Ex Post Analysis of Economic Impacts from Wind Power Development in U.S. Counties*

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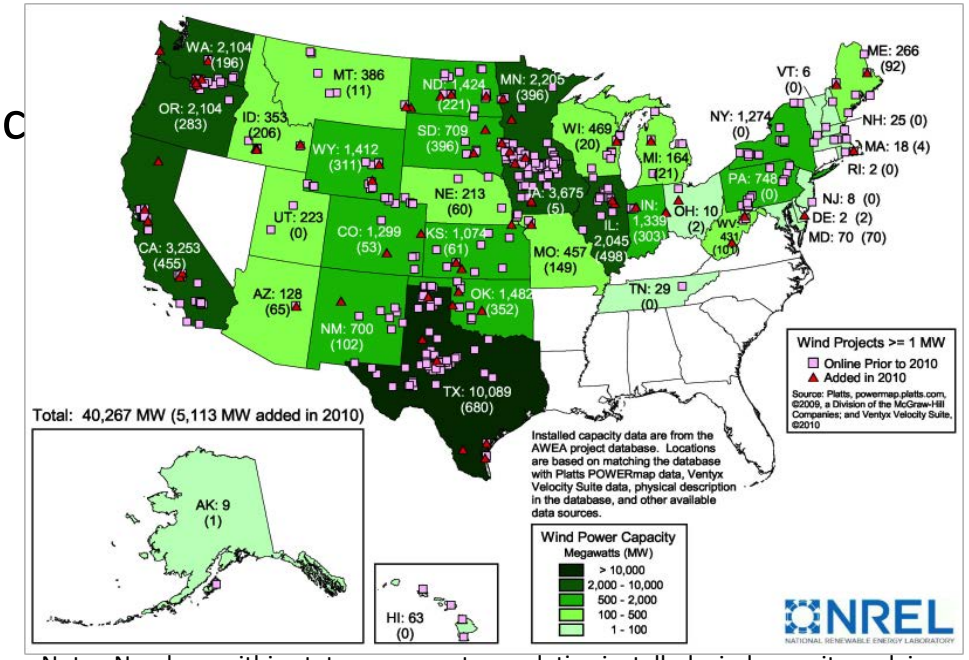
BRIEFING SUMMARY

September 2012

* The views expressed here are those of the authors and may not be attributed to the USDA, Economic Research Service, U.S. Department of Energy (DOE), Lawrence Berkeley National Laboratory, or the National Renewable Energy Laboratory. Berkeley Lab's and NREL's contributions to this work were funded by the U.S. DOE (Wind & Water Power Program) under Contract No. DE-AC02-05CH11231.

Background

- Over the last five years, wind has contributed >30% of the new electric generation capacity in the U.S.
- U.S. is the 2nd largest country in annual wind power additions and in cumulative capacity, behind China
- At the end of 2011, wind was capable of generating >3% of the nation's electricity supply
- Studies have shown that wind energy could one-day meet at least 20% of U.S. electric supply



Note: Numbers within states represent cumulative installed wind capacity and, in parentheses, annual additions in 2010.

- Some concentration in wind installations in the Great Plains and Rocky Mountain regions

Motivation

- Economics of wind energy and federal/state policy have played major roles in driving development
- Motivating factors for policy support include potential environmental benefits, fuel diversity, and **economic development**
  - Possibility of *local* economic development gains is particularly salient in rural areas, where wind power plants are often constructed
- Project-level case studies and modeled input-output estimates are often used to assess economic development impacts, but…
- Questions persist on the existence, magnitude, distribution and durability of these economic development impacts

Research Question and Summary of Approach

- Question: What are the observed county-level personal income and employment effects from wind power development?
- Approach: Conduct *ex post* econometric analysis of the county-level personal income and employment effects of wind power development from 2000-2008 in a large 12-state, wind-rich region of the country
- Unique Aspects: Evaluate *actual* county-level impacts from a large amount of wind development in the central portion of the U.S., accounting for local spatial spillovers from wind development and factors influencing wind turbine locations, while avoiding many of the potential weaknesses apparent in other methods
  - Creates opportunity to loosely test the validity of previous input-output estimates with actual impacts from past wind power development
- Focus is on local, county-level net impacts: current work does not address net effects on a state or national basis

