Renewable resource rents, taxation and the effects of wind power on rural economies

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Abstract: The rapid growth of utility-scale wind energy generation is a potentially important boon to rural economies in the United States. Yet econometric estimates suggest that the local economic benefits of wind energy generation have been modest, perhaps because the sector is capital-intensive and financed almost exclusively by external capital. In this paper we argue that a) both the presence of a critical - but unpaid - factor of production (the wind) and generous federal subsidies are quantitatively important sources of economic rent, and b) a large portion of these rents accrue to providers of capital who reside outside the local economy. We build a partial equilibrium model that illustrates the mechanisms that generate economic rent, and integrate it into a small open economy general equilibrium model of a county's economy. We calibrate the partial and general equilibrium models to data from two rural counties in Indiana, quantify the economic rents, and consider the consequences of a resource rent tax. Resource rent taxes generate significantly larger economic benefits for communities that host wind power, and offer an opportunity to spread the sector's economic benefits more broadly within them. Broadly distributed revenues from resource rent taxes might facilitate greater acceptance of utility scale wind power in communities where the sector would otherwise be unwelcome. State public utility commissions provide an analytical infrastructure that could support local taxation of the kind that we consider.

Keywords: Renewable resources, wind power, resource rent tax, rural economic development

JEL codes: F11, D33, D58, H71, R13

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"Industries based on cheap sources of energy or producing fuels and minerals are typically capital-intensive and, in a developing country, they have limited scope for local purchase of supplies. Hence, whatever national benefit is to be derived from them must come mainly through taxation. The central task of economic management in the resource-based industries is thus to maximise the contribution that these industries make to government revenue." Garnaut and Clunies Ross (1975)

"Never seen (a wind) project die because of tax structure." Anonymous wind developer quoted in Mills and Rozuno (2018)

I. Introduction

In 2020, 337.5 million megawatt hours (MWh) of electricity were generated by wind power in the United States, up from only 5.6 million MWh in the year 2000 (Table 7.2b, EIA 2021a). The *utility-scale* generation assets that produce the vast majority of this electricity are typically located in rural areas, and their presence is seen as a potential boon to the local economies in which they are located (Ailworth 2017).[1] The presumed positive effects of the industry on rural economic development have been a key political rationale for federal subsidies to the sector (Grassley 2020). But the industry is capital intensive, and financed almost exclusively by capital that is external to the communities that host it. The sector buys few intermediate inputs, and most of its capital goods are purchased from outside the counties where generation assets are installed. These features of the sector can act to limit the local economic impact of wind energy generation.

A small empirical literature finds that local benefits from the arrival of utility-scale wind power are modest.[2] Relatedly, many local governments have restricted investments in utility-scale wind generating capacity through moratoria, outright bans, or by imposing restrictive provisions that make utility-scale investments uneconomical.[3] These facts raise the question: *Are there policies that can magnify the local economic benefits of hosting wind powered electricity generation, thus making community acceptance of wind-powered turbines more likely?* This paper investigates the possibility that state and local tax policy can increase the local benefits the sector generates. The paper also investigates a related set of questions concerning the likely effects of the arrival

[1] DOE (2012) defines "utility-scale" turbines as those with nameplate capacity of 1 megawatt (MW) or more. The utility-scale projects we consider consist of many large turbines located in proximity to one another on "wind farms." Utility-scale turbines are subject to local oversight, especially through limits the planning commission imposes on the siting of large structures.
[2] See Brown, *et al.* (2012), De Silva, *et al.* (2016), and Mauritzen (2020). We review this literature later in the paper.
[3] See Bednarikova, *et al.* (2020) for further discussions of local policies used to restrict wind power generation in Indiana. Bessette and Mills (2021) study the phenomenon in the broader context of the US Midwest.

of wind power on the distribution of incomes in local economies, and the scope for local tax policy to affect distributional outcomes. A maintained hypothesis in our analysis is that a more even distribution of the benefits generated by the sector would improve its chances of broader acceptance in rural America.[4]

To address these issues we build and calibrate a small open economy model with endogenous investment in a rural county's wind sector. The general equilibrium model is a multi-sector adaptation of Corden and Neary (1982), with the wind energy sector as the booming sector.[5] The model is static, but external providers of capital must earn a return that is at least as high as their opportunity cost in order to provide factor services to the wind energy sector. The arrival of the wind energy sector generates economic rents, which are attributable to a) the presence of an important unpaid factor of production (the wind), and/or b) generous federal subsidies. We use data from two counties in Indiana to quantify the size of these rents, and to identify the factor owners who receive those rents. A resource rent tax allows the rents to be redistributed without limiting investment. In the calibrated model we redistribute rents to the local citizenry, subject to the constraint that the construction of utility-scale wind farms remains incentive compatible, both for external capital and for local landowners who must accept the presence of turbines on their land. The rents that the tax extracts from external capital provide additional income to residents of the county, income that increases demand for locally supplied retail services. The consequences of this increase in demand follow the standard intuition of Corden and Neary, but their magnitude is weakened by our assumption that consumers can imperfectly substitute retail services from outside the county for domestic retail services with a rising relative price.

[4] A key rationale given for restricting investments in generation capacity is typically the negative externality that the turbines impose on the local viewscape. We do not model this externality or attempt to quantify it. We presume that only a small minority of the local population - those residing in the immediate vicinity of the turbines - are materially affected by changes in the viewscape. Our view of the problem is that the venue for local political contests around the matter (the local planning commission) is one that gives outsized influence to this vocal minority. The relatively small number of direct local beneficiaries of the industry (i.e. the landowners hosting the turbines and a small number of not-yet-present well-paid workers who service them) may lose this political contest. More broadly distributed material benefits (including payments to those who live and work in the local towns) would presumably broaden the coalition of county residents that would support acceptance of the turbines.

[5] Our choice of a Dutch Disease model is intended to highlight the possibility of negative economic consequences of the sector's arrival on some local agents, especially employers in the other tradeable industries. The model also captures a potentially important positive channel, local spending of new income generated by the sector, which we view as an important aspect of the problem.

Our case study focuses on data from the initial wave of utility-scale wind turbines constructed in the U.S. state of Indiana. Most of these investments were supported by incentives from the American Recovery and Reinvestment Act of 2009 (ARRA). We calculate that production from these investments generated approximately $9.72 of economic rent per MWh of electricity produced in the counties we study.[6] These rents accrue primarily to external capital owners, but also to landowners who lease their land for use by the wind farms. In a general equilibrium in which we assume that all locally-supplied factors are owned by a single representative agent, we calculate that the *arrival* of the wind powered electricity generation industry raises real incomes by 1.1 percent in the smaller of the two counties and by 0.2 percent in the larger county. We estimate that an incentive compatible resource rent tax that captures a larger share of the rents for local communities could increase local incomes by as much as 9.1 percent and 2 percent, respectively. These benefits are the result of increased tax payments by the sector to local governments, which rise by a factor of seven in each county when rent taxes are imposed. In order to highlight the distributional consequences - of the sector's arrival and of the rent tax - we extend the model, assigning income from locally supplied factors to distinct agents and allowing the redistribution of tax revenues to be targeted solely to local suppliers of labor. The redistribution of all economic rents to labor via taxation raises real labor income by 16 percent in the smaller county and by 3.5 percent in the other.

