Effect

Table 1 clearly suggests some degree of market segmentation between Germany and Denmark. Several German firms—including the German market leader, Enercon—choose not to compete in the foreign market at all. Those firms that do export seem to fair much better at home. This is especially true

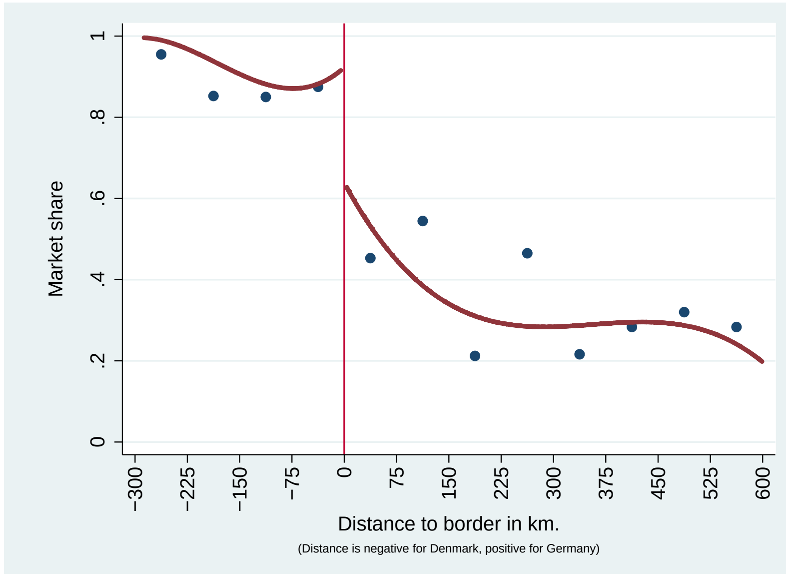

Figure 3: **Market share of five large Danish firms by proximity to the border.** Regression discontinuity fit of projects supplied by Danish firms using a cubic polynomial of distance to border. Dots are aggregated market shares in bins of 75 km width.

considering the German firm Nordex, whose market share is more than four times larger at home despite facing additional competition from German-only firms.[12]

The fact that all Danish firms enter Germany, while four of five German firms choose not to compete in Denmark is consistent with the existence of large fixed costs for exporting. Because the German market is much larger than Denmark (930 projects were installed in Germany in this period, versus 297 in Denmark — see the map of projects in Figure 2), these fixed costs can be amortized over a larger number of projects in Germany than Denmark.

For those firms that do export, the decline in market share moving from foreign to domestic markets reported in Table 1, may have many different causes. First, market structure changes as the set of firms competing in Denmark is smaller than that in Germany. Second, due to transportation costs, foreign firms will have higher costs than domestic ones simply because projects are likely to be nearer to domestic manufacturing plants. Finally, there may be some variable border costs which must be paid for each foreign project produced.

As a first pass, we employ a regression discontinuity design (RDD) to detect the effect of the border on large Danish firms' market share. Assuming that wind and demand conditions do not change

[12] Our results on fixed costs of exporting suggest that Nordex's fixed costs to export to Denmark are much smaller than other German firms. There is an interesting anecdotal explanation for why this may be the case. It actually started its operations as a Danish firm in 1985, but shifted its center of business and production to Germany in the early mid 90s due to struggles in the Danish market. Another German firm acquired its majority voting rights in 1996. It became listed at the German stock market in 2001.

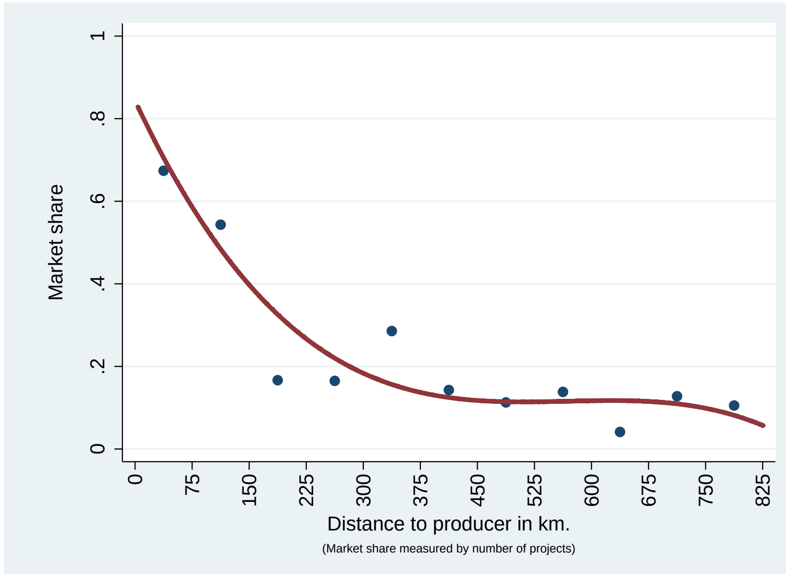

Figure 4: **Market share of Vestas by proximity to primary production facility.**
Proportion of projects won by Vestas projected on a cubic polynomial of distance to Vestas's production facility. Dots are aggregated market shares in bins of 75 km width.

abruptly, the RDD uncovers the impact of the border. Figure 3 plots the average market share of the largest five Danish wind turbine manufacturers by distance to the Danish-German border. The market share of the largest five Danish firms drops sharply from around 90 to 60 percent.

These results give us reason to believe that the border matters in the wind turbine industry. However, the discontinuity of the border does not separately identify the effect of changes in market structure between Germany and Denmark from the impact of variable border costs. Because variable border costs are incurred at precisely the point where market structure changes, we are unable to use the RDD approach to separate the two effects. This motivates our use of a structural model. In the following section, we propose and estimate a model to account for the changes market structure at the border by modeling the competition for projects as a Nash-Bertrand game.

Distance between a firm and a potential wind farm is another potential source of market segmentation. The impact of distance on firm costs is illustrated by Figure 4. This figure documents Vestas's declining market share as the distance to its main manufacturing location increases. While Figure 4 suggests that costs increase with distance from the manufacturing base, it cannot easily be used to estimate distance costs. The impact of the border—roughly 160 km from Vestas's manufacturing plant—confounds the relationship. Moreover, in an oligopolistic industry, Vestas's share is a function of not only its own costs but of those of competitor firms. Our model will jointly solve for the probability that each competing firm wins a project based on the project's location in relation to all firms. We are thus able to use the rich variation in projects across space to estimate the impact of distance on firm costs.

