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

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- What do we know?
  - Trade between Canadian provinces is 22 times higher than trade between Canadian provinces and US states (McCallum 1995)
  - Deviation from the law of one price in US-Canadian prices implies a border of 75,000 miles (Engel and Rogers 1996).

Issues

- Aggregation bias
  - sectoral - Hillberry (2002), Broda and Weinstein (2008)
  - spatial - Hillberry and Hummels (2008), Holmes and Stevens (2012)

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- Within-country heterogeneity and cross-border differences in market structure
  - Gorodnichenko and Tesar (2009)
- Our approach:
  - Look at a individual purchase decisions in a specific industry, where we can map production locations and delivery points.
  - Use a structural model to control for differences in market structure.

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- document substantial cross-border market segmentation;
- build an oligopoly model with heterogeneous firms and trade;
- estimate distance- and border-related costs, separating border costs into fixed and variable components;
- use the estimated model to analyze counterfactual scenarios in which various border frictions are eliminated.

Preview of Results

- Variable border costs are large: $40 - 50\%$ of overall variable trade costs.
- We put bounds on fixed costs that indicate they are substantial and heterogeneous across firms.
- Counterfactual experiments indicate border frictions decrease industry welfare by 5% in Denmark and 10% in Germany.
- Reduced-form regressions based on price differentials overstate the "width of the border."

Industry & Data

- Wind energy producers own or lease land, and purchase wind turbines from a small number of manufacturers who install and maintain turbines.
- High transportation costs. Transport Technology
- Business-to-business: no local distribution costs
- Investment good: minimal scope for purely demand-driven home-bias
- European single market policy:
  - No tariffs, efforts to eliminate non-tariff barriers.
  - Energy subsidies do not depend on nationality of turbine producer.
- Little exchange rate uncertainty

How Representative Is this Industry?

To assess the representativeness of the industry in terms of trade costs, we run gravity equations on trade flows in wind turbine components (HS codes 730820, 841290, 848340, 850164, 850231, 8482xx, 8501xx).

	I	II
Common border	0.614^{***}	0.634^{***}
	(0.0956)	(0.0850)
Common language	0.405^{***}	0.440^{***}
	(0.0688)	(0.0844)
Common currency	0.276^{*}	0.203
	(0.150)	(0.157)
RTA	0.413^{***}	0.413^{***}
	(0.0838)	(0.0853)
(Log) Distance	-1.088^{***}	-1.142^{***}
	(0.0974)	(0.0885)
Common Intercept	Yes	No
Clustered Errors	Yes	Yes
Fixed effects	Yes	Yes
N	23584	23584
R^2	0.416	0.470

▸ MORE

Data

- All turbine installations in Denmark (296 projects) and Germany (929 projects) in 1995-1996
  - Turbine characteristics (height, KW, diameter, project ID)
  - Manufacturer identity
  - Project location
- Production location for each manufacturer
- Calculate producer-to-project distances (road and great circle)
- No transaction prices

More on data

Firm Market Shares

Manufacturer	Nationality	% Market share in Denmark	% Market share in Germany
Vestas	(DNK)	45.45	12.04
Micon	(DNK)	19.19	8.17
Bonus	(DNK)	12.12	5.05
Nordtank	(DNK)	11.45	4.73
Wind World	(DNK)	4.38	2.73
Total		92.59	32.72

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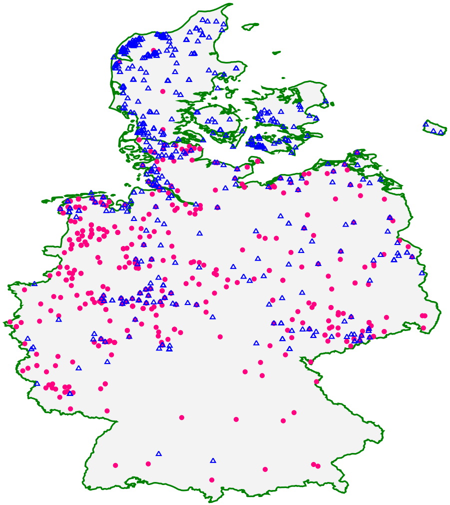
Total		92.59	32.72
Enercon	(DEU)		32.58
Tacke	(DEU)		14.95
Nordex	(DEU)	1.68	7.53
Suedwind	(DEU)		2.37
Fuhrlaender	(DEU)		2.15
Total		94.27	92.3