Potential Economic Development Impacts of Wind Development

- Direct employment and income of those employed in the industry, particularly in the construction phase but also in the operations phase
- Demand for various goods and services produced or sold in the local economy from construction and operations expenditures
- Land lease payments made to local landowners on whose land wind turbines are located
- Owners of wind turbines that happen to reside in the local economy spend a portion of the profit from wind project operations locally
- Property taxes or payments in lieu of property taxes paid by wind energy operators to local governments
- Spending by those employed in sector, other local residents, and governments from these additional sources of income may further induce local economic impacts
- Wind power development in one community may affect employment and income in neighboring communities, causing localized feedback effects
- Wind power development may affect overall demand for land and alternative uses of land; alternative investment opportunities; desire of people to live, visit or work in the area → accounting for net effects is important

Existing Literature

- Previous estimates of local economic development impacts have most-often relied on two methods:
  - **Project-level case studies** of the gross, direct impacts of actual wind power plants based on data from particular project developers and/or operators
  - **Input-output model estimates** of potential direct, indirect and induced impacts of individual planned (or completed) wind power plants or of an aggregate amount of assumed wind development activity
- Many input-output analyses have focused on state-level impacts, but limited research on local and county-level impacts during the operations phase has found a range of impacts from:
  - Local employment: 0.1 to 0.6 jobs per MW during operations phase for absentee-owned plants (0.5 to 1.3 jobs per MW for less-common locally-owned plants)
  - Labor income: $5,000/MW to $18,000/MW for absentee-owned plants ($18,000-$43,000/MW for less-common locally-owned plants)
  - Total Economic Output: $13,000 to $55,000/MW for absentee-owned plants ($82,000-$140,000/MW for less-common locally-owned plants)
- We have not found in existing literature *ex post* analyses of county-level impacts using econometric methods applied to aggregate actual wind development

Potential Limitations to Project-Level Case Studies and Input-Output Model Estimates

General	• When applied to local level, typically focus on gross (not full "net") effects (of somewhat lesser concern for local analysis)
Project-Level Case Studies	• Often rely on self-reported data • Focus on direct impacts (typically ignoring indirect and induced impacts) • Representativeness of individual case studies unclear • Results not always presented consistently
Input-Output Estimates	• Assume industrial inputs and factors of production are used in fixed proportions, and that supply is perfectly elastic • Coefficients sometimes based on national data, with imperfect adaptation to local conditions and for new industries • Do not account for households and governments unless other adjustments are made • Displacement and opportunity costs not fully accounted for • Spatial feedback of development on nearby communities not typically captured

Possible Advantages and Disadvantages of Ex Post Econometric Approach

- Possible advantages
  - Need not apply the many assumptions required by input-output models
  - Can be based on large, representative set of actual wind power plants
  - Captures direct, indirect, and induced impacts
  - Substitution, displacement, and net effects within counties are addressed
  - Allows for a more complete set of impacts to be considered
  - Predictions of ex ante input-output models can be loosely tested

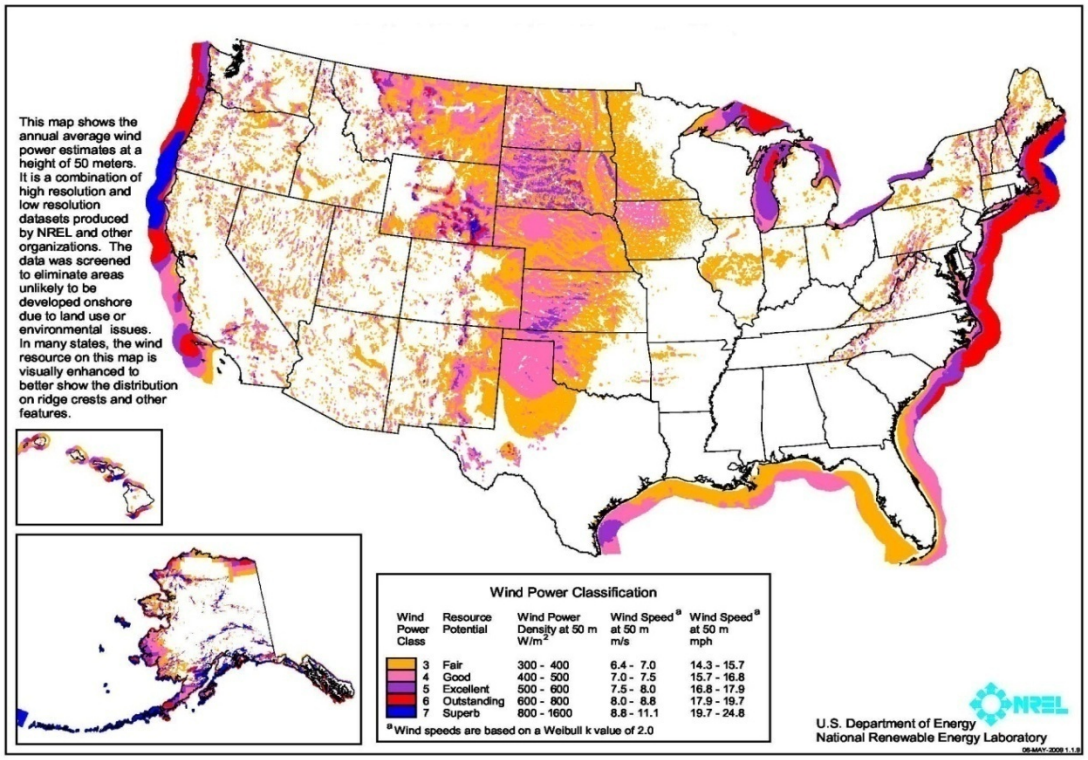
- Possible disadvantages
  - Does not address net effects on a state or national scale
  - Only focuses on past impacts (or forecasting future impacts based on observed past events)