3 Model

We begin by describing the environment. There are two countries, Denmark and Germany, indexed by $\ell \in \{D, G\}$. Each country has M_ℓ large domestic firms and a local fringe. Large firms are heterogeneous in their location and productivity. There is a fixed set of N_ℓ projects in each country characterized by their location and size (total megawatt of generation capacity). We model cross-border competition in two stages. In the first stage, large firms decide whether they will pay a fixed cost to enter the foreign market. In the second stage, competing firms bid for each project. Project owners independently choose a turbine supplier among competing firms. We now present the two stages following backward induction, starting with the bidding game.

3.1 Project Bidding Game

In this stage, the set of active firms is taken as given by all players, as it was realized in the entry stage. For ease of notation, we drop the country index for the moment and describe the project bidding game in one country. A total of J large firms and the competitive fringe compete over N projects. Note that $J \geq M$, i.e. the number of active firms in the country is greater or equal than the number of domestic producers depending on the number of foreign firms that entered the market in the first stage. Each project i is characterized by its size S_i, and a particular location. Wind and land conditions at the site largely determine the size of the project in total megawatt output by determining the capacity and number of turbines which can be placed on the site (Manufacturers all offer a wide variety of turbine capacities). The per-megawatt payoff function of a project owner i for choosing firm j is

$$V_{ij} = d_j - p_{ij} + \epsilon_{ij}.$$

The return to the project owner depends on the quality of the wind turbine, d_j, the per-megawatt price p_{ij} charged by manufacturer j, and an idiosyncratic choice-specific shock ϵ_{ij}.[13] It is well known that discrete choice models only identify relative differences in valuations. We thus model a non-strategic

[13] We assume away project-level economies of scale by making price bids per-megawatt. Our data does not enable us to identify project-level economies of scale. We check whether foreign turbine manufacturers tend to specialize on larger projects abroad. We find that the average project size abroad is very similar to the average project size at home for each exporting firm.

fringe as an outside option. We denote it as firm 0, and normalize the return as

$$V_{i0} = \epsilon_{i0}.$$

We assume ϵ_{ij} is distributed i.i.d. across projects and firms according to a Type-I extreme value distribution.[14] The $\boldsymbol{\epsilon}_i$ vector is private information to owners who collect project-specific price bids from producers. After receiving all price bids, denoted by the vector $\mathbf{p}_i$, owners choose the firm who delivers them the highest payoff. Using the familiar logit formula, the probability that owner i chooses one of the strategic large firms j is given by

$$Pr[i \text{ chooses } j] \;\equiv\; \rho_{ij}(\mathbf{p}_i) \;=\; \frac{\exp(d_j - p_{ij})}{1 + \sum_{k=1}^{J} \exp(d_k - p_{ik})} \qquad \text{for } j \in \{1, ..., J\}. \tag{1}$$

The probability of choosing the fringe is

$$Pr[i \text{ chooses the fringe}] \;\equiv\; \rho_{i0}(\mathbf{p}_i) \;=\; 1 - \sum_{j=1}^{J} \rho_{ij}(\mathbf{p}_i).$$

Now we turn to the problem of the firm. The cost of supplying project i to firm j is a function of its heterogeneous production cost ϕ_j, its distance to the project, and whether or not it is a foreign producer:

$$c_{ij} = \phi_j + \beta_d \cdot \text{distance}_{ij} + \beta_b \cdot \text{border}_{ij}, \tag{2}$$

where

$$\text{border}_{ij} = \begin{cases} 0 & \text{if both } i \text{ and } j \text{ are located in the same country,} \\ 1 & \text{otherwise.} \end{cases}$$

In other words, all firms pay the distance related cost ($\beta_d \cdot \text{distance}_{ij}$) but only foreign firms pay the variable border cost ($\beta_b \cdot \text{border}_{ij}$). The distance cost captures not only the cost of transportation but also serves as a proxy for the cost of post-sale services (such as maintenance), installing remote controllers to monitor wind farm operations, gathering information about sites further away from manufacturer's location and maintaining relationships with local contractors who construct turbine towers. The border component captures additional variable costs faced by foreign manufacturers. This may include the cost of dealing with project approval procedures in the foreign market and coordinating transportation of

[14]Project owners do not have any home bias in the sense that ϵ_{ij}'s are drawn from the same distribution for all producers in both countries.

bulky components with various national agencies.

Firms engage in Bertrand competition by submitting price bids for projects in the markets they are active. They observe the identities and all characteristics of their competitors in the game except the valuation vector $\boldsymbol{\epsilon}_i$. In a pure-strategy Bayesian-Nash equilibrium, each firm chooses its price to maximize expected profits given the prices of other firms:

$$E[\pi_{ij}] = \max_{p_{ij}} \; \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j}) \cdot (p_{ij} - c_{ij}) \cdot S_i,$$

which has the first order condition

$$\begin{aligned} 0 &= \frac{\partial \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})}{\partial p_{ij}}(p_{ij} - c_{ij}) + \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j}), \\ p_{ij} &= c_{ij} - \frac{\rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})}{\partial \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})/\partial p_{ij}}. \end{aligned}$$

Exploiting the properties of the logit form, this expression simplifies to an optimal mark-up pricing condition:

$$p_{ij} = c_{ij} + \frac{1}{1 - \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})}. \quad (3)$$

The mark-up is increasing in the (endogenous) probability of winning the project, and is thus a function of the set of the firms active in the market and their characteristics. Substituting (3) into (1), we get a fixed point problem with J unknowns and J equations for each project i:

$$\rho_{ij} = \frac{\exp\left(d_j - c_{ij} - \frac{1}{1-\rho_{ij}}\right)}{1 + \sum_{k=1}^{J} \exp\left(d_k - c_{ik} - \frac{1}{1-\rho_{ik}}\right)} \qquad \text{for } j \in \{1, ..., J\}. \quad (4)$$