Project Locations



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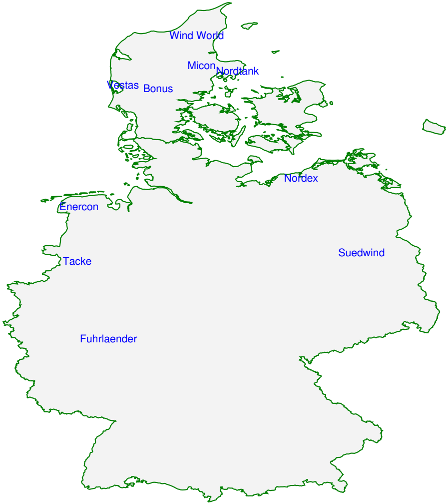
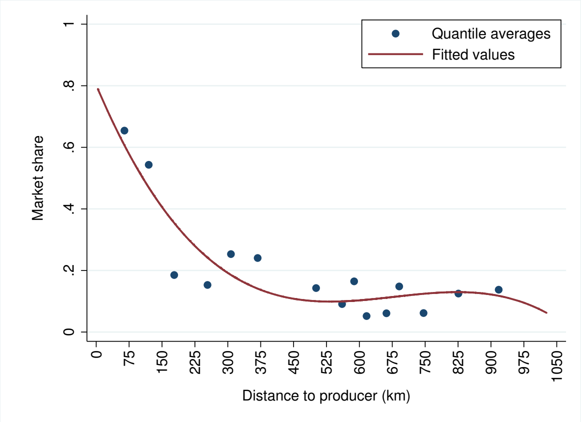
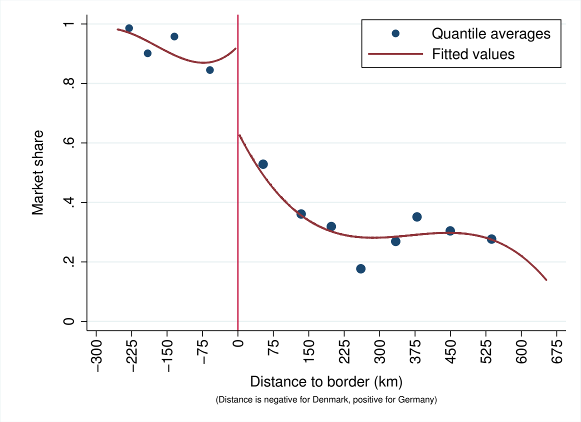


Distance and Market Share



Vestas Market Share by Distance to Plant

Border and Market Share



Danish Market Share by Distance to Border

Regression

Model

Environment

- 2 countries: $\ell \in \{D, G\}$
- Each country has:
  - N_ℓ wind farm locations (projects),
  - A finite set $\mathcal{M}_\ell$ of large heterogeneous firms, each with a production location,
  - A local competitive fringe.
- A finite set $\mathcal{J}_\ell$ of active firms and the fringe compete over projects ($\mathcal{M}_\ell \subseteq \mathcal{J}_\ell$).

Timing of Events

- 1st stage: entry game
  - Pay a firm-specific fixed cost of f_j to enter the foreign market.

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- 1st stage: entry game
  - Pay a firm-specific fixed cost of f_j to enter the foreign market.
- 2nd stage: bidding game
  - Active set of firms in a country ($\mathcal{J}_\ell$) simultaneously submit project-specific price bids for all N_ℓ projects.
  - Project owners independently choose a supplier.