Our paper is a contribution to the literature on the efficient taxation of natural resource rents. Garnaut and Clunies-Ross (1975) argue that a) the capital intensity of mining projects and b) limited scope for local sourcing of inputs means that the primary economic benefits of mining projects for developing countries must come mainly through taxation. In the context of mining, highly volatile commodity prices are a potential source of resource rents, and the authors propose a time-consistent approach to taxing such rents. The circumstances of wind energy – in terms of capital intensity and limited local sourcing – are similar to the developing country mining context, but the sources of economic rent are different. We argue that the presence of an unpaid - but critical - factor of production (the wind) is an important source of rents, as are generous federal subsidies paid to facilitate investment in the sector. Our identification of resource rents in

[6] The size of these rents vary over time. Changes in the rents are driven by changes in turbine technology, the prices of electricity and changes in the scale of federal subsidies to the sector. Technology has improved since the period we study, even as prices in long-term electricity contacts and federal subsidies have fallen. We consider the implications of such changes for our analysis in section 6.

a renewable energy sector appears to be novel, relative to the resource rent literature, which has focused on non-renewable resources, especially petroleum.[7]

We also contribute to the literature on economic impacts of wind energy. A large number of studies - generally conducted outside the discipline of Economics - employ input-output models in an effort to quantify *ex ante* economic impacts of wind power in national and/or state contexts.[8] A more recent literature has used *ex post* econometric methods to measure the effect of investments in wind energy or other renewables on economic outcomes at the county level.[9] Such studies are useful for measuring aggregate outcomes, but have limited ability to quantify distributional consequences or to assess the impact of local economic policy choices.[10] Our approach, a calibrated general equilibrium model, is better suited to tax policy analysis than is either econometrics or input-output modelling.[11]

Our work is tangentially related to the recent literature on the economic impact of place-based policies.[12] Federal subsidies to the wind sector, which were made especially generous in response to the global financial crisis, indirectly subsidize investment in a subset of rural areas with adequate wind resources and relatively easy access to the electric grid. In our work these federal policies are exogenous, but their existence creates room for local governments to respond optimally, taxing excess profits earned through investments subsidized by federal policy. Federal

[7] See Lund (2009) and Smith (2013) for reviews of the resource rent tax literature.

[8] The JEDI model (NREL 2004) is an input-output framework that has been developed specifically for this purpose. The use of an input-output model is intended to highlight the economic contribution of demand spillovers to upstream sectors that provide inputs (both intermediates and inputs in capital goods used in the sector). NREL (2014) use the JEDI model to study the impacts of the first 1000 MW of capacity in Indiana. Such estimates suffer from the standard weaknesses of the input-output framework for economic analysis (see Gretton 2013). Input-output models are also poorly suited for analysis of tax policy, which is a primary focus of our analysis.

[9] Brown, *et al.* (2012) use an instrumental variables model to estimate a causal effect of new wind generating capacity on per capita income. In a sample of counties in the US Midwest, they estimate that the arrival of the wind sector in the years 2000-2008 increased the personal income by 0.2 percent and employment by 0.4 percent for the median county. In a sample of Texas counties, De Silva, *et al.* (2016) estimate that the arrival of 100 MW of capacity generates an increase of 0.03 percent increase in per capita income in the median population county. Mauritzen (2020) estimates that a 400 MW wind farm generates a 2 percent permanent increase in local wages on average, but also finds significant variability across locations in the size of the estimated effect**.**

[10] De Silva, *et al.* (2016) appears to be the only study that has addressed distributional outcomes. Their OLS regressions using data from Texas find a smaller impact of wind capacity on median incomes than on mean incomes. The authors also find cross-industry heterogeneity in the effect of the sector's arrival on employment and sales**.**

[11] Connolly (2020) uses a computable general equilibrium model to study the effect on Scotland of offshore wind energy developments. Like his, our paper studies the likely consequences of the sector's arrival on a local economy. We also isolate resource rents and consider the implications of taxing those rents.

[12] Prominent examples include Klein and Moretti (2014) and Busso, *et al.* (2013). Neumark and Simpson (2015) offer a review. Popp, *et al.* (2020) study the impact of the entire set of green subsidies in the ARRA on local employment.

subsidies are one source of economic rents in the sector, rents that state and local governments can capture through efficient taxation. We demonstrate that economic rents in the sector can be sizable, and show that the taxation of these rents can raise local incomes and ameliorate distributional consequences of the arrival of utility scale wind generation on a local economy.

These lessons have an important policy context. The growth of renewable energy in the United States is subject to substantially more local control than is the case in other countries (Bessette and Mills, 2021). In the context that we study (Indiana), local restrictions on the construction of utility-scale turbines are thought to have reduced investments in wind energy production by as much as $5 billion.[13] Foregone investments in other states would expand that number considerably. Larger and more evenly distributed economic benefits from wind energy generation would presumably make hosting the sector more attractive to rural communities, whose consent is critical to meeting national and international renewable energy goals.

The organization of the paper is as follows. Section 2 provides technological, policy and geographical background. Section 3 describes the partial equilibrium model and calibrates the model to quantify economic rents. Section 4 outlines the general equilibrium model and an extension. In section 5 we calibrate the general equilibrium model and use it to quantify the potential implications of a resource rent tax. Section 6 offers a brief discussion of the administrative viability of local resource rent taxes. Section 7 concludes.

Section 2. Background and setting

The qualitative insights of the models we develop are quite general, but in order to provide quantitative insights we calibrate them to a specific context. Because wind generation technology changes rapidly over time, model calibration depends on the choice of a specific time period. We believe the period surrounding the global financial crisis is of interest because a) federal subsidies to the sector were large and transparent, and b) this period saw rapid growth in utility-scale wind power generation capacity, including the introduction of the sector into many rural communities. In this period, the predominant technology consisted of turbines with approximately 1.5 MW of nameplate capacity, and "hub heights" of approximately 80 meters. Our calibration depends on the technical and cost parameters of this generation of turbines.

[13] This estimate is from the Indiana Conservative Energy Alliance, a lobby group supporting more wind energy development that is quoted in Bednarikova (2020).

The development of the utility-scale wind power sector has been generously supported by the United States federal government. The longest-lived subsidy has been the production tax credit (PTC), which is per unit production subsidy for electricity produced by renewable fuels.[14] Since 2008, wind energy developers have had the choice to receive an up-front investment tax credit (ITC) instead of the production-dependent PTC (CRS, 2020). As part of the federal government's response to the global financial crisis, Section 1603 of the ARRA authorized federal grants to subsidize investments in projects beginning in 2009 or 2010 (CRS, 2020). The high cost of acquiring external capital during the global financial crisis made these grants a preferred alternative to the ITC and PTC during the latter half of the time period we study. Information on the size of Section 1603 grants made to individual projects is publicly available, which is another reason that our calibration considers the impact of projects constructed during this time period.

Section 2.1 Geographical context

Although our insights are, for the most part, general to other locations, we focus our attention on two neighboring counties in West-Central Indiana: Benton County and White County. These were the first two counties in Indiana to host utility-scale wind farms, and those counties received their initial investments during our period of interest.[15] The wind conditions in both counties are similar, and the initial investments in wind energy production were at large and similar scales. The counties have similar economic structures, though White County has a larger population and agriculture plays a smaller role there. We use data from the two counties because the comparative approach offers insight into the effects of the industry on counties where the size of the wind sector, relative to the population, is substantially different.