Analysis Focuses on 12-State Region in Great Plains and Eastern Edge of Rocky Mountains

Current analysis focuses on 1,009 counties in 12 contiguous states in the middle portion of country in order to:

- focus on windy states where wind development has occurred
- emphasize a contiguous region of the country with relatively homogenous characteristics

U.S. Wind Resource Map



Empirical Model Used

Changes (2000 – 2008) in county-level annual per capita personal income and employment (*y*) are hypothesized to be affected by:

- a county's socio-economic and demographic characteristics (*X*) measured in 2000 or prior
- a county's total wind power capacity additions in MW per capita (*D*) from 2000 to 2008
- neighboring counties' total wind power capacity additions (W*D*) from 2000 to 2008
- state-level fixed effects (*S*)

$$y = Z(X,D)\beta + WD\delta + \alpha S + u,$$

where *W* is a (n x n) spatial weight matrix defining neighbors

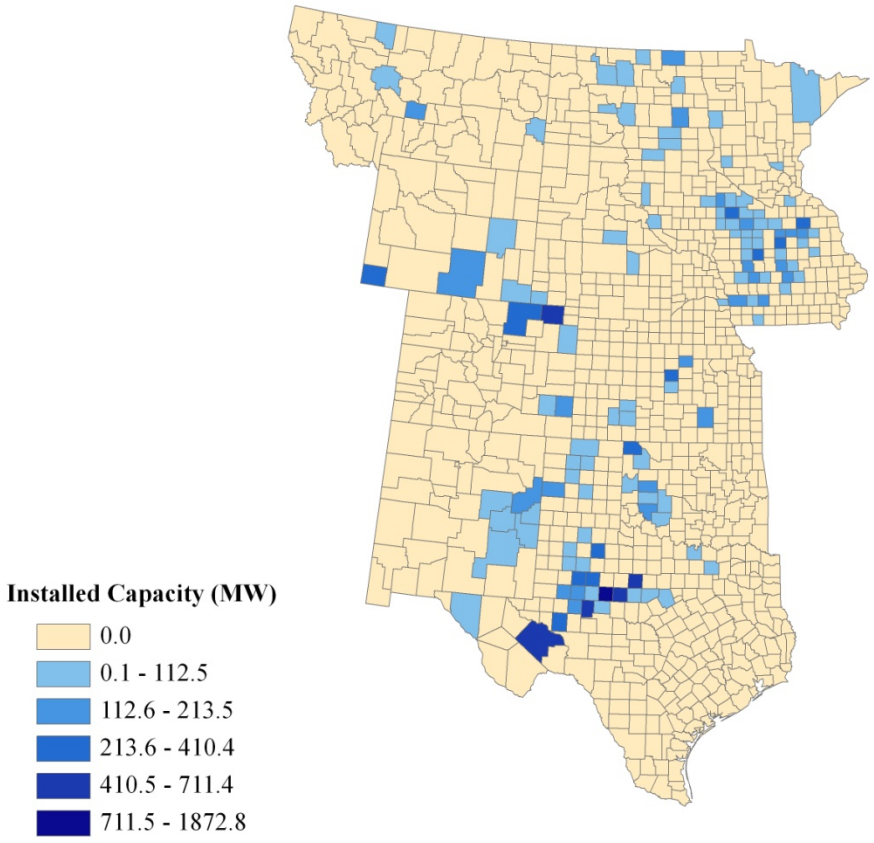
Accommodates endogeneity with instrumental variables: accounting for endogeneity in turbine location important because change in income could impact amount of wind capacity, or because wind capacity is impacted by unobserved factors that themselves impact income