Windfarm owner's problem

- Owner's observe manufacturers' prices and choose best manufacturer to build Windfarm.
- Per-KW payoff of a project owner i for choosing firm j is

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

d_j : quality of the wind turbine j
p_{ij} : price bid by manufacturer j
ϵ_{ij} : unobservable random utility, iid across projects and firms

- Competitive fringe is firm 0 with return

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

CRTS

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$$Pr[i \text{ chooses } j] \equiv \rho_{ij}(\mathbf{p}_i) = \frac{\exp(d_j - p_{ij})}{1 + \sum_{k=1}^{|\mathcal{J}|} \exp(d_k - p_{ik})}$$

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- The probability of choosing the fringe is

$$\rho_{i0}(\mathbf{p}_i) \; = \; 1 - \sum_{j=1}^{|\mathcal{J}|} \rho_{ij}(\mathbf{p}_i)$$

Manufacturer's pricing problem

- The cost of supplying project i to firm j (per KW)

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

where

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

- $\beta_b \cdot \text{border}_{ij}$ is the (variable) border cost.

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- $\beta_b \cdot \text{border}_{ij}$ is the (variable) border cost.
- Alternative specifications
  - heterogenous distance costs: β_{dj}
  - economies of scale in the variable border cost: $\beta_{sb} \cdot \text{border}_{ij} \cdot S_i$

- Game of imperfect but symmetric information: firm observe the identities and all characteristics of active competitors except the valuation vector $\boldsymbol{\epsilon}_i$.
- Engaging in Bertrand-Nash competition, firm solves

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

has F.O.C.

$$p_{ij} = c_{ij} - \frac{\rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})}{\partial \rho_{ij}(p_{ij}, \mathbf{p}_{i,-j})/\partial p_{ij}}.$$

- Using $\rho_{ij}(\cdot)$ from owner's decision, F.O.C. simplifies to an optimal mark-up pricing condition:

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

Fixed Point of the Pricing Game

- Substituting optimal pricing p_{ij} into probability of winning $\rho_{ij}(\mathbf{p}_i)$ yields a fixed point problem with $|\mathcal{J}|$ unknowns and $|\mathcal{J}|$ equations:

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

- A unique pure strategy equilibrium exists for this class of games - Caplin and Nalebuff (1991).

Entry Game

- Expected foreign market operating profits where $\mathcal{J}_{-j}$ is the set of other active firms:

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

- Enter foreign market if

$$\Pi_j(\mathcal{J}_{-j} \cup j) \geq f_j.$$

- Multiple equilibria possible.

Estimation

- Estimation strategy:
  - Take the 1st stage outcome as given:
    observed entry decisions are an equilibrium outcome as in Bresnahan and Reiss (1991).

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  - Estimate the 2nd stage game by maximum likelihood.
  - Calculate fixed cost bounds that rationalize observed entry decisions in the 1st stage.

Substitute

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

into

$$\rho_{ij}^{\ell} = \frac{\exp\left(d_j - c_{ij}^{\ell} - \frac{1}{1-\rho_{ij}}\right)}{1 + \sum_{k=1}^{|\mathcal{J}_\ell|} \exp\left(d_k - c_{ik}^{\ell} - \frac{1}{1-\rho_{ik}}\right)}.$$

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

- Firm-specific quality and production cost parameters are not separately identified.
- Let $\xi_j \equiv d_j - \phi_j$.

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- Let $\xi_j \equiv d_j - \phi_j$.
- Parameter vector to be estimated:

$$\theta = (\beta_b, \beta_d, \xi_1, \ldots, \xi_{|\mathcal{M}_D|+|\mathcal{M}_G|})$$

Maximum Likelihood Estimator

Let $y^{\ell}_{ij} = 1$ if firm j won project i in country ℓ, $= 0$ otherwise.

$$(\hat{\theta}, \hat{\rho}) = \max_{\theta,\, \rho} \sum_{\ell \in \{D,G\}} \sum_{i=1}^{N_\ell} \sum_{j=0}^{|\mathcal{J}_\ell|} (\rho^{\ell}_{ij})^{y^{\ell}_{ij}}$$

subject to

$$\rho^{\ell}_{ij} \;=\; \frac{\exp\left(\xi_j - \beta_d \cdot \text{distance}_{ij} - \beta_b \cdot \text{border}^{\ell}_{ij} - \frac{1}{1-\rho^{\ell}_{ij}}\right)}{1 + \sum_{k=1}^{|\mathcal{J}_\ell|} \exp\left(\xi_k - \beta_d \cdot \text{distance}_{ik} - \beta_b \cdot \text{border}^{\ell}_{ik} - \frac{1}{1-\rho^{\ell}_{ik}}\right)}$$

$$\rho^{\ell}_{i0} \;=\; 1 - \sum_{j=1}^{|\mathcal{J}_\ell|} \rho_{ij}(\mathbf{p}_i) \qquad \forall \ell, i, j$$