Table 1 provides some context about the two counties, reporting economic and demographic statistics in 2007 (a period roughly coincident with the installation of the first turbines). BEA (2020) estimates of the counties' total personal income - which we take to be good indicators of the counties' economic size - put White County near the median US county in 2007, while Benton County is near the 25th percentile. Using population rather than income as a measure of

[14] Wind facilities that begin construction prior to January 1, 2022 receive $0.018/kWh of production during the first ten years of operation (EIA 2021b). The PTC was first authorized in 1992 (CRS, 2020).
[15] The entire first round of investments in White County were subsidized through the 1603 program. Some investments in Benton County preceded the program, and so received different forms of subsidy.

county size, these two counties are somewhat smaller, relative to the distribution of US counties. Both counties' per capita incomes are above the US median, with Benton County having somewhat higher value of per capita income than White County. White County is at the 55th percentile of US counties in population density, and Benton County is at the 32nd percentile.

Table 1. Demographic and economic characteristics of case study counties.

	Benton County, IN		White County, IN	
	Level	Percentile in US	Level	Percentile in US
Personal income (2007)	$292 million	0.233	$778 million	0.512
Population (2007)	8,805	0.190	24,762	0.485
Per capita income (2007)	$33,190	0.665	$27,802	0.566
Population density (2000)	23.13 persons / sq mile	0.320	49.92 persons / sq mile	0.550
Net cash farm income (2007)	$52.3 million	0.869	$72.9 million	0.928
Corn sales (2007)	$84.9 million	0.963	$103.4 million	0.979
Soybean sales (2007)	$44.3 million	0.967	$36.7 million	0.932
Nameplate capacity of generating assets (2011)	840.55 MW	0.989	500.85 MW	0.960
Estimated value of electricity (2011)	$178.8 million	n/a	$106.8 million	n/a

Table notes: Personal income, population and per capita income data from BEA (2020). Net cash farm income, corn sales and soybean sales from 2007 US Census of Agriculture. Generating capacity data are taken from Hoen*, et al.* (2018). The estimated value of generated electricity are author calculations that incorporate the capacity figures, a capacity factor of 0.38**,** and a $63.86 per MWh price of electricity. $63.86 was the median levelized price in PPA contracts concluded during the years 2007-2010 for projects that operate in the territory of the Midwest Independent System Operator.

In order to understand the dependence of the two counties on agriculture, we report statistics from the 2007 US Census of Agriculture. Total net farm income in the two counties is quite high by US standards; in 2007, both counties were in the top 15 percent of US counties. The ratio of net farm income to total personal income was approximately 0.18/1 in Benton County, and 0.09/1 in White County. Agriculture in both counties is dominated by corn and soybean production. Both counties were in the top 5 percent of US corn-producing counties, and the top 10 percent of soybean-producing counties.

Finally, we turn to the size of the wind sector in the two counties. Because we wish to focus our analysis on the first wave of investments in the counties, we report values of generating capacity that began operating prior to 2011. At the end of 2010, the two counties had 840.55 MW (Benton) and 500.85 MW (White) of installed capacity that was operational. At that time, both counties' installed capacity measures put them in the top four percent of the 349 US counties with installed capacity. Put another way, Benton County was ranked 5th among US counties in wind generating capacity at the close of 2010, and White County 15th. There were no operational utility-scale turbines in either county as late as 2007, so the initial wave of investments in these two counties is clearly large, even in the context of a much larger US market.

In order to put the size of the sector in further context, relative to the local economies, we estimate the market value of wind generated electricity produced in each county in 2011. Assuming prices of $63.86 per MWh and a capacity factor of 0.38 (two values we use throughout our subsequent calculations, and justify later in the paper) the installed capacity in Benton County produced electricity worth approximately $178.8 million in Benton County and $106.8 million in White County. These estimates suggest that the value of the electricity generated in the two counties is of the same order of magnitude as corn and soybean sales combined.

In our view the figures in Table 1 support a claim that these two counties are a useful laboratory for studying local implications of wind power. Both counties host a large wind sector, which allows for sizable impacts of wind energy generation on the local economy. The two counties have similar wind conditions, and, during the period we study, installed turbines with similar technological capabilities. The counties differ somewhat in the scale of the wind sector, and in the population, so the size of the wind sector on a per capita basis is larger in Benton than in White County. The consequences of this difference are visible in our results.

Section 3. A partial equilibrium model of renewable resource rents

We begin the description of our modeling framework by outlining a static partial equilibrium model of production in the utility-scale wind energy sector. Although the time profile of costs and revenues in the sector would seem to be quite different, the structure of the industry is such that the use of a static model is reasonable.[16] In the model firms make an annualized output

[16] The sector is capital intensive, and the vast majority of these costs are paid up front. Most of the ongoing costs are also predictable at the time of investment. Leases for the land used to host the turbines are contracted through the length of the project. Payments to a local government are either negotiated up front or are largely predictable tax liabilities. Labor costs linked to ongoing maintenance are also largely predictable. Electricity prices are known at the

decision taking output and input prices, subsidies and taxes as given. Output quantities are constrained by limits the local government has set on the amount of generating capacity allowed. Economic rents emerge as the gap between revenues (gross of subsidies) and costs (gross of taxes). Rents in the model can be understood as supernormal profits earned by the industry because the counties' good wind conditions allow the factor bundle to produce at an average cost that lies below the contracted price of electricity. One can also conceive of these rents as payments that would go to a hypothetical supplier of local wind services, if there were one. Federal subsidies also contribute to the size of these rents.

We first describe an important constraint on production: at any given time the number of installed turbines depends upon the decisions of a local government (i.e. the local planning commission). Aggregate capacity in a county is calculated as the sum of the 'nameplate' capacities of each of the installed turbines. We represent the quantity of nameplate capacity installed in a county as V.[17]

Another key factor in the supply of wind energy services is the quality of the local wind resource. The engineering literature on wind-generated electricity defines the "capacity factor" of a wind turbine or wind farm as a parameter that translates nameplate capacity into expected electricity output.[18] The capacity factor takes into account both the technological features of the turbines and the quality of the wind resource in which they are located. The capacity factor enters as a parameter in our model, and we denote it a.

Firms in the model maximize profits by choosing the quantity of electricity output, E. The choice of E is constrained by the number of turbines allowed by the county government and by the capacity factor a. In order to represent production in units of MWh, we also represent the number of hours in a year as h. Formally, we represent the physical constraint on production as

$$E \leq aVh. \qquad (1)$$

beginning of the project (and fixed through the life of the project) via Power Purchase Agreements (PPAs), in which a counterparty commits to purchasing the future stream of electricity at a known, fixed price. Federal subsidies are also known (and sometimes paid entirely) at the beginning of the project.

[17] The Latin term for wind is *ventum*, so we use V to indicate variables relating to the wind. This follows from a similar convention that indicates land with the letter T, following the Latin for land, *terra*.

[18] Variable wind conditions and the need for occasional repairs mean that the turbines are not always in operation, and sometimes operate at less than full speed. The capacity factor is a productivity measure that links nameplate capacity (which measures capacity of the turbines at full speed) to the actual output of electricity.