Our framework fits into the class of games for which Caplin and Nalebuff (1991) show the existence of a unique pure strategy equilibrium. Finally, the expected profits of manufacturer j for project i can be calculated as,

$$E[\pi_{ij}] = \frac{\rho_{ij}}{1 - \rho_{ij}} S_i.$$

3.2 Entry Game

Before bidding on projects, an entry stage is played in which all large firms simultaneously decide whether or not to be active in the foreign market by incurring a firm-specific fixed cost f_j. Let $\Pi_j(\mathcal{J} \cup j)$ be the expected profit of manufacturer j in the foreign market where $\mathcal{J}$ is the set of active bidders other than

j. This is simply the sum of the expected profit of bidding for all foreign projects:

$$\Pi_j(\mathcal{J} \cup j) = \sum_{i=1}^{N} E[\pi_{ij}(\mathcal{J} \cup j)]. \tag{5}$$

Manufacturer j enters the foreign market if its expected return is higher than its fixed cost:

$$\Pi_j(\mathcal{J} \cup j) \geq f_j. \tag{6}$$

Note that this entry game may have multiple equilibria. Following the literature initiated by Bresnahan and Reiss (1991), we assume that the observed decisions of firms are the outcome of a pure strategy equilibrium. Therefore, if a firm in our data is active in the foreign market, (6) must hold for that firm. On the other hand, if we do not observe firm j in the foreign market, than we can infer the following lower bound on fixed export cost,

$$\Pi_j(\mathcal{J} \cup j) \leq f_j. \tag{7}$$

We use these two necessary conditions two construct inequalities which bound f_j from above or from below using the estimates from the bidding game to impute the expected payoff estimates of every firm for any set of active participants in the foreign market.[15] We now turn to the estimation of the model.

4 Estimation

Estimation proceeds in two steps. In the first step, we estimate the structural parameters of the project-bidding game. In the second step, we use these estimates and solve for equilibria in the project-bidding game with counterfactual sets of active firms to construct the fixed costs bounds. Before proceeding with the estimation, we must define the set of active firms in every country. Under our model, the set of firms that have positive sales in a country is a consistent estimate of the active set of firms.[16] Therefore, we define a firm as active in the foreign market if it has any positive sales there.

We now reintroduce the country index: ρ_{ij}^{ℓ} is firm j's probability of winning project i in country ℓ. The number of active firms in market ℓ is J_ℓ, and $\text{border}_{ij}^{\ell}$ equals zero if project i and firm j are both

[15] Pakes, Porter, Ho, and Ishii (2006) proposed using these bounds to construct moment inequalities for use in estimating structural parameters. Holmes (2011) and Morales, Sheu, and Zahler (2011) applied this methodology to the context of spatial entry and trade. Because we observe only a single observation of each firm's entry decision, a moment inequality approach is not applicable in our setting.

[16] Under our model, every active firm has a positive probability of winning every project. Therefore, as the number of projects goes to infinity, every active firm wins at least one project.

located in country ℓ, and one otherwise. Substituting the cost function (2) into the winning probability (4):

$$\rho_{ij}^{\ell} = \frac{\exp\left(d_j - \phi_j - \beta_d \cdot \text{distance}_{ij} - \beta_b \cdot \text{border}_{ij}^{\ell} - \frac{1}{1-\rho_{ij}^{\ell}}\right)}{1 + \sum_{k=1}^{J_\ell} \exp\left(d_k - \phi_k - \beta_d \cdot \text{distance}_{ik} - \ \beta_b \cdot \text{border}_{ik}^{\ell} - \frac{1}{1-\rho_{ik}^{\ell}}\right)}. \tag{8}$$

From this equation, one can see that firms' production costs ϕ_j and quality level d_j are not separately identified given our data.[17] We thus capture these two effects jointly by firm fixed-effects $\xi_j = d_j - \phi_j$.

We collect the parameters to estimate into the vector $\theta = (\beta_b, \beta_d, \xi_1, \ldots, \xi_J)$. We estimate the model via constrained maximum likelihood, where the likelihood of the data is maximized subject to our equilibrium constraints. The log-likelihood function of the project data has the following form,

$$L(\rho) = \sum_{\ell \in \{D,G\}} \sum_{i=1}^{N_\ell} \sum_{j=1}^{J_\ell} y_{ij}^{\ell} \log \rho_{ij}^{\ell}, \tag{9}$$

where $y_{ij}^{\ell} = 1$ if manufacturer j is chosen to supply project i in country ℓ and 0 otherwise. The maximum likelihood estimator of the structural parameters maximizes this likelihood subject to the equilibrium constraints. In other words, $\hat{\theta}$, together with the vector of expected project win probabilities $\hat{\rho}$, solves the problem,

$$\begin{aligned} \max_{\theta,\, \rho} \quad & L(\rho) \\ \text{subject to:} \quad & \rho_{ij}^{\ell} = \frac{\exp\left(\xi_j - \beta_d \cdot \text{distance}_{ij} - \beta_b \cdot \text{border}_{ij}^{\ell} - \frac{1}{1-\rho_{ij}^{\ell}}\right)}{1 + \sum_{k=1}^{J_\ell} \exp\left(\xi_k - \beta_d \cdot \text{distance}_{ik} - \ \beta_b \cdot \text{border}_{ik}^{\ell} - \frac{1}{1-\rho_{ik}^{\ell}}\right)} \\ & \text{for } i \in \{1, ..., N_\ell\},\ j \in \{1, ..., J_\ell\},\ \ell \in \{D, G\}\ . \end{aligned} \tag{10}$$

Our estimation is an implementation of the Mathematical Programming with Equilibrium Constraints (MPEC) procedure Judd and Su (2010). For the empirical implementation, we reformulate the system of constraints in (10) in order to simplify its Jacobian.[18] The reformulated system of constraints,

[17] The difference between productivity and quality would be identified if we had data on transaction prices. Intuitively, for two manufacturers with similar market shares, high prices would be indicative of higher quality products while low prices would be indicative of lower costs.

[18] The reformulation greatly increases the sparsity of the jacobian. Without this reformulation, the jacobian of the constraint matrix the problem would be considerably less computationally tractable.

for $i \in \{1, ..., N_\ell\}$, $j \in \{1, ..., J_\ell\}$, $\ell \in \{D, G\}$ is,

$$\log \rho_{ij}^\ell - \log \rho_{i0}^\ell = \xi_j - \beta_d \cdot \text{distance}_{ij} - \beta_b \cdot \text{border}_{ij}^\ell - \frac{1}{1-\rho_{ij}^\ell} \qquad \text{for } j \in \{1, ..., J_\ell\}, \tag{11}$$

$$\sum_{j=1}^{J_\ell} \rho_{ij}^\ell + \rho_{i0}^\ell = 1. \tag{12}$$

The reformulation is a transformation of each firms first order condition for each project, as well as an adding up constraint to ensure that total market share is equal to unity. The reformulated constraints are mathematically equivalent to those in (10). We estimate the model by maximizing (9) subject to the system of constraints defined by (11) and (12) using the KNITRO optimization package. In our baseline specification, this is a problem with 12,314 variables (12 structural parameters and 12,302 equilibrium win probabilities for each firm in each market) and 12,302 equality constraints.