▸ Computational

Border and Distance Costs

	Baseline	Heterogeneous Distance Costs	Scale Economies
Border Cost, β_b	0.873	0.880	0.953
	(0.219)	(0.239)	(0.228)
Distance Cost (100km), β_d	0.200		0.193
	(0.032)		(0.032)
Project Size × Border, β_{sb}			-0.063
			(0.053)
Heterogeneous Firm Quality/Productivity	Yes	Yes	Yes
Heterogeneous Distance Cost	No	Yes	No
Control for Project Size	No	No	Yes
Log-Likelihood	-2361	-2314	-2352
N	1225	1225	1225

Robustness to spatial correlation

- Distance elasticities range between
  - 0.95 and 1.4 for exporting firms,
  - 0.17 and 0.83 for domestic firms.

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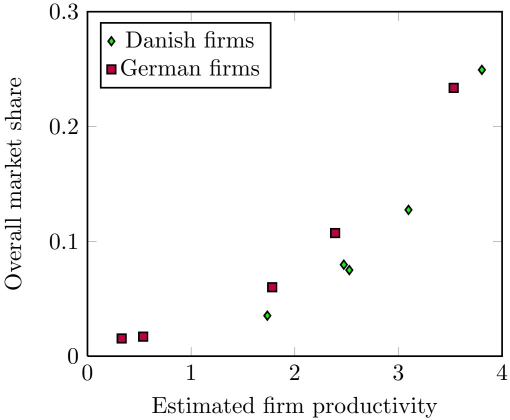
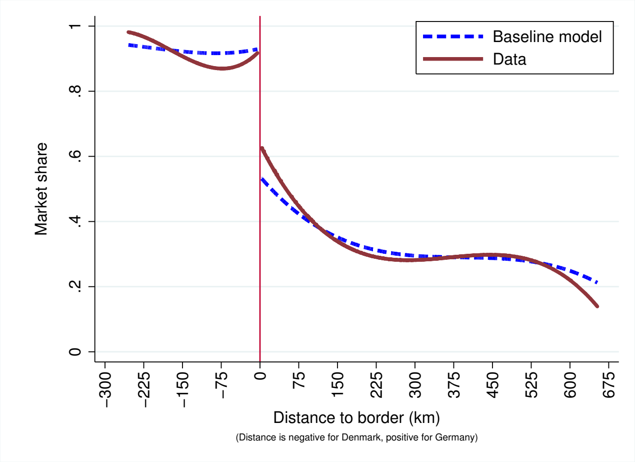
- Average shipping distance from Denmark to Germany is 623 km. For Danish exporters, border costs make up 40% of total variable trade costs; the rest is distance.
- Average shipping distance from Germany to Denmark is 420 km. For German exporters, border costs make up 50% of total variable trade costs.

Firm "Productivity" Estimates



- Consistent with market shares.
- Danish firms are more productive than German firms.

Model Fit



Danish Market Share by Distance to the Border.

Fixed Cost Bounds

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- Using parameter estimates, we calculate expected profit from entering the foreign market, $\Pi_j = \sum_{i=1}^{N} E[\pi_{ij}]$.
- We use Π_j to put bounds on f_j:

$$
\begin{aligned}
f_j &\leq \Pi_j && \text{if a firm is exporting,} \\
f_j &\geq \Pi_j && \text{otherwise.}
\end{aligned}
$$

Table: Fixed Cost Bounds

	Lower	Upper
Vestas (DNK)		163.36
		(23.47)
Bonus (DNK)		47.53
		(19.52)
Micon (DNK)		80.12
		(13.64)
Nordtank (DNK)		43.28
		(8.92)
Wind World (DNK)		17.35
		(3.94)
Enercon (DEU)	22.35	
	(4.89)	
Tacke (DEU)	7.25	
	(1.72)	
Nordex (DEU)		6.32
		(1.82)
Suedwind (DEU)	1.26	
	(0.45)	
Fuhrlaender (DEU)	0.66	
	(0.32)	

Note: Scale is normalized by variance of ϵ.