The industry maximizes profits, subject to (1). A Lagrange multiplier representation of the problem is as follows:

$$\max_{E,\lambda} \mathcal{L} = (P_E + S - C(\overline{IP}, 1))E + P_V(aVh - E) \qquad (2)$$

where P_E is the price of electricity per MWh (set outside the county), S a per unit production subsidy from the federal government, $C(\overline{IP}, 1)$ a unit cost function given a vector of prices for market-supplied inputs $\overline{IP}$, and $(P_E + S - C(\overline{IP}, 1))E$ are the profits available to this price-taking but output-constrained industry. P_V is the Lagrange multiplier on the supply constraint, and represents the implicit factor price of wind services.

The first order Kuhn-Tucker conditions associated with the optimization of (2) are as follows

$$P_E + S - C(\overline{IP}, 1) - P_V \leq 0 \quad \perp \quad E \geq 0 \qquad (3)$$

and

$$aVh \geq E \quad \perp \quad P_V \geq 0 \qquad (4)$$

where $\perp$ indicates a complementary slackness condition. Using (3), note that $E > 0$ implies that P_V measures the gap between revenues and costs per unit of energy. This is the resource rent.

To facilitate transparent calibration to available data, we define the unit cost function $C(\overline{IP}, 1)$ as a Cobb-Douglas function that uses the prices of capital, labor, land and intermediate inputs. Denoting these, respectively as P_K, P_L, P_T and P_M, the unit cost function in the model is written as

$$C(\overline{IP}, 1) = (P_K(1 + ptax))^{\alpha_K} P_L^{\alpha_L} P_T^{\alpha_T} P_M^{\alpha_M}$$

where the α terms are cost shares that sum to 1. This formulation also includes an annualized measure of local taxes paid by the wind industry (*ptax*), which would include property taxes as well as other payments.[19]

Factor incomes are attributable to two sources: standard payments for factor services, and (potentially) a share of the economic rents. Normal factor payments are calculated by applying

[19] The normal return on capital in the model, P_K, is taken to represent the return that capital holders earn after corporate and other federal and state taxes have been assessed. This is consistent with its treatment in the study we use to detail annualized production costs. The taxes we consider in this paper are only local taxes on the wind industry: property taxes and our proposed resource rent tax.

Shephard's Lemma to the cost function, and multiplying by the factor price and the scale of output. Income from economic rents is allocated to the factors in a manner that is determined outside the model.[20] We denote the share of total rent payments that accrue to factor *f* with the parameter γ_f, with $\sum_f \gamma_f = 1$. The income paid to factor *f*, Y_f is the sum of the normal factor returns and the rent payments:

$$Y_f = \alpha_f C(\overline{IP}, 1)E + \gamma_f P_V V.^{21} \quad (5)$$

The partial equilibrium model consists of equations 3-5. The model solves for variables P_V, E, and Y_f given values of the parameters P_E, S, P_f, α_f, a, V and γ_f. Calibration of the partial equilibrium model requires data-driven choices of its input parameters, given observed values of the equilibrium.[22]

Section 3.1. Calibration of the Partial Equilibrium Model

We calibrate the model by choosing parameters that are consistent with publicly available information on the expected revenues, cost components, subsidies received and taxes paid by the developers who constructed the 80-meter turbines in Benton and White Counties during the years 2007 to 2010. Our data come from a mix of sources. Estimates of output at the county level rely on data for *V*, which we take from Bednarikova *et al.,* (2020). The capacity factor *a* is a representative value for this generation of turbines, 0.38 (see Tegen, *et al.* (2012)). Available information on county-level estimates suggest this figure is reasonable for Benton and White Counties.[23] The number of hours in a year is *h* = 8670. Tegen, *et al.* (2012) detail components of annualized costs of construction and operation for turbines that use the technology we consider. We take these figures to be inclusive of rents, and use available data on factor quantities

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[20] In practice the allocation of rents is determined by contracts that outside capital negotiates with the landowners. Some of the rents also appear to be shared with local governments through "economic development" payments.

[21] Note that for Cobb-Douglas functions, simple manipulation following Shephard's lemma returns $\alpha_f \frac{C(\overline{IP},1)}{P_f}$ as the unit demand for factor f. Multiplying by P_f turns quantities into values, so unit factor payments become $\alpha_f C(\overline{IP}, 1)$.

[22] When we move to calibration of the GE model we will also make appropriate price normalizations.

[23] The information available on capacity factors in the two counties is not precise, but suggests that the local capacity factors may be slightly higher than the figure we use. NREL calculations of capacity factors for 60,000 square kilometers in Indiana shows that approximately 5000 square km in Indiana have capacity factors for 80M turbines that exceed 0.35. The best locations in the state have capacity factors as high as 0.42. The figure does not show the location of the most productive acres within Indiana, but other NREL data show that a region including these two counties hosts the best wind conditions in the state. See figures 3 and 1 in Bednarikova, *et al.* (2020). We believe 0.38 to be a conservative estimate of the capacity factor for these turbines in these locations.

employed and on factor prices to determine the portion of the industry's payments to factors that compensate the factors' opportunity costs. The remaining payments to individual factors are taken to be rents. Project level estimates of federal investment subsidies under the 1603 program help us to pin down an estimate of S. Translation of all information into common units (MWh of electricity) allows an estimate of the economic rent per unit of output, P_V. This information is reported in Table 2.

A critical component of the calibration is our estimate of the price of electricity. Normally this price is volatile, but a useful feature of the industry for our calibration is that wind turbine investments are typically funded through long-lived Power Purchase Agreements (PPAs) that see an electricity buyer commit to paying a fixed price for all the electricity produced throughout the life of the project.[24] Wiser, *et al.* (2021) provide a database of PPA prices, over time and geography. This database provides data on contract prices, but does not link the reported prices to specific projects. The data are comprehensive however, and we are able to collect PPA price data for projects located with the area administered by the Midwest Independent System Operator (MISO) for the years 2007-2010. PPA prices in this region during this time period have a mean of \$65.56/MWh and a median of \$63.86/MWh.[25] We use the median price as the price relevant to our calibrations.

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[24] These contracts are critical for the wind farm developers because they can be used as leverage to obtain lower cost financing. Contract buyers benefit from the ability to lock in a fixed price of electricity for a long duration, typically 20-30 years. The risk of subsequent fluctuations in the price of electricity are borne by the electricity buyer, who does not appear in our model.

[25] The range is quite large, from \$40.69 to \$124.93/MWh. However, the gap between the contracts at the 25th and 75th percentile is much smaller: \$54.53/MWh to \$73.77/MWh. The wide range of prices is likely due to the fact that the PPA data include the prices of renewable energy certificates (RECs), which are marketable certificates that capture the additional market value linked with the production of renewable energy. Our conversations with market participants indicate that the value of RECs typically depend on the degree to which state level renewable portfolio standards. Strict portfolio standards for utilities located in a state generates sizable demands for RECs in that state. Indiana's portfolio standards are not linked solely to the production of renewable energy, and are therefore not binding during this period.