As a robustness check on our baseline specification, we also try an alternative cost specification where distance related costs are firm-specific:

$$c_{ij}^\ell = \phi_j + \beta_{dj} \cdot \text{distance}_{ij} + \beta_b \cdot \text{border}_{ij}^\ell.$$

Note that the difference between this and the baseline specification (2) is that distance cost coefficients are heterogeneous (β_{dj} vs. β_d). This cost function is consistent with Holmes and Stevens (2010) who document that in U.S. data, large firms tend to ship further away, even domestically.[19] If heterogeneous shipping costs were present in the wind turbine industry, they might bias our baseline estimate of the border effect upwards through a mis-specification of transport costs, since smaller firms would not export due to higher transport costs instead of the border effect. In the following section, we present results for both specifications.

Once we have recovered the structural parameters, we are able to calculate bounds on the fixed costs of entry for each firm, f_j, using the equations (6) and (7). This involves resolving the model with the appropriate set of firms while holding the structural parameters fixed at their estimated values. To calculate standard errors for these bounds, we use a parametric bootstrap procedure.[20]

[19] They rationalize this observation in a model where heterogeneous firms invest in their distribution networks. Productive firms endogenously face a lower "iceberg transportation cost."

[20] In other words, we repeatedly draw θ_b from the asymptotic distribution of $\hat{\theta}$ and recalculate the bound each time. The distribution of bound statistic generated by this procedure is a consistent estimate of the true distribution.

4.1 Parameter estimates

The results of the maximum likelihood estimation are presented in Table 2, with our baseline specification reported in first column. Both the cost of crossing the border and the cost of distance are economically and statistically significant. Based on our estimate, the impact on variable costs associated with exporting are equivalent to an additional 432 kilometers of travel distance between manufacturing location and project site. The mean distance from Danish firms to German projects in our data is 623 kilometers. The distance from German firms to Danish projects is 602 kilometers. Consequently, border frictions represent roughly 40 percent of exporters total transport costs.

To get a sense of the importance of transport costs on market outcomes, we calculate the distance elasticity of the equilibrium probability of winning a project for every project-firm combination.[21] For exporters, the median distance elasticity ranges from .95 to 1.40. That is, the median effect of a one percent increase in the distance from an exporting firm to a project abroad (holding all other firms' distances constant) is a decline of .95 to 1.40 percent in the probability of winning the project. For domestic firms, the median distance elasticities are lower, ranging from .17 to .83. The difference is due to both the smaller distances firms must typically travel to reach domestic projects and the impact of the border on equilibrium outcomes. It appears transport costs have a significant impact on firm costs and market shares for both foreign and domestic firms. For exporting firms, it seems that border costs frictions are a substantial proportion of transport costs.

As discussed above, the firm fixed effects reflect the combination of quality and productivity differences across firms. We find significant differences between firms. Unsurprisingly, the largest firms, Vestas and Enercon, also have the highest fixed effects. Broadly speaking, Danish firms appear to be stronger than German firms, although there is significant within-country heterogeneity. The results suggest that controlling for firm differences is important to correctly estimate the border effect and distance costs.

Since our model delivers expected purchase probabilities for each firm at each project site, we can use the regression discontinuity approach to visualize how well our model fits the observed data. Figure 5 shows how distance and the border impact the probability of a Danish firm winning a given project. The x-axis is distance to the Danish-German border, where negative distance is inside Denmark. The red (solid) curve is a cubic regression-discontinuity fit of the observed data on whether a project was supplied

[21] The distance elasticities we report are a function of the characteristics of all firms at a particular project site in a very specific industry. It is difficult to directly compare these distance elasticities with distance elasticities of aggregated trade volumes frequently reported in the trade literature that rely on national or regional capital distance proxies (e.g., McCallum (1995); Eaton and Kortum (2002); Anderson and van Wincoop (2003))

Table 2: **Maximum Likelihood Estimates.**

	Baseline	Heterogeneous Distance Costs
Border Variable Cost, β_b	0.869	0.867
	(0.219)	(0.239)
Distance Cost (100km), β_d	0.201	
	(0.032)	
Bonus (DK)		0.169
		(0.066)
Nordtank (DK)		0.277
		(0.073)
Micon (DK)		0.134
		(0.051)
Vestas (DK)		0.287
		(0.049)
WindWorld (DK)		0.016
		(0.068)
Enercon (DE)		0.296
		(0.063)
Fuhrlaender (DE)		1.794
		(0.236)
Nordex (DE)		-0.071
		(0.087)
Suedwind (DE)		-0.231
		(0.104)
Tacke (DE)		0.103
		(0.071)
Firm Fixed Effects, ξ_j		
Bonus (DK)	2.473	2.332
	(0.223)	(0.297)
Nordtank (DK)	2.526	2.811
	(0.229)	(0.326)
Micon (DK)	3.097	2.786
	(0.221)	(0.268)
Vestas (DK)	3.805	4.180
	(0.215)	(0.265)
WindWorld (DK)	1.735	0.818
	(0.273)	(0.418)
Enercon (DE)	3.533	3.859
	(0.175)	(0.270)
Fuhrlaender (DE)	0.330	3.305
	(0.263)	(0.506)
Nordex (DE)	1.782	0.683
	(0.203)	(0.400)
Suedwind (DE)	0.537	-1.188
	(0.270)	(0.510)
Tacke (DE)	2.389	2.104
	(0.177)	(0.263)
Log-Likelihood	-2363.00	-2315.82
N	1226	1226