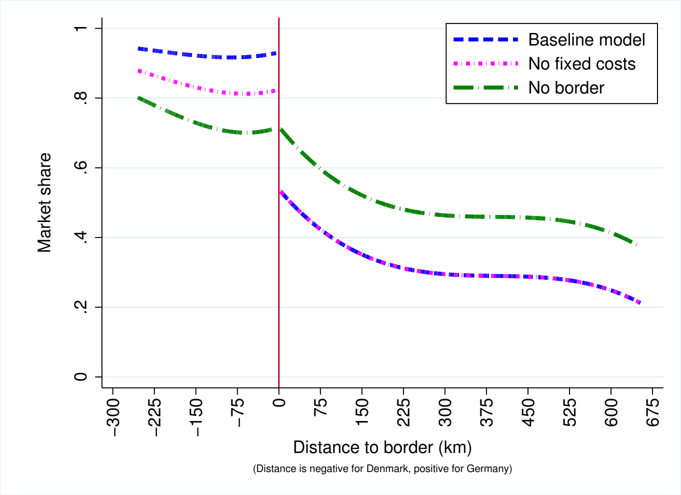
- Firm heterogeneity is needed to explain entry patterns.
- Generally, payoff to entering Germany (a larger market) is much higher than Denmark.

Counterfactuals

We use the model to quantify the impact of border frictions on trade, market shares and welfare.

Two-part counterfactual analysis:

1. Eliminate fixed cost of entry, leaving variable border costs in place.
2. Remove all border frictions (fixed and variable)



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Market Shares

		Data	Baseline Estimates	No Fixed Costs	No Border
Denmark	Danish Firms	92.57	92.65	83.93	74.19
			(1.53)	(2.26)	(3.65)
	German Firms	1.69	2.18	11.56	21.94
			(0.60)	(2.06)	(3.90)
Germany	Danish Firms	32.29	32.36	32.36	49.34
			(5.43)	(5.43)	(7.55)
	German Firms	59.63	59.31	59.31	44.90
			(3.93)	(3.93)	(5.811)

Note: Market share measured in projects won.

- "Gap" in Danish share at home versus abroad shrinks from 60% to 50%.

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Germany	Danish Firms	32.29	32.36	32.36	49.34
			(5.43)	(5.43)	(7.55)
	German Firms	59.63	59.31	59.31	44.90
			(3.93)	(3.93)	(5.811)

Note: Market share measured in projects won.

- Shrinks to 25% percentage points when all border frictions are removed. Remainder is due to distance.

Welfare Analysis: Denmark

	Baseline	No Fixed Costs		No Border	
	(Levels)	(Levels)	(% Chg)	(Levels)	(% Chg)
(A) Consumer Surplus	70.15	73.47	4.73	77.45	10.41
	(4.94)	(4.98)	(1.03)	(5.39)	(2.20)
(B) Danish Firm Profits	29.33	25.82	-11.94	22.13	-24.53
	(0.54)	(0.74)	(2.27)	(1.26)	(4.48)
(C) German Firm Profits	0.53	2.92	454.48	5.82	1005.55
	(0.15)	(0.55)	(123.38)	(1.14)	(299.03)
Domestic Surplus (A+B)	99.47	99.29	-0.18	99.58	0.11
	(5.17)	(5.11)	(0.07)	(5.09)	(0.25)
Total Surplus (A+B+C)	100.00	102.21	2.21	105.40	5.40
	(5.09)	(5.07)	(0.51)	(5.39)	(1.28)

Welfare Analysis: Germany

	Baseline (Levels)	No Border (Levels)	(% Chg)
(A) Consumer Surplus	68.99	79.62	15.42
	(6.42)	(8.30)	(1.90)
(B) Danish Firm Profits	10.43	16.41	57.66
	(1.59)	(2.41)	(4.96)
(C) German Firm Profits	20.58	14.44	-29.96
	(1.86)	(2.31)	(5.62)
Domestic Surplus (A+C)	89.57	94.05	4.98
	(5.78)	(6.68)	(1.39)
Total Surplus (A+B+C)	100.00	110.46	10.46
	(6.72)	(8.59)	(1.77)

- Germans enjoy a 50% higher increase in consumer surplus than the Danes.
- This is despite Denmark experiences new import competition in the extensive margin and Germany doesn't.