Table 2. Calculation of per unit costs and economic rents, turbines installed 2007-2010

Item	Citations	Per 1.5MW turbine (1 acre)	Per MW	Per MWh
PPA price	Wiser et al., (2021)			$63.86
Gross capital cost	Tegen et al. (2012)	*$3,232,500*	$2,155,000	$61
Section 1603 grants	U.S. Dept of Treasury (2011)	*$828,028*	*$552,018*	*$15.86**
Net capital cost				*$45.14**
O&M (with land lease and labor)	Tegen et al. (2012)	*$51,000*	$34,000	$10
O&M (without land lease and labor)	Tegen et al. (2012); Bednarikova et al. (2020)			*$6.96 (Benton)** *$7.13 (White)**
Labor cost	Bednarikova et al. (2020)	*$9,183 (Benton)* *$5,028 (White)*	*$6,122 (Benton)* *$5586.15 (White)*	*$1.84 (Benton)* *$1.67 (White)**
Land lease payment	Bednarikova et al. (2020)	*$6,000*	$4,000	*$1.2*
Cash rent for land	Dobbins et al. (2007)	$157/acre		
Assumed opportunity cost of land		$1,000/turbine		*$0.2**
Implied landowner economic rent	Own calculation			*$1**
Capital economic rent	Own calculation	*$42,252*	*$28,168*	*$8.72**

Table notes: This table provides source information and figures used to calibrate the partial equilibrium model and calculating economic rents. * Indicates own estimation.

Tegen, *et al.* (2012) provide detailed information on the elements of costs associated with the construction, operation and maintenance of a 1.5 MW turbine of the generation we consider. Their levelized cost of energy (LCOE) calculations imply that capital costs were $61/MWh for the projects we study. These estimates assume a real, after-tax “fixed charge rate” of 9.5 percent and a 20-year project life.[26] The calculations also assume a mix of debt and equity financing at interest rates observed in projects constructed during our period of interest. Our rent calculations presume that rate of return assumed in Tegen et al (2012) fully compensates outside capital for its opportunity costs.

[26] Tegen et al, citing Short et al (1995), define the fixed charge rate as “the amount of revenue per dollar of investment that must be collected annually from customers to pay the carrying charges on that investment. Carrying charges include return on debt and equity, income and property tax, book depreciation, and insurance.”

The capital costs of all of the White County projects we study (as well as one of the Benton County projects) were offset to degree by the grants from section 1603 of the ARRA. US Dept of Treasury (2011) offers project-level detail on section 1603 grants awarded. Since all of the White County projects used this funding mechanism, we use payments to White County projects to estimate the scale of the subsidy *S*. Those payments totaled $276,478,428, which corresponds to $912,470 per 1.5 MW turbine, or approximately $15.86/MWh of energy produced (Department of Treasury, 2018). Our estimate of the net capital cost paid by developers is thus $45.14/MWh.

Most of the other costs of production are paid by the developers over the life of the project. These are largely predictable, and their approximate scale published in the literature. Tegen, *et al.* (2012) put operating and maintenance (O&M) costs of this generation of turbines at $10/MWh. O&M costs include payments to landowners, labor, and suppliers of intermediates.

To estimate labor costs, we extrapolate backward local estimates of direct labor employed by the industry in Benton and White counties (from Bednarikova, *et al.* (2020)), and of estimated compensation costs in the industry.[27] These calculations imply labor costs of $1.84/MWh in Benton County and $1.67/MWh in White County. We assume that these are normal factor payments, without any embedded rents.[28]

Landowners in the region who had turbines installed on their land in 2007-2010 receive payments of approximately $6000-$7000 per turbine annually.[29] We consider these to include both payments for factor services and a share of the economic rents. Landowners are in a position to extract rents because they control the industry's access to the wind. But accepting the turbines also generates an opportunity cost - the market value of factor services that the land would otherwise provide. One estimate of the opportunity cost would be the cash rental rate for

[27] We collected the annual salary for wind technicians from Indeed.com, approximately $60,000/year. Bednarikova (2020) reports locally-sourced data on 2020 employment for our two counties. We require employment data for 2007-2010, which we lack. We assume that employment is proportional to total nameplate capacity. Total capacity during the period of interest was approximately 75% of the value in 2020. As such, we assume that wind employment from 2007-2010 was 75% of the reported employment figures in Bednarikova (2020). We multiply by $60,000 to estimate the approximate wage bill.

[28] Workers in the sector earn high wages, relative to local counterparts. In our view, these reflect additional skill, joint production with high levels of capital, and hedonic wages linked to irregular schedules and the possible dangers of turbine maintenance activities.

[29] These prices are contracted and subject to non-disclosure clauses, so there is no formal data available. Several different sources in the counties have nonetheless provided estimates attributable to "coffee shop talk." It appears that the contracted prices are in fact quite similar, and in the range of $4000/MW of capacity per turbine per year. We therefore use $6000/ turbine in our estimates for 1.5 MW turbines.

farm land. One local official interviewed for Bednarikova, *et al.* (2020) suggests a working assumption that one acre of land is required for each turbine. In a survey of cash rental rates for west central Indiana, Dobbins, *et al*. (2007) report the average cash rental rate for agricultural land in this region was $157/acre in 2007. In order to be conservative in our rent calculation, we assume an opportunity cost of $1000/turbine.[30]

Assuming a $6000 annual payment, and a $1000/turbine opportunity cost of the associated land, landowners earn economic rents of $5000 per turbine. Our standard adjustments for the capacity factor and for annual hours of operation put the value of landowners economic rent at $1/MWh. The implied market value of land's factor services is $0.20/MWh.

Of the $10/MWh of O&M costs, the calculations so far imply that approximately $3/MWh in Benton County and $2.87/MWh in White County are paid to suppliers of land and labor. We attribute the remaining O&M costs to intermediates.[31]

We calculate the economic rents accruing to capital as the revenue ($63.86/MWh) less operating and maintenance costs ($10/MWh) and the cost of private capital ($45.14). Economic rents to capital owners, presumably resident outside the county, thus amount to $8.72/MWh.[32] As noted above, landowner rents are (conservatively) $1/MWh. Together these imply total rents in the sector of $9.72/MWh. Together, these estimates imply model parameters of γ_K = 0.897, and γ_T = 0.103.

In order to move to quantitative exercises we also need to calibrate the electricity generation sector's cost function, $C(\overline{IP}, 1)$. This entails calculation of factor and input cost shares. Were there no rent embedded in the Tegen. *et al.* estimates, the denominator for calculating cost shares would be $71 (total gross cost per MWh). Since that figure does include rents, and taxes, we

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[30] This would account for either higher rates of land use (because of access roads, for example), or additional costs of allowing turbines that put the opportunity cost of land above the cash rental rate.

[31] Tegen, *et al.* also include payments to governments in the O&M costs. These payments turn out to be somewhat large, relative to the county economies, but small relative to the cost of building and maintaining the turbines. In our model, we include a role for the industries' existing payments to local governments. We treat these payments as an *ad valorem* tax imposed on wind industry capital, since property taxes are the primary source of such payments.