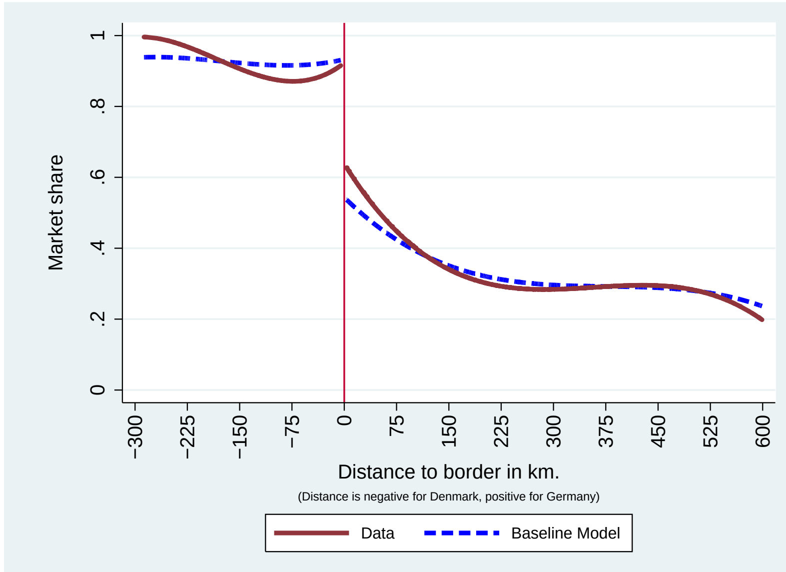

Figure 5: **Model fit: Expected Danish market share by distance to the border.**

by a Danish firm as a function of distance to the border. This regression does not control for project-to-firm distances.[22] The blue (dotted) curve is fitted using the expected win probabilities calculated from the structural model, which explicitly controls for both firm heterogeneity and project-to-manufacturer distances, but does not explicitly include distance to the border. The size of the discontinuity is somewhat larger using the structural model, although the qualitative result that the border effect is large is apparent using both methods. Overall, the model appears to fit the data well.

To address our concern that differences in transport costs across firms may affect our estimation of the border effect, we allow for heterogeneity in transport costs in the second column of Table 2. The border variable cost coefficient is practically unchanged and remains strongly significant, indicating that our border effect estimate is not driven by transport cost heterogeneity. Turning to the distance costs themselves, most firms, particularly the larger ones, have distance costs that are close to our homogenous distance cost estimate. It does not appear that small firms have systematically higher transport costs. The smallest firm in our data, Suedwind, is estimated to be distance loving; this firm is based in Berlin, but has built several turbines in the west of Germany.[23] Overall, we believe that these results indicate that heterogeneous distance costs are not driving cross-border differences in this industry. While a formal likelihood ratio test rejects the null hypothesis of homogeneous distance costs, we use our preferred baseline specification for the counterfactual analysis below.

[22] This is the same curve as that presented in Figure 3.

[23] Nordex, who is also located in the east of Germany, also has a negative coefficient, but it is statistically insignificant.

4.2 Fixed cost bounds

Not all firms enter the foreign market. Rather, firms optimally choose whether or not to enter the foreign market by weighing their fixed costs of entry against the expected profits from exporting. Hence, firm-level heterogeneity in profits, fixed costs, or both is necessary to rationalize the fact that different firms make different exporting decisions. Since our model naturally allows for heterogeneity in firm operating profits, this section considers whether heterogeneity in firm fixed costs of exporting are also needed to rationalize observed entry decisions.

Since we only observe a single export decision for each firm, firm fixed costs are not identified. However, we can use our model to place a bound on fixed costs for each firm. Firms optimally make their export decision based on the level of fixed costs of foreign entry and expected operating profits in the export market as described in Section 3.2. Based on the parameter estimates in Table 2, we can derive counterfactual estimates of firm operating profits for any set of active firms in the Danish and German markets. Therefore, we can construct an upper bound on fixed costs for firms entering the foreign market using (6), and a lower bound on fixed costs for firms that stay out of the foreign market using (7). While the scale of these bounds is normalized by the extreme-value error term, comparing them across firms gives us some idea of the degree of heterogeneity in fixed costs.

Table 3 presents the estimates of fixed cost bounds for each firm. The intersection of the bounds across all firms is empty. For example, there is no single level of fixed costs which would simultaneously justify WindWorld entering Germany and Enercon not entering Denmark. Hence, some degree of fixed costs heterogeneity is necessary to explain firm entry decisions.

One possibility is that fixed cost for entering Germany differ from those for entering Denmark. Since all Danish firms enter the Danish market, any fixed cost below 17.35 (the expected profits of Wind World for entering Germany) would rationalize the observed entry pattern. In Germany however, the bounds do not intersect. The lower and upper bound of Enercon and Nordex have no intersection. Some background information about Nordex supports the implication of the model that Nordex may have much lower entry costs into the Danish market than Enercon. Nordex was launched as a Danish company in 1985 but shifted its center of business and production activity to Germany from the early 1990s onwards. Consequently, Nordex could keep a foothold in the Danish market at lower costs than the other German firms, who would need to form Danish contacts from scratch.[24]

[24]Because of Nordex's connection to Denmark, we perform a robustness check on our variable border cost estimate by re-estimating the model allowing Nordex to sell in Denmark without having to pay the border variable cost. The border cost estimate increases in this specification, but the difference is not statistically significant. Since Nordex is the only exporting German firm, this robustness check also serves as a check on our specification of symmetric border costs. See Balistreri and Hillberry (2007) for a discussion of asymmetric border frictions.

Table 3: **Export Fixed Cost Bounds (f_j).**

	Lower	Upper
Bonus (DK)		47.55
		(19.52)
Nordtank (DK)		43.29
		(8.91)
Micon (DK)		80.13
		(13.62)
Vestas (DK)		164.32
		(23.60)
WindWorld (DK)		17.35
		(3.93)
Enercon (DE)	22.32	
	(4.87)	
Fuhrlaender (DE)	0.66	
	(0.32)	
Nordex (DE)		6.33
		(1.82)
Suedwind (DE)	1.26	
	(0.45)	
Tacke (DE)	7.24	
	(1.71)	

Note: Scale is normalized by variance of ϵ.