Instrumental variables for wind turbine location: (1) presence and (2) level of total wind power technical resource potential (class 3 through 7); establish instrument validity with weak instrument, over-identification, and exogeneity tests

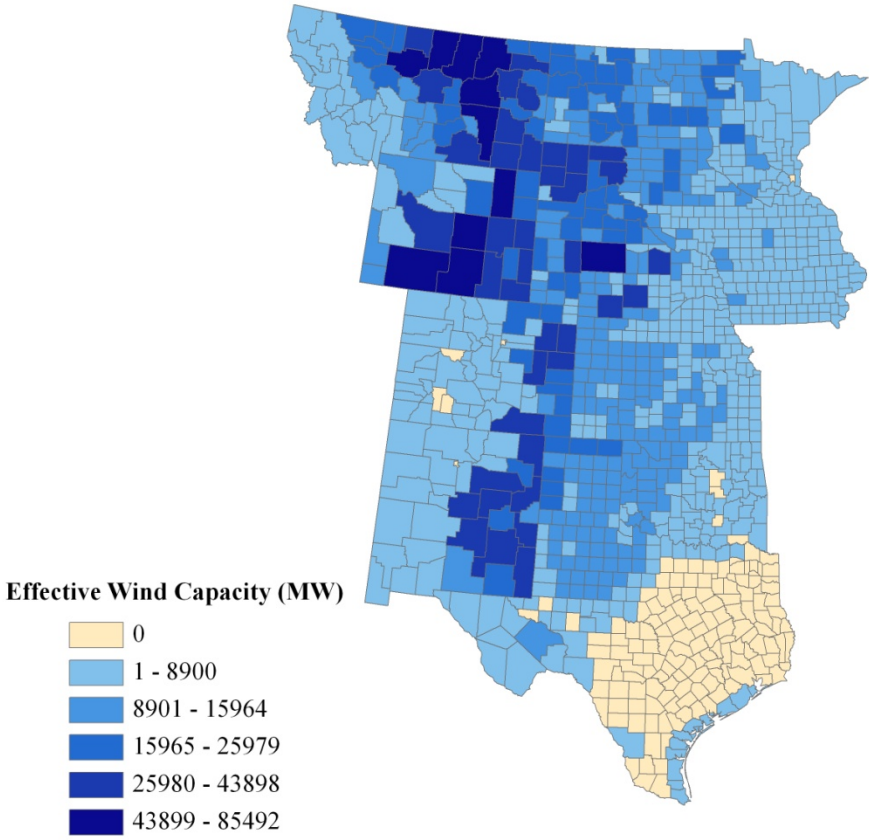
Factors Influencing Change in Per Capita Income and Employment: Control Variables

- **Initial conditions** – per capita personal income in 2000
- **Economic Demand** – population level and poverty rate
- **Economic growth** – distance to population centers and natural amenity scale
- **Urban agglomeration economies** in context of rural/urban interdependencies – population density, metro county
- **Economic structure and regional specialization** – shares of employment in agriculture, construction, manufacturing, and retail trade; share of farmland to total area
- **Human capital** – share of adult population with associates, bachelors, and masters degrees
- **Labor accessibility** – unemployment rate, share of adult men and women working full time
- **Demographics and consumption ability** – rural share of population, farming share of population, African American share of population, children share of population, elderly share of population
- **Infrastructure and government assistance** – miles of Interstate highway, and population weighted distance to highway on-ramp
- **State fixed effects –** to control for differences in unobserved state policies or conditions that might impacts changes in per capita county income

Factors Influencing Change in Per Capita Income and Employment: Actual Wind Power Capacity Installed at County-Level from 2000 to 2008



County-Level Wind Power Technical Resource Potential: Used to Develop Instrumental Variables for Wind Power Capacity Additions