[32] In their estimates of capital costs, Tegen, *et al.* assume straight line depreciation of capital costs. The Modified Accelerated Cost Recovery System (MACRS) offers a more generous tax treatment by allowing more rapid depreciation schedule. If we recalculate, assuming that the developers applied MACRS, we estimate that these projects earned rents of $12.36/MWh. We use the smaller figure as it offers a more conservative estimate of the benefits of resource rent taxation.

adjust the denominator in the share calculation. \$71 less \$9.72 of rent on the turbines generates a denominator of \$61.28/MWh. The numerator in the calculation of the capital share α_K is the total cost of capital less the capital providers' economic rent, or \$52.28/MWh. This implies $\alpha_K = 0.86$. The factor share of land in the cost function is calculated with the opportunity cost (\$0.2/MWh) over \$61.28 ($\alpha_T = 0.003$). The labor share is $\alpha_L = 0.028$ in Benton County and $\alpha_L = 0.015$ in White County. The remainder of the non-tax cost is attributed to intermediates ($\alpha_M = 0.11$ in Benton County and 0.12 in White County).

Section 4. General equilibrium model

Our calibration of the partial equilibrium model of the wind industry completed, we turn to the general equilibrium model. We formulate the model as a mixed complementarity problem, following closely James Markusen's teaching notes on the construction and calibration of simple general equilibrium models with trade.[33] We employ a small open economy model, adapting it to include an endogenous supply of external capital to the wind sector, imported intermediates, a trade imbalance, and an imported final consumption good that is an imperfect substitute for local retail. All of these features are presumably important in the context we study. Our model also contains a role for tax policy and redistribution.

Other than the features we describe above, ours is a textbook model. Since the vast majority of intermediate goods are imported into these counties, a simple model structure seems appropriate. We view the simplicity of the model as a reasonable expression of the economic structure of these small economies.[34] The simplified model structure facilitates straightforward calibration of the model, and allows us to see model mechanisms operating clearly.

The model structure follows Corden and Neary (1982). This "Dutch Disease" model was developed to help understand likely short- to medium-term effects, on a small open economy, of a "boom" in a single tradeable sector. The textbook model has three sectors – a non-tradeable

[33] See Markusen (undated). Mathiessen (1985) first described the representation of general equilibrium as a mixed complementarity problem, and discusses computational algorithms for solving a model of this kind. Rutherford (1995) offers mixed complementarity representations of three additional models, and discusses two algorithms for solving models of this type. Markusen synthesizes these insights, along with subsequent developments, for the purpose of pedagogy.

[34] One assumption of standard international trade models that may not be well-suited to the analysis of US county economies are the assumptions regarding factor mobility, especially as they relate to labor. We conduct a robustness check where we assume that all employment in the wind sector is done by labor that immigrates to the county when the wind sector arrives.

sector, a "booming" tradeable sector, and a "lagging" tradeable sector. Each sector employs a sector-specific factor and an intersectorally mobile factor. In the model, a "boom" in one of the tradeable sectors has two effects. In the *resource movement effect* the expansion of the booming sector draws some portion of the mobile factor out of the other two sectors. In the *spending effect*, spending of new income from the boom leads the non-tradeable sector to expand at the expense of the tradeable sectors. An appreciation of the real exchange rate follows from an increase in the relative price of the non-tradeable. The size of each of the two effects depends on model parameters. Net impacts - on the economy and on most factors of production - depend on the relative sizes of the two effects.

The booming sector in our model is the wind energy sector. Reflecting local realities, we use two lagging tradeable sectors (manufacturing and agriculture) rather than one. We split these sectors in our model because they differ so substantially in their factor demands (especially for land), and because we wish to track (and tax) the rents that landowners receive from the wind sector. We aggregate a variety of non-tradeable services, including private sector retail as well as local government employment, which includes schools and public administration. Labor in the model is intersectorally mobile. Land is quasi-specific; it can be used in either the wind or agriculture sectors. With the exception of the wind energy sector (which imports its capital services from outside the county), each sector has its own locally-owned sector-specific capital. All sectors use imported intermediates purchased at prices that are fixed throughout the experiments.

<u>Model Equations</u>

We model the sectors other than the wind energy sector as competitive industries that take both output and input prices as given. Each sector *s* has a zero-profit condition, which we represent as a variational inequality:

$$c^s(\overline{IP}, 1) \geq P^s \quad \perp \quad Q^s \geq 0 \qquad (6)$$

The left-hand side of the variational inequality compares unit costs and prices. The right-hand side indicates that sector output Q^s is positive when the zero-profit condition holds with equality, as is the case throughout our exercises.[35]

[35] The variational inequality in (6) can be derived from profit maximization that chooses Q, given P^s and $\overline{IP}$.

Each sector's cost function is assumed to be Cobb-Douglas with cost share parameters for labor, land, sector-specific capital and imported intermediate good. The demand (D) for input $i \in I$ by sector s is derived by applying Shephard's Lemma to $c^s(\overline{IP}, 1)$ and scaling by Q^s:

$$D_i^s = \alpha_i^s \frac{c^s(\overline{IP},1)}{P_i} Q^s \,. \tag{7}$$

Inputs are either sourced locally or externally. Intermediate inputs for all sectors are assumed to be imported into the county. Wind industry capital services are also imported. All other factors - land, labor, and sector-specific capital in the non-wind industries - are locally supplied. In the case of imported inputs, input prices are fixed, and (7) determines the quantity of inputs used. In the case of locally supplied factors, a factor market clearance condition relates factor supplies and demands, and determines the factor's price. The variational inequality associated with market clearance for locally supplied factors is:

$$S_f \geq D_f^E + \textstyle\sum_s D_f^s \qquad \perp \quad P_f \geq 0 \tag{8}$$

where S_f is the local supply of the factor input f, D_f^E and D_f^s are factor input demands from the electricity and conventional sectors, respectively. P_f is the (endogenous) price of the factor input.[36]

Arbitrage conditions link local prices to prices in the broader US market. These apply both to the county's imports and exports, to intermediates and to final goods. For exports, the arbitrage condition is

$$P^s \geq P_{US}^s * PFX \qquad \perp \quad X^s \geq 0, \tag{9}$$

where P_{US}^s is the price in the broader US market (which is taken as given), PFX is the "price of foreign exchange" variable, and X^s the quantity of exports of good s.[37] An equivalent condition applies to sales of electricity when the industry is allowed to operate. The arbitrage that determines quantities of imported intermediates is similar:

[36] Factors *f* are a subset of inputs *I*. We use separate notation for *f* and *I* when it facilitates exposition, as it does in the factor market clearance equation. Intermediates, the inputs that are not factors of production, are all assumed to purchased outside of the county economy at fixed prices.

[37] The variational inequality in (9) relates to profit maximization of perfectly firms engaged in arbitrage. PFX can be understood as a measure of the nominal exchange rate between local and US currencies. In this context the value should, of course, be 1. We choose PFX as the model numeraire, and set it to 1 throughout all exercises.

$$P_{i,US} * PFX \geq P_i \quad \perp \quad M_i \geq 0 \tag{10}$$

with $P_{i,US}$ again the price of the input on the broader US market, P_i the local input price, and M_i the quantity of sector s inputs purchased outside the county.[38] Conditions analogous to (10) determine the quantity of intermediates (M^E) and capital services (K^E) imported by the electricity sector.[39] Imports of final retail (Q^r_{US}, to be derived shortly) are also determined by an arbitrage condition like (10). We assume no imports of agricultural or manufacturing products for final consumption, treating final goods produced downstream of these sectors as part of retail consumption.