Of course, the Nordex anecdote also highlights some important caveats with regard to our bounds. By assuming a one-shot entry game, we are abstracting away from entry dynamics. If exporting is less costly to continue than to initiate, then the bounds we calculate—which consider only profits from operating in 1995 and 1996—will be biased downward. Data limitations, particularly the small number of firms, prevent us from extending the model to account for dynamic exporting decisions along the lines of Das, Roberts, and Tybout (2007). However, we believe that our results are illustrative of the degree of heterogeneity in fixed costs necessary to explain entry patterns.[25]

5 Border Frictions, Market Segmentation and Welfare

We now use the model to study the impact of border frictions on national market shares, firm profits, and consumer welfare. We perform a two-step counterfactual analysis. In the first step, we eliminate fixed costs of exporting, which results in all firms entering the foreign market. We then re-solve the model for

[25] It is important to note that the variable cost estimates presented in Table 2, as well as the counterfactual results below, are robust to dynamic entry as long as firm pricing decisions have no impact future entry decisions. This assumption is quite common in the literature on structural oligopoly models, e.g., Ericson and Pakes (1995).

Table 4: **Counterfactual Market Shares of Large Firms (%).**

		Data	Baseline Estimates	No Fixed Costs	No Border
Denmark	Danish Firms	92.57	92.65	83.95	74.26
			(1.52)	(2.26)	(3.64)
	German Firms	1.69	2.18	11.56	21.94
			(0.60)	(2.05)	(3.88)
Germany	Danish Firms	32.37	32.42	32.42	49.32
			(5.42)	(5.42)	(7.55)
	German Firms	59.57	59.24	59.24	44.90
			(3.93)	(3.93)	(5.80)

Note: Market share measured in projects won.

this new set of active firms, keeping variable costs incurred at the border in place.[26] This counterfactual allows us to examine the importance of the change in competitive environment at the border. In the second step, we additionally remove the variable cost of the border by setting β_b equal to zero. This eliminates all border frictions such that the only reason for differing market shares across national boundaries are due to plant-to-project distances and firm heterogeneity.[27] While the results of this experiment constitute an upper bound on what can be achieved if border frictions could be entirely eliminated, it is important to keep in mind that natural barriers such as different languages will be difficult to eliminate in practice. All standard errors are calculated using the parametric bootstrap procedure described above.

5.1 Market Shares and Segmentation

We begin our analysis by considering how national market shares in each country react to the elimination of border frictions. Furthermore, because market shares are directly observed in the data, the baseline model's market share estimates can also be used to assess the fit of our model to national level aggregates. Table 4 presents the market share of the major firms of Denmark and Germany in each country, with the fringe taking the remainder of the market. Comparing the first two columns, the baseline predictions of the model closely corresponds to the observed market shares. All of the market shares are within the 95 percent confidence interval of the baseline predictions, which suggests that the model is a good fit.

In the third column, we re-solve the model by eliminating fixed costs of exporting and keeping

[26] We implicitly assume that the change in market structure does not induce domestic firms to exit the industry, or new firms to be created.

[27] We eliminate first fixed border costs and then variable costs because changes in variable border costs when fixed costs are still positive could induce changes in the set of firms that enter foreign markets. Because they are not point identified, we are unable to estimate fixed border costs. Even with reliable estimates, the entry stage with positive fixed costs is likely to result in multiple equilibria.

the variable border cost in place. In response, the four German firms who previously competed only domestically start exporting to Denmark. As a result, the market share of German firms in Denmark rises over 10 percentage points.[28] Danish firms, however, still maintain a substantial market share advantage in their home market. Since all five large Danish firms already compete in Germany, there is no change in market shares on the German side of the border when fixed costs of exporting are removed.[29] The difference in response to the elimination of fixed costs between the Danish and German markets is obvious, but instructive. The reduction or elimination of border frictions can have very different effects based on market characteristics. In our case, because there are more projects in Germany than Denmark, the return to entry is much larger in Germany. This may be one reason why we see more Danish firms entering Germany than vice versa.[30] As a result, reducing fixed costs of exporting to Germany has no effect on market outcomes, whereas the impact of eliminating fixed cost of exporting to Denmark is substantial.

The fourth and final column of Table 4 displays the model prediction of national market shares if the border were entirely eliminated. In addition to setting f_j equal for all firms, we also eliminate variable border costs by setting β_b equal to zero.[31] This results in a large increase in imports on both sides of the border. The domestic market share of Danish firms falls from 92.6 percent to 74.3 percent. Domestic market share of large Danish firms remains high due to firm heterogeneity and the fact that they are closer to Danish projects. In Germany, a slight majority of projects import Danish turbines once the border is eliminated, which reflects the strength of Danish firms (especially Vestas) in the wind turbine industry. On both sides of the border, we see an approximate 20 percent increase in import share when the national boundary is eliminated.

Overall, our results indicate that border frictions generate significant market segmentation between Denmark and Germany. As a back of the envelope illustration, consider the difference between the market share of Danish firms in Denmark and Germany. The gap in the data and baseline model is roughly 60 percentage points. Not all of this gap can be attributed to border frictions since differences in transportation costs due to geography are also responsible for part of the gap. However, when we remove border frictions, our counterfactual analysis indicates that the gap shrinks to 25 percentage points. Thus, more than half of the market share gap is attributable to border frictions. When considering the sources

[28]For space and clarity, we do not report standard errors of changes in market shares in Table 4. All of the (non-zero) changes in market shares across counterfactuals are statistically significant.

[29]Because of this duplication, we simply omit the column which removes fixed cost of entry in Germany in the tables below.

[30]This argument assumes fixed costs of exporting are of the same order of magnitude for both countries, which appears to be the case.

[31]Because adjustments to variable costs may result in a change in firms optimal entry decisions, we are unable to perform a counterfactual eliminating variable border costs alone.

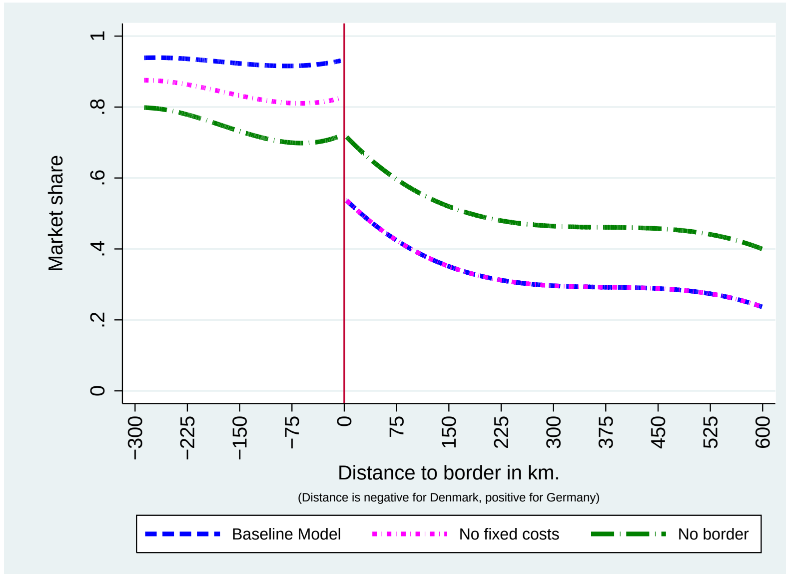

Figure 6: **Counterfactuals: Expected Danish market share by distance to the border.**