- Germans enjoy a 50% higher increase in consumer surplus than the Danes.
- This is despite Denmark experiences new import competition in the extensive margin and Germany doesn't.
- Germans get better access to competitive Danish firms in the intensive margin.
- Danes get benefits of increased competition, but only one highly competitive firm (Enercon) added to the already competitive market.

Reduced-form Border Effect vs. Structural Estimate of the Border Cost

- A typical regression à la Engel and Rogers to estimate the border effect using prices:

$$|p_k^j - p_\ell^j| \;=\; \delta_d^j \cdot \text{distance}_{k\ell} + \delta_b^j \cdot \text{border}_{k\ell} + \delta_k^j + \delta_\ell^j + \epsilon_{k\ell}^j,$$

where p_k^j is the price of a tradeable good j in various cities k, ℓ.

- The "width" of the border is $\frac{\hat{\delta}_b^j}{\hat{\delta}_d^j}$.

We use the estimated model to compare the reduced-form width of the border with its “true” value.

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- An econometrician observes prices p_k^j for ‘good’ j in various locations, thus knows the locations of projects, but not the locations of producers. i.e. she does <u>not</u> observe producer-to-project distances (distance_{kj}).

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Thought experiment:

- Suppose that our model is the correct description of the world.
- An econometrician observes prices p_k^j for 'good' j in various locations, thus knows the locations of projects, but not the locations of producers. i.e. she does not observe producer-to-project distances (distance_{kj}).
- For each producer j, she estimates:

$$|p_k^j - p_\ell^j| \;=\; \delta_d^j \cdot \text{distance}_{k\ell} + \delta_b^j \cdot \text{border}_{k\ell} + \delta_k^j + \delta_\ell^j + \epsilon_{k\ell}^j.$$

Firm	$\hat{\delta}_b/\hat{\delta}_d$ in km
Bonus	844.2
Nordtank	886.5
Micon	816.6
Vestas	709.1
WindWorld	888.9
Nordex	3253.8

while the "true" width of the border is 432 km.

Price differential in the model:

$$|p_k^j - p_\ell^j| \;=\; \left|\hat{\beta}_d\big(\text{distance}_{kj} - \text{distance}_{\ell j}\big) + \hat{\beta}_b\big(\text{border}_{kj} - \text{border}_{\ell j}\big) + \left(\frac{1}{1-\hat{\rho}_{kj}} - \frac{1}{1-\hat{\rho}_{\ell j}}\right)\right|$$

Estimated price differential:

$$|p_k^j - p_\ell^j| \;=\; \delta_d^j \cdot \text{distance}_{k\ell} + \delta_b^j \cdot \text{border}_{k\ell} + \delta_k^j + \delta_\ell^j + \epsilon_{k\ell}^j.$$

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$$\text{distance}_{k\ell} > (\text{distance}_{kj} - \text{distance}_{j\ell})$$

- Omitted variable bias $\Rightarrow \delta_b \uparrow$
  mark-up differential absorbed by the error term, positively correlated with $\text{border}_{k\ell}$

What Are These Costs?

- Fixed border costs:
  - maintaining a national sales presence
  - certification for turbine models
  - national grid connection requirements
- Variable border costs:
  - transportation across the border requires coordination
  - obtaining project permits from a large number of authorities
  - extra contracting costs, language barriers
- Expectations: fear of policy reversals, future exchange rate uncertainty.