Summary Statistics

Variable	Label	Mean	Std. Dev.
Change in per capita income 2000 – 2008[1] ($/capita)	dpci	11593	5488
Change in per capita employment 2000 – 2008[1] (jobs/capita)	demp	0.050	0.056
Change in installed wind capacity 2000 – 2008 (MW/capita)	mwcap	0.003	0.022
Technical wind resource potential (power class 3 – 7, MW)	twrp	8042.33	9422.48
Per capita income ($)[1]	pci	23640	5370
Population (thous.)[1]	pop	45.20	166.08
Poverty rate (%)[2]	poverty	13.43	5.98
Natural amenity scale[3]	nascale	3.45	1.13
Agriculture, forestry, fishing, & hunting share of employment[1]	agffh	0.11	0.09
Construction share of employment[1]	const	0.07	0.02
Manufacturing share of employment[1]	manuf	0.11	0.07
Retail & trade share of employment[1]	retrade	0.11	0.02
Adult population (25 yrs >) with associates degree (%)[2]	pedas	6.05	2.07
Adult population (25 yrs >) with bachelors degree (%)[2]	pedbs	12.23	4.60
Adult population (25 yrs. >) with masters degree (%)[2]	pedms	3.48	1.88
Population density (persons per square mile)[2]	popdens	57.75	221.03
Amount of Interstate highway (miles)[4]	interst	12.44	22.31
Distance to nearest urban population of 25,000(miles)[5]	d25k	43.53	38.95
Distance to nearest urban population of 100,000 (miles)[5]	d100k	93.38	75.25
Distance to nearest urban population of 250,000 (miles)[5]	d250k	154.00	109.86
Distance to nearest urban population of 500,000 (miles)[5]	d500k	238.80	165.68
Distance to nearest urban population of 1,000,000 (miles)[5]	d1000k	402.80	243.21
Unemployment rate (%)[6]	uer	3.83	1.56
Farmland share of total acres[7]	farmland	0.42	0.28
Population weighted distance to highway on-ramp (km)[5]	hwyaccess	45.60	43.02
Rural population share[2]	rurpopsh	0.65	0.31
Farmer population share[2]	frmpopsh	0.09	0.08
African American population share[2]	afrpopsh	0.02	0.05
Child population share[2]	chdpopsh	0.26	0.03
Elderly population share[2]	eldpopsh	0.16	0.05
Share of adult men working full time[2]	wfullmsh	0.65	0.06
Share of adult women working full time[2]	wfullwsh	0.42	0.05
Metro county (yes/no)[8]	metro	0.20	0.40

Notes: N = 1,009; Source: [1] Bureau of Economic Analysis, REIS; [2] Census Bureau, 2000 Census; [3] Economic Research Service; [4] US DOT; [5] ERS GIS team calculations; [6] Bureau ofLabor Statistics; [7] Census Bureau, U.S. Counties; [8] Office of Management of Budget

Empirical Models

- **OLS:** assumes no local spatial spillovers and that wind power development (*mwcap)* is exogenous
- **Instrumental Variables 1 (IV 1):** assumes no local spatial spillovers but that wind power development (*mwcap)* is endogenous
- **Instrumental Variables 2 (IV 2):** accounts for local spatial spillovers and assumes that wind power development (*mwcap, and Wxmwcap)* is endogenous

- Results for IV 2 model suggests weak instruments bias and found no statistical evidence for spatial spillovers→ results presented here for IV 1 model are preferred