of border frictions, we find that removing fixed costs of exporting alone accounts one-third of the market share gap that is attributed to border frictions, while the remaining two-thirds are realized by removing both fixed and variable border frictions. Since fixed and variable costs interact, the overall impact of border frictions cannot be formally decomposed into fixed and variable cost components. We take these results as evidence that both fixed and variable border frictions are substantial sources of market segmentation.

In addition to national market share averages, our model allows us to examine predicted market shares at a particular point in space. In Figure 6, we use the regression discontinuity approach described above to visualize the impact of the counterfactual experiments. The blue (dashed) line represents expected market shares baseline model, and is identical to that presented in Figure 5. The red (dotted) line displays counterfactual expected market shares when fixed border costs are removed. This reduces Danish market share in Denmark, where more German firms enter, but leaves market shares unchanged in Germany, since all Danish firms enter even when fixed costs are present. Finally, the green (dashed-dotted) line shows the counterfactual estimates when all border costs are eliminated. The discontinuity at the border is entirely eliminated, and only the impact of firm-to-manufacturer distances cause differences in market share on either side of the border.[32]

[32]The kink at the boundary is a function of our regression discontinuity approximation method, we estimate either side of the border as a separate cubic polynomial in distance to the border. As we would expect, there is no significant discontinuity at the boundary when all border effects are removed.

Table 5: **Baseline and Counterfactual Profit Estimates.**

	Denmark			Germany	
	Baseline	No Fixed Costs	No Border	Estimates	No Border
Bonus (DK)	47.06	41.02	34.83	47.55	75.46
	(13.00)	(11.98)	(10.71)	(19.52)	(28.88)
Nordtank (DK)	44.70	38.98	33.11	43.29	68.72
	(4.97)	(4.50)	(4.19)	(8.91)	(13.73)
Micon (DK)	82.76	72.63	62.07	80.13	126.74
	(7.36)	(6.80)	(6.75)	(13.62)	(21.14)
Vestas (DK)	156.96	139.46	120.69	164.32	256.08
	(14.60)	(12.46)	(11.83)	(23.60)	(37.23)
WindWorld (DK)	20.73	18.13	15.44	17.35	27.59
	(3.19)	(2.76)	(2.49)	(3.93)	(6.32)
Enercon (DE)		21.46	42.56	428.91	305.06
		(4.54)	(9.37)	(48.68)	(53.60)
Fuhrlaender (DE)		0.57	1.14	17.31	11.98
		(0.26)	(0.56)	(4.20)	(3.28)
Nordex (DE)	6.33	5.43	10.79	75.69	51.24
	(1.82)	(1.48)	(2.45)	(15.15)	(13.20)
Suedwind (DE)		1.09	2.16	21.74	14.85
		(0.37)	(0.78)	(5.23)	(3.90)
Tacke (DE)		6.47	12.93	151.86	104.83
		(1.42)	(3.19)	(16.60)	(17.33)

Note: Scale is normalized by variance of ϵ.

5.2 Firm Profits

We now turn to an analysis of winners and losers from border frictions, starting with individual firms. Table 5 presents the level of operating profits predicted by our model under the baseline and two counterfactual scenarios.[33] While the scale of these profit figures is arbitrary, they allow for comparison both across firms and across scenarios. The table separates profits accrued in Germany and Denmark for each firm. For example, in the baseline scenario, we see that Bonus made 47.06 in profits in Denmark, and 47.55 in Germany. If the border were removed entirely, Bonus's profits in Denmark would fall to 34.83, while their profits in Germany would rise to 75.46. On overall, Bonus would see its total profits increase as a result of the elimination of border frictions, as gains in Germany would more than offset loses from increased competition in Denmark.

From Melitz (2003), we would predict that small firms tend to loose from trade liberalization while large firms tend to gain. It is true that when fixed costs are eliminated, the large German firms—Enercon and Tacke—take the lion's share of the gains. However, we find that all German firms—even the largest

[33]Operating profits are calculated according to (5) and do not include fixed costs.

firm, Enercon—would loose from the entire elimination of the Danish-German border. Underlying this result is the significant size asymmetry between Germany and Denmark. The losses German firms face due to increased competition in the larger German market overwhelm all gains they receive from friction-free access to the Danish market. Our model estimates Danish firms to be highly productive, so eliminating the border is quite costly to German incumbents. In addition, variable border frictions are estimated to be so high that even a small Danish exporter like WindWorld becomes much more competitive in Germany when they are removed. Despite being a relatively small player, WindWorld gains from the elimination of border frictions since increased profits in the larger Germany market outweigh its losses at home. However, WindWorld's gains are insignificant when compared to the gains of the large Danish firms, such as Vestas. Overall, we find that because a German firm's domestic market is considerably larger than its export market, border frictions protect the profit of German firms over those of Danish firms.

5.3 Consumer Surplus and Welfare

Finally, we analyze the overall impact of the border on welfare in the Danish and German wind turbine markets. For each country, Table 6 presents consumer surplus (i.e., surplus accruing to site owners) and firm profits (aggregated by country) under the baseline and our two counterfactual scenarios. For comparison purposes, we normalize welfare such that baseline total surplus for each country is equal to 100.[34] We define domestic surplus as the total surplus in the country that accrues to consumers and domestic firms.

The first column reports the breakdown of surplus under the baseline scenario, we see that in both Denmark and Germany, consumers receive roughly 70 percent of the total surplus. In Denmark, the bulk of the remaining 30 percent goes to Danish firms (recall that only 1 German firm is active in Denmark), while in Germany, approximately 10 percent goes to Danish firms and 20 percent to German firms.