<u>Income and welfare</u>

In our benchmark model, a local representative agent receives factor income and a share of the economic rents from the wind sector, as well as factor income from the other sectors, transfers and tax revenue.

$$Y = \sum_f \left(\alpha_f \frac{C(\overline{FP},1)}{P_f} P_f E \right) + (1 - tax)\gamma_T P_V aVh + \sum_s \sum_f \alpha_f \frac{C(\overline{FP},1)}{P_f} P_f Q^s + T + TR \tag{11}$$

where *T* is transfer income from outside the county and *TR* is tax revenue. Our focus is on new taxes that arrive with the wind sector, which have two sources: property taxes (TR_{Prop}) and resource rent taxes (TR_{RR});

$$TR = \underbrace{ptax(\alpha_K P_E E) P_K^E K^E}_{TR_{Prop}} + \underbrace{taxP_V aVh}_{TR_{RR}}. \tag{12}$$

Consumer behavior is summarized by a unit expenditure function. Consumers have constant elasticity of substitution (CES) preferences over the output of a locally supplied retail sector ($r \in s$), and an imported final retail good. In the mixed complementarity framework, this is modeled as a zero-profit condition relating the cost of a single unit of utility to its price, *PU,* (on the left-hand side of the variational inequality) determining the quantity of utility achieved, *U*, (on the right-hand side).

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[38] As with (9), equation (10) are the via Kuhn-Tucker conditions associated with profit-maximizing arbitrageurs.
[39] This is the condition that disciplines participation in the wind energy sector by outside actors, most notably capital. In the model, capital's return on participation includes the normal factor return and the rents that it receives. Any local taxation of capital that would cause the after-tax return to capital to fall below the US after tax price of capital would shut down participation by capital, shutting down the sector.

$$\left(\theta^r * P^{r\ 1-\sigma} + (1-\theta^r) * P_{US}^{r\ 1-\sigma}\right)^{\frac{1}{1-\sigma}} \geq PU \quad \perp \quad U \geq 0, \qquad (13)$$

where θ^r is a distributional parameter governing the importance of domestic retail in consumer preferences and P_{US}^r is the price of final retail goods and services that are imported by the county.

Goods market clearance conditions are as follows: The market for the locally supplied final retail clears with local supply equal to local demand.

$$Q^r \geq \frac{\theta^r (P^r)^{-\sigma}}{PU^{1-\sigma}} U \qquad \perp \quad P^r \geq 0, \qquad (14)$$

with demand determined by an application of Shephard's Lemma, and scaled by U. Prices for the imported final retail good are fixed for market participants in the county. Imported quantities demanded of the imported final retail good Q_{US}^r are:

$$Q_{US}^r = \frac{(1-\theta^r) * \left(P_{US}^r\right)^{-\sigma}}{PU^{1-\sigma}} U. \qquad (15)$$

The trade balance equation is as follows:

$$(PE+S)E + \sum_s PX^s X^s + T \geq \sum_s IP^s M^s + IP^E M^E + PK^E K^E + \gamma_K (1-tax) P_V aVh + P_{US}^r Q_{US}^r$$

$$\perp \quad PFX \geq 0 \qquad (16)$$

(PE+S)E is the value of electricity exports, gross of the federal subsidy *S*. When the wind sector arrives in the county, these new revenues appear in the balance of payments, and must be balanced either by reductions in exports of other goods ($\sum_s PX^s X^s$), or by corresponding increases in payments to the outside world (on the right-hand side of 16). *T* captures net payments to the county from other sources, and is held fixed throughout our exercises. $\sum_s IP^s M^s$ and $IP^E M^E$ represent purchases of inputs by the preexisting and the wind energy sectors, respectively. $PK^E K^E$ represents payments for the factor services of wind energy capital. The economic rents, net of taxes, that are paid to external capital is captured by $\gamma_K (1-tax) P_V aVh$. $P_{US}^r Q_{US}^r$ represents local consumer's purchases of final retail services from outside the county. The variable that is determined by the balance of payments condition is PFX, the model's numeraire.

The primary mechanisms driving the model's response to rent taxes operate through equations (11), (12) and (16). Setting *tax*>0 increases local tax revenues (in 12), increasing local incomes in turn (11). A positive tax also reduces the county's rent payments to external capital (16). This can be balanced by increased purchases of outside retail ($P^r_{US}Q^r_{US}$) or of intermediates for the preexisting sectors ($\sum_s IP^s M^s$). There will also tend to be a reallocation of output among the pre-existing sectors $\sum_s PX^s X^s$, with higher local incomes generating growth in the non-tradeable retail sector, which comes at the expense of agriculture and manufacturing. Since the tax is an efficient tax on rents in the electricity sector, it does not affect the sector's output decisions, nor does it directly affect factor prices. Changes in the relative size of the preexisting sectors affect factor prices, which in turn affect factor input demands by each of the sectors.

Section 4.1 Extension to multiple local agents

So far, the model assumes a representative local agent that receives all the income earned in the county. In reality, households are likely to differ substantially in their sources of income. If so, the arrival of the wind sector is likely to have significant distributional consequences across households. In order to study this possibility, we construct five local households, each of which is an owner of one of the five locally supplied factors.[40] This allows our analysis of the distributional consequences of the wind energy boom to go beyond simple movements in relative factor prices (as is done in Corden and Neary). This important because the allocation of economic rents is central to the distributional questions we raise.

In terms of model equations, the shift from a representative agent to a multiple agent version of the model is simple. Each of the five locally supplied factors - land, labor, and the sector-specific capitals for agriculture, manufacturing and retail - is given their own income equation. That equation appears as

$$Y_f = \sum_s \alpha_f \, c^s(\overline{FP}, 1) \, Q^s + \left(\alpha_f \, c(\overline{FP}, 1) \, E + (1 - tax)\gamma_f P_V V\right) +$$

$$\delta_f(T * PFX + TR_{Prop}) + \theta_f TR_{RR} \qquad (17)$$

[40] One could also specify different θ^r parameters for each household in the expenditure function. Since we lack data that would inform these choices, we refrain from doing so. We assume that households' allocation of retail spending across local and outside retail services is unaffected by their factor ownership.

This term is a disaggregation of (11), and most of the notation follows from there. δ_f is calibration parameter that defines the share of county wide transfer income and property tax revenue that accrues to each factor *f* ($\sum_f \delta_f = 1$). θ_f is a policy parameter; it defines the share of resource rent tax revenues that are allocated to the household holding factor *f*, with $\sum_f \theta_f = 1$.

Section 4.2 Calibration of the GE model.

As in Markusen, we calibrate the model by construction of a social accounting matrix (SAM), which is a matrix representation of flows of income/expenditure between households and firms, and between the county of interest and the broader US economy. Our small rural counties lack a fully developed input-output table that would support the construction of a detailed SAM, but our simple structure and the ready availability of other data allow us to complete the task. Calibration of the model requires a reconciliation of the data that produces a measure of a) the scale of output for each sector, b) the share of sector revenues that go to each input, c) measures of total factor incomes of local factors, d) data on economywide income, which allows inferences about the size of net transfers into the county, and e) shares of final expenditures on domestic and external retail services. We use data from various sources to construct these SAMs.