Thank You

Computational Method

- Mathematical Programming with Equilibrium Constraints (MPEC) by Judd and Su (2011)
- Instead of nested MLE:

$$\max_{\theta} L(\theta, \sigma(\theta))$$

s.t. $\sigma(\theta)$ is defined by $f(\theta, \sigma(\theta)) = 0$,

Computational Method

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use constrained MLE:

$$\max_{\theta, \sigma} L(\theta, \sigma)$$

s.t. $f(\theta, \sigma) = 0$.

BACK

Regression

$$y_i = \alpha_0 + \sum_{k=1}^{k=3} \alpha_k \cdot \text{distance}_i^k + \gamma \cdot \text{Germany}_i + \sum_{k=1}^{k=3} \eta_k \cdot \text{distance}_i^k \cdot \text{Germany}_i + \epsilon_i.$$

Variable	**Coefficient**	**(Std. Err.)**
Germany	-0.289	(0.115)
constant	0.925	(0.123)
distance	0.002	(0.004)
distance^2	0.000	(0.000)
distance^3	0.000	(0.000)
distance×Germany	-0.005	(0.004)
(distance×Germany)^2	0.000	(0.000)
(distance×Germany)^3	0.000	(0.000)
N		1201
R^2		.279
F		68.352

▸ BACK

Robustness to Spatial Correlation

- Check the iid assumption for ϵ_{ij} draws.
- Could be violated for two reasons:
  - Local unobservables (politics or geographic features of an area)
  - Economics of density (reputation, reduced costs of routine maintenance)

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  - Economics of density (reputation, reduced costs of routine maintenance)
- Moran's I (spatial correlation) of "generalized" errors is 0.1

Robustness to Spatial Correlation

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$$\hat{\epsilon}_i = \gamma + \psi W \hat{\epsilon}_i + \nu_i$$

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  but magnitudes are economically small (0.035 for Vestas, 0.046 for Enercon).
- As a robustness check, we include *"distance to closest installed turbine"* in our cost function: if a supplier gains cost advantage due to previous sales in the area, the coefficient would be negative.

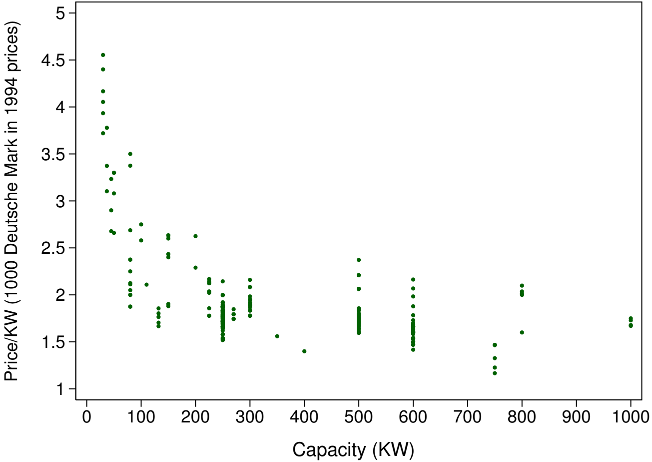
  It turns out to be insignificant.

  $(\beta_d, \beta_b) = (0.14, 0.69)$ vs $(0.2, 0.87)$ in the benchmark.

BACK

Scale Economies

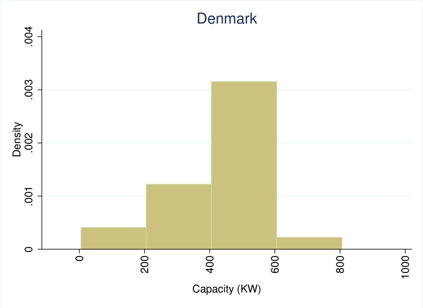
List price evidence

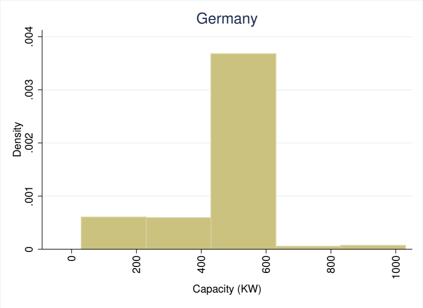


▸ BACK

Observable Product Differentiation?