The next two columns present results from the counterfactual where only fixed costs of entry are removed. As discussed above, this counterfactual only affects the Danish market outcomes, since all Danish firms already sell in Germany in the baseline scenario. We report both surplus levels, and the percentage change from the baseline level. Note that, because of the correlation in the level estimates due to the uncertainty in firm fixed effects, the percent change estimates are much more precise than a

[34]Because of its larger size, the total surplus in Germany is much larger than in Denmark, cross country comparisons of total surplus are available by request.

Table 6: **Counterfactual Welfare Analysis by Country.**

		Baseline	No Fixed Costs		No Border	
		(Levels)	(Levels)	(% Chg)	(Levels)	(% Chg)
Denmark	(A) Consumer Surplus	70.15	73.46	4.72	77.42	10.36
		(4.94)	(4.97)	(1.03)	(5.38)	(2.19)
	(B) Danish Firm Profits	29.33	25.83	-11.92	22.16	-24.44
		(0.54)	(0.74)	(2.26)	(1.26)	(4.47)
	(C) German Firm Profits	0.53	2.91	452.99	5.79	999.18
		(0.15)	(0.55)	(122.97)	(1.13)	(297.29)
	Domestic Surplus (A+B)	99.47	99.29	-0.18	99.58	0.10
		(5.17)	(5.11)	(0.07)	(5.09)	(0.25)
	Total Surplus (A+B+C)	100.00	102.21	2.21	105.37	5.37
		(5.09)	(5.07)	(0.51)	(5.39)	(1.28)
Germany	(A) Consumer Surplus	68.99			79.57	15.34
		(6.42)			(8.30)	(1.90)
	(B) Danish Firm Profits	10.43			16.41	57.27
		(1.59)			(2.41)	(4.96)
	(C) German Firm Profits	20.58			14.44	-29.84
		(1.86)			(2.31)	(5.62)
	Domestic Surplus (A+C)	89.57			94.01	4.96
		(5.78)			(6.68)	(1.39)
	Total Surplus (A+B+C)	100.00			110.42	10.42
		(6.72)			(8.59)	(1.77)

Note: Levels are scaled such that baseline total surplus from projects within a country is 100. % Change is percent change from baseline level.

naïve comparison of the level estimates would suggest. Removing fixed costs of exporting causes four German firms to enter the Danish market, which both increases price competition and provides additional variety to Danish site owners. As a result consumer surplus increases by 4.72 percent. Danish firms, who face harsher domestic competition, see profits decline by 11.92 percent. Since the number of German firms increased from 1 to 5, total German profits skyrocket in percentage terms, however this is due to a very small initial base. Even after removing fixed costs, German firms take less than three percent of the available surplus in Denmark in profits. Interestingly, the gains of Danish consumers from removing fixed export costs are almost perfectly offset by the loses from Danish firms. Domestic surplus actually declines by a statistically significant but economically negligible amount. When we account for the gains by German firms, total surplus increases by the statistically and economically significant 2.21 percent.

The final two columns of Table 6 display the surplus effects from removing border frictions entirely. As we would expect, site owners see significant benefits from the removal of border frictions, as consumer surplus rises by 10.36 percent in Denmark and 15.34 percent in Germany. The increase in Denmark is more than twice as high as the increase realized from only removing fixed border costs.

These increases come at the cost of domestic producers, who see home profits decline by 24.44 percent in Denmark and 29.84 percent in Germany.[35] In Denmark, the removal of border frictions results in a transfer of surplus from domestic firms to consumers, netting to essentially no change in domestic surplus. However, when we include the benefits of exporters, total surplus increases by 5.37 percent. The story in Germany is a bit different. Consumer gains outweigh domestic firm losses in Germany and domestic surplus increases by 4.96 percent. Essentially, removing border frictions improves German site owners access to high-productivity Danish firms and erodes Enercon's substantial market power in Germany. When we include the benefits to Danish exporters, elimination of the border raises surplus in the German market by a substantial 10.42 percent.

We conclude this section by repeating an important disclaimer. Our counterfactuals represent complete elimination of the border effect. In reality, the border effect is generated by a complex combination of political, administrative, and cultural differences between countries. Therefore, it is unlikely that any policy initiative would succeed in completely eliminating the border. We prefer to view our findings as illustrative of the magnitude of the border and its effect on firms and consumers in the wind turbine industry. Policy makers may view the results as an upper bound on what can be accomplished through political integration.

6 Conclusion

The large differences in market shares in the wind turbine industry in Denmark and and Germany arise not only through costs associated with transportation, but also through fixed barriers of foreign market entry and higher variable costs associated with crossing the border. These border costs are substantial and our counterfactual analysis shows that the gap in national market shares can be reduced considerably when these costs are eliminated.

The role of national boundaries in the wind turbine industry has important policy implications for the European Union. Due to growing concerns about climate change, many governments, including European Union members and the United States, subsidize the renewable energy generation. As a result, wind turbines are a growing source of the Europe's electricity supply. The efficiency of government subsidies in the wind electricity output market is closely related to the degree of competition in the upstream market for wind turbines themselves, which is the object of our study. While wind energy output is subsidized, the production of wind turbines themselves is relatively free from government

[35] Of course, these declines do not account for benefits realized in the export market. See Table 5 for an accounting of how each firm fairs as both an domestic producer and an exporter under our counterfactual scenarios.

regulation. However, if there are substantial frictions to international trade in turbines, a national subsidy to downstream wind power may implicitly be a subsidy to domestic turbine manufacturers. This is against the intentions of the EU subsidy proceedings that aim to eliminate distortions of subsidies given by member states exclusively to firms operating on their territory. In fact, Denmark, who has some of the highest output subsidies in Europe is also one of the most successful European producers of wind turbines. With large border frictions in the upstream market, EU members may wish to harmonize output tariffs to ensure equal treatment of European firms in accordance with the principles of the European single market project. Further, our results indicate that the welfare gains from a hypothetical removal of all border frictions between Germany and Denmark (including barriers that are difficult to remove such as language) are substantial.

More broadly, our study uses transaction-level data for a specific industry to document the impact of fixed and variable border costs while controlling for several sources of bias which plague analyses of aggregated trade flows. Our model and the detailed geographical information on manufacturers and projects allows us to better control for spatial differences in competition on either side of the border than the existing literature. The model combines conventional tools from the literature into a novel approach to analyze spatial oligopolistic competition in a multi-country setting. We believe the framework outlined in this paper can be useful tool for other researchers with spatial firm level data.

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