Empirical Models: Regression Output

Personal Income

	OLS		IV Estimation		IV Estimation – Local Spillovers	
Variable	Coefficient	Robust S.E.	Coefficient	Robust S.E.	Coefficient	Robust S.E.
mwcap	9326.30**	4858.10	11150.05**	5410.78	13948.23**	6268.66
W×mwcap					-10593.58	11614.18
pci	457.74***	159.19	458.89***	162.51	457.28***	163.12
pop	-2.05	1.27	-2.05	1.30	-2.06	1.30
poverty	3.65	105.96	6.69	108.20	8.69	108.56
nascale	150.71	131.31	151.06	134.11	158.51	134.15
agffh	-17346.00***	6018.60	-17383.61***	6149.17	-17573.79***	6162.49
const	-12938.00	9232.60	-12648.34	9432.33	-13076.99	9606.09
manuf	-24799.00***	2881.70	-24740.39***	2944.06	-25007.41***	2990.97
retrade	-7169.80	9242.90	-7069.71	9440.70	-7627.98	9529.68
pedas	215.86**	95.44	215.64**	97.52	212.87**	97.80
pedbs	-47.69	91.53	-48.18	93.47	-48.39	93.66
pedms	-400.69***	153.90	-399.62**	157.24	-410.88***	158.31
popdens	-0.09	0.92	-0.09	0.94	-0.10	0.94
metro	-1467.80***	366.43	-1458.50***	374.42	-1458.54***	374.28
uer	261.29	170.40	259.04	174.95	250.08	175.10
interst	10.22	8.54	10.20	8.73	10.00	8.72
farmland	1245.50	915.45	1254.78	935.34	1301.06	936.79
hwyaccess	10.25*	5.49	10.28*	5.61	10.22*	5.62
d25k	-3.74	4.51	-3.78	4.61	-3.94	4.61
d100k	3.14	3.20	3.15	3.27	3.08	3.28
d250k	-1.89	2.57	-1.90	2.63	-1.82	2.63
d500k	3.21***	1.13	3.24***	1.16	3.26***	1.16
d1,000k	-0.35	0.71	-0.36	0.73	-0.39	0.73
rurpopsh	2206.10***	828.51	2194.24***	846.41	2133.58**	851.29
frmpopsh	10340.00	6336.60	10331.45	6469.94	10264.92	6475.08
afrpopsh	2427.70	3134.50	2519.21	3200.89	2462.54	3216.80
chdpopsh	-19243.00**	8823.80	-19247.39**	9013.07	-19521.30**	9024.85
eldpopsh	-3740.70	8182.10	-3592.00	8353.54	-3466.64	8358.86
wfullmsh	20288.00***	5134.90	20409.65***	5246.88	20627.76***	5249.64
wfullwsh	-17788.00***	4961.00	-17810.95***	5068.54	-17796.97***	5078.13
constant	6011.40	6330.20	5832.22	6464.29	6009.57	6496.73
Adj. R^2	0.38		0.41		0.41	
F-test (IVs)	–		9.26***		2.72***, 11.77***	
Hansen J	–		7.30		7.67	

Employment

	OLS		IV Estimation		IV Estimation – Local Spillovers	
Variable	Coefficient	Robust S.E.	Coefficient	Robust S.E.	Coefficient	Robust S.E.
mwcap	-0.0655	0.1000	0.4817*	0.2812	0.3721*	0.2253
W×mwcap					0.0835	0.2732
pci	0.0028*	0.0016	0.0031*	0.0016	0.0031*	0.0016
pop	-0.00002	0.00001	-0.00002	0.00001	-0.00002	0.00001
poverty	-0.0001	0.0012	0.0008	0.0013	0.0006	0.0013
nascale	0.0009	0.0015	0.0010	0.0016	0.0010	0.0016
agffh	-0.0989	0.0784	-0.1101	0.0819	-0.1068	0.0813
const	-0.2971***	0.1128	-0.2102*	0.1183	-0.2207*	0.1190
manuf	-0.2200***	0.0387	-0.2023***	0.0403	-0.2031***	0.0392
retrade	-0.2195*	0.1207	-0.1895	0.1237	-0.1899	0.1220
pedas	-0.0006	0.0014	-0.0007	0.0015	-0.0006	0.0014
pedbs	-0.0019	0.0014	-0.0021	0.0014	-0.0021	0.0014
pedms	-0.0012	0.0033	-0.0009	0.0034	-0.0009	0.0034
popdens	-0.00002	0.00001	-0.00002	0.00001	-0.00002	0.00001
metro	-0.0181***	0.0053	-0.0153***	0.0054	-0.0156***	0.0054
uer	0.0019	0.0023	0.0013	0.0026	0.0014	0.0025
interst	0.00002	0.0001	0.00001	0.0001	0.00001	0.0001
farmland	-0.0363***	0.0114	-0.0335***	0.0119	-0.0343***	0.0120
hwyaccess	0.00001	0.00006	0.00002	0.0001	0.00002	0.0001
d25k	-0.00006	0.00005	-0.0001	0.0001	-0.0001	0.0001
d100k	0.00002	0.00004	0.00002	0.00004	0.00002	0.00004
d250k	-0.00002	0.00003	-0.00002	0.00003	-0.00002	0.00003
d500k	0.00001	0.00001	0.00002	0.00001	0.00002	0.00001
d1,000k	0.000001	0.00001	-0.000003	0.00001	-0.000003	0.00001
rurpopsh	0.0047	0.0102	0.0011	0.0107	0.0022	0.0105
frmpopsh	0.0333	0.0675	0.0308	0.0778	0.0317	0.0752
afrpopsh	-0.0561	0.0467	-0.0287	0.0475	-0.0326	0.0480
chdpopsh	-0.2001*	0.1183	-0.2015*	0.1216	-0.1991	0.1227
eldpopsh	0.0413	0.0868	0.0859	0.0902	0.0778	0.0897
wfullmsh	0.2839***	0.0778	0.3205***	0.0849	0.3129***	0.0834
wfullwsh	-0.1262*	0.0678	-0.1330*	0.0712	-0.1321*	0.0706
constant	0.0037	0.0808	-0.0500	0.0829	-0.0428	0.0820
Adj. R^2	0.21		0.21		0.22	
F-test (IVs)	–		9.26***		2.72***, 11.77***	
Hansen J	–		1.08		1.03	