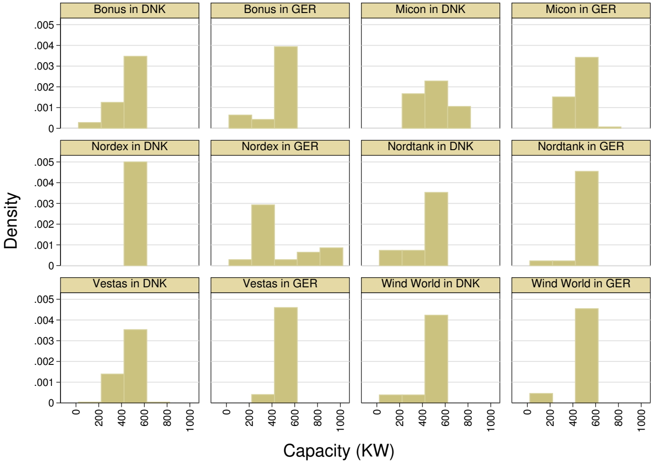
Figure: KW Capacity Histograms by Market





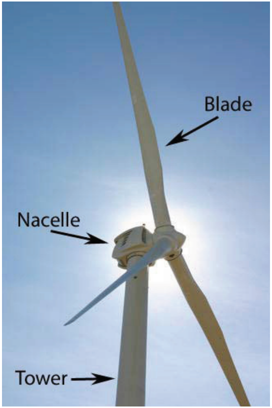
Majority of turbines have 400-600 KW capacity.

No evidence for observable product differentiation by producers across markets:



All producers sold turbines with 400-600 KW capacity in both markets (no scale effect in exporting).

Technology



▸ BACK

BACK

Gravity of Wind

To assess the representativeness of the industry in terms of trade costs, we run gravity equations on trade flows in wind turbine components (HS codes 730820, 841290, 848340, 850164, 850231, 8482xx, 8501xx).

	I	II
Common border	0.614^{***}	0.634^{***}
	(0.0956)	(0.0850)
Common language	0.405^{***}	0.440^{***}
	(0.0688)	(0.0844)
Common currency	0.276^{*}	0.203
	(0.150)	(0.157)
RTA	0.413^{***}	0.413^{***}
	(0.0838)	(0.0853)
Distance	-1.088^{***}	-1.142^{***}
	(0.0974)	(0.0885)
Common Intercept	Yes	No
Clustered Errors	Yes	Yes
Fixed effects	Yes	Yes
N	23584	23584
R^2	0.416	0.470

MORE

Gravity of Wind

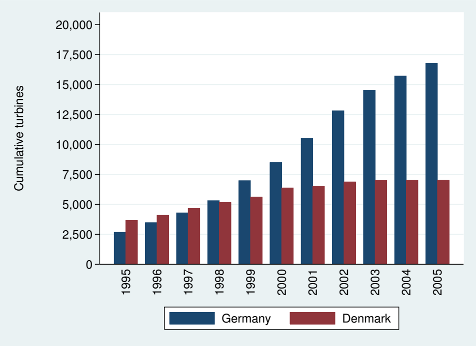
By components:

	I	II	III	IV	V
Common border	0.440	0.909	0.676	0.861	0.281
	(0.168)	(0.176)	(0.297)	(0.187)	(0.278)
Common language	0.570	0.736	0.592	0.885	0.579
	(0.187)	(0.206)	(0.376)	(0.196)	(0.367)
Common currency	-0.157	0.317	-1.010	0.106	-0.134
	(0.205)	(0.264)	(0.451)	(0.205)	(0.314)
RTA	0.330	0.441	-0.137	0.349	0.585
	(0.137)	(0.160)	(0.264)	(0.141)	(0.265)
Distance	-1.404	-1.293	-0.986	-1.436	-0.805
	(0.0937)	(0.118)	(0.182)	(0.0959)	(0.167)
Component	Blade	Tower	Generating sets	Gear box	Generators
N	4561	3265	1380	4106	1430
R^2	0.622	0.448	0.591	0.706	0.610

BACK

Why do we use 1995-1996 data only?

- Stable set of firms, mergers and acquisitions after 1997.
- Buyers are mostly independent power producers.
- Danish market matures after 2000.



BACK