In our model, the domestic economy is made up of three sectors: agriculture, manufacturing and retail services. Our first goal in calibration is to define the make-up of these sectors, and to calculate total county wages in each sector. The Quarterly Census of Employment and Wages (QCEW) offers county-level information each quarter on employment and wages by North American Industry Classification (NAICS) sector. We aggregate the NAICS codes up to our three sectors. This accomplished, it is straightforward to calculate the wage bill for each sector in each county.

Our next exercise is to calculate input cost shares for the manufacturing and services sectors. To do this, we aggregate the "use" tables of the 2007 U.S. input-output table to match our aggregate sectors. Since we have specific knowledge of agriculture in the two counties, we take the agriculture sector to be a weighted average of only two of the agricultural sectors in the BEA table (Grains and Oilseeds). We weight these by 70% grain and 30% oilseeds to calculate input shares for local agriculture.[41] From the tables, we collect each aggregate sector's measure of

[41] This weighting reflects the weighting of corn and soybeans respectively in the 2007 Census of Agriculture's value of crops sold for the two counties.

output, and subtract tax payments. For each sector, the labor share is calculated as payments to labor over this value. Likewise, the intermediate share is the share of intermediate purchases in gross output net of taxes. For the manufacturing and retail services sectors, each sector's capital share is its operating surplus over the same denominator. The land share in these latter two sectors is taken to be zero.

In the agriculture sector, we assume that payments to both capital and land are captured in the input-output table's operating surplus measure. The question is, how should these payments be divided between the two factors? We turn to the 2007 Census of Agriculture, which reports both the total value of agricultural land and structures and the total value of agricultural machinery for each county. The sector-specific capital share is calculated by applying the share of machinery in this sum to the share of operating surpluses in gross output net of taxes. The "land" factor share in agriculture is proportional to the share of land and buildings in the census of agriculture data.[42]

The work so far produces calibrated cost functions for all three of the conventional sectors s. All sectors have relatively large intermediate input shares. Retail and manufacturing are relatively labor intensive. Agriculture does not use labor intensively; it is the land intensive sector.

The next step in calibration is to determine gross output by sector, and the magnitude of each sector's input payments. For agriculture, our gross output measure comes from the 2007 Census of Agriculture, which reports the value of sales of soybeans and of corn for each county. We treat this sum as gross output in the sector, and calculate payments to each input using the Cobb-Douglas shares calculated from the BEA table. For the manufacturing and retail sectors, we lack good county-level data on sector gross output, but the QCEW provides good information on employment and wages. This information allows a direct calculation of each sector's payments to labor. Dividing this value by each sector's factor share produces an estimate of sector gross output; applying the remaining input shares to gross output generates sector payments to capital and for intermediates.

These estimates in turn allow an estimate of the Gross Domestic Product (GDP) of each county prior to the arrival of the wind energy sector. GDP is simply the sum of payments received by

[42] Since buildings are better thought of as capital, our treatment may overstate the cost share of land in agriculture, and understate the cost share of ag-specific capital.

the local factors in the non-wind sectors. This value can be compared against data on county-wide household income. Our imputed GDP is lower than reported county-wide income figures, which we find to be intuitive. Many county residents would have sources of income from outside the county (Social Security payments, external investment or labor income, etc.).[43] In the model we treat the gap between implied local factor incomes and measured county incomes as a net transfer from the outside world, T. We calibrate T and assume it is unchanged throughout the exercises.

The last calibration challenge we face is how to account for local residents' consumption purchases from outside the county. These are small rural counties, so residents would frequently travel to larger nearby counties for consumption and entertainment. They might also be expected to purchase retail goods and services on-line. Since there would be no available data that could inform this, we simply treat this as a calibration residual. The gap between county-wide personal income and the gross output of the local retail sector is assumed to represent consumption of goods purchased outside the county. The share of domestic consumption in total county income is the model parameter θ^r. For both counties in the model, domestic retail accounts for approximately half of total spending.

The calculations here are sufficient to produce the SAM for each county. Tables A1 and A2 in the appendix report the SAMs for Benton and White Counties respectively. Table A3 provides similar figures for the wind sector in each county; these govern the economic impact of the wind sector's arrival in our counterfactual exercises.

Calibration also requires a choice of the elasticity of substitution, σ. In international trade and the economic geography literatures, authors typically assume a value of $\sigma=5$. Estimates of this magnitude come from studies of trade in goods. It is not immediately clear what the most appropriate assumption is when we are considering a rural county's retail services aggregate. One might suspect that the retail purchases from outside the county are a relatively poor substitute for locally produced retail services. However, in these rural counties people often travel to more densely populated counties nearby, so substitution of many retail services may not be so difficult. In our preferred estimates, we use $\sigma=5$. But we also estimate with $\sigma=1$, a Cobb-

[43] Imputed GDP in Benton County is \$157.5 million, compared with a BEA estimate of household income of \$271 million. Imputed GDP in White County is \$476.7 million against a household income estimate of \$730 million.

Douglas parameterization, and show that the size of σ affects the strength of the Dutch Disease. The main policy lessons are, however, robust to the choice of σ.

When we move to the multiple agent model, there is another set of parameters that must be calibrated. The δ_f parameters govern the allocation across households of transfer payments and property tax revenues. This is another situation where we lack good data. What we do in this instance is to calculate each factor's share of the county's GDP, and award the same share of transfer income and of property tax revenue to that factor. This share is δ_f.

Section 4.3 Equilibrium in the calibrated model.

The calibration and simulation methods used in the standard GAMS framework are straightforward, but too lengthy to explain in detail here. Briefly, each of the model equations is scaled by value data taken from the SAM. Quantity units are chosen such that $X of value is equal to X quantity units; an assumption that sets all benchmark prices to 1. The scaling of the model equations in calibration means that the quantity variables can also be treated as index values that are benchmarked at 1. Well-established model consistency checks – an application of Walras' Law and a homogeneity test – ensure that the calibrated model solves correctly for a general equilibrium. The counterfactual exercises - both the arrival of the wind sector and the equilibrium with taxes - produce changes in the price and quantity indexes whose solutions are represented in terms of $(1 \pm \%\Delta)$. The model is solved in levels, but the results are reported in a manner that is consistent with the hat calculus methods of Dekle, Eaton and Kortum (2007). A consistency check at the new equilibrium (another application of Walras' Law), ensures that the model is fully consistent even after we move away from the benchmark. For details about these procedures, see Markusen's teaching notes.

Section 4.4 Counterfactual analysis

Our counterfactual analysis includes two thought experiments. First, we consider the impact of the arrival of the wind sector on the local economy. This shock is calibrated to data on the scale of the initial wave of investments (2007-2010), and illustrates our estimate of the wind energy sector's arrival on local outcomes. In our second exercise, we consider the effects of applying an optimal resource rent tax (calculated jointly with the effects of the arrival of the wind sector). We conduct counterfactual analysis for both the representative agent model and the multiple household model, and do so for both counties.

Counterfactual 1. Arrival of the wind sector.

The policy variable that we change to capture the effects of the sector's arrival is the wind capacity variable V. In the initial calibration, V = 0, which implies the $E = aVh$ term in equation 1 is zero in the benchmark. In each county's counterfactual exercise, we model the arrival of the wind sector by setting aVh to be the dollar value of electricity generated by each county. This treatment normalizes P_E to 1, implicitly changing units of electricity from MWh in the partial equilibrium model to dollar-equivalent units of electricity in the general equilibrium model