Results: Personal Income

N = 1009 counties	OLS	IV 1	IV 2
mwcap	9,326**	11,150**	13,948**
Adj. R^2	0.38	0.41	0.41
Durbin-Wu-Hausman		7.98***	
F-test for weak instruments		9.26***	2.72***, 11.77***
Hansen J		7.30	7.67

Asterisks represent statistical significance at the 90%, 95%, and 99% confidence levels.

Because the outcome measure is the change in per capita personal income from 2000 to 2008, while the key explanatory variable is wind power installations over 2000-2008, the results should be dominated by operating period impacts, but will also be influenced by construction period impacts associated with wind power plants built in 2008.

Results: Employment

N = 1009 counties	OLS	IV 1	IV 2
mwcap	-0.07	0.48*	0.37*
Adj. R^2	0.21	0.21	0.22
Durbin-Wu-Hausman		1.90*	
F-test for weak instruments		9.26***	2.72***, 11.77***
Hansen J		1.08	1.03

Asterisks represent statistical significance at the 90%, 95%, and 99% confidence levels.

Because the outcome measure is the change in per capita employment from 2000 to 2008, while the key explanatory variable is wind power installations over 2000-2008, the results should be dominated by operating period impacts, but will also be influenced by construction period impacts associated with wind power plants built in 2008.

Results: Interpretation

OLS results: Each additional MW of wind power installed from 2000-2008 increased annual total county-level personal income by **$9,326** in 2008 and had no statistically evident impact on employment in 2008, relative to 2000: but… endogeneity of wind power development question the results of this model

Instrumental Variables Model 1 results: Each additional MW of wind power installed from 2000-2008 increased annual total county-level personal income by **$11,150** in 2008 and increased total county-level employment by **0.48** in 2008, relative to 2000

Conclusions

- The first *ex post* study to use detailed econometric methods to measure the economic development impacts of wind power installations in U.S. counties
- Taking into account factors influencing wind turbine location, wind power development between 2000 and 2008 is found to have increased total annual personal income in 2008 by approximately $11,150 per MW and increased total employment by 0.48 per MW
- Translates to a median increase in total county-level personal income of 0.22% for counties with wind development from 2000-2008 (0.03% and 0.86% at the 25th and 75th percentiles)
- Translates to a median increase in total county-level employment of 0.4% for counties with wind development from 2000-2008 (0.1% and 1.4% at the 25th and 75th percentiles)

Comparison to Input-Output Estimates

- These econometric results are not strictly comparable to the input-output estimates presented earlier because they:
  - emphasize the broader category of personal income rather than the narrower category of labor income (or the even-broader category of total economic output)
  - include construction period impacts for installations occurring in the year 2008
  - represent the estimated net effect of wind power development
- Nonetheless, the estimated impacts of ~$11,150/MW and 0.48 jobs/MW are of a similar general magnitude to input-output derived estimated impacts on labor income ($5,000/MW to $18,000/MW) and employment (0.1 to 0.6)
- Though not strictly comparable, this suggests that input-output estimates of the economic impacts of wind energy (at least at the county or local level) may not be unduly impacted by the generic limitations to those models discussed earlier and do not appear to be over-stating the impacts of wind development

Future Research Possibilities

- Evaluation of net vs. gross effects on a state, national and global basis
- Attempt to separate construction- and operation-period local economic development impacts
- Extend econometric analysis to other outcome variables including migration and property values
- Extend econometric analysis to decompose income impacts into constituent parts, e.g., wage vs. rental
- Extend econometric analysis to additional years and more regions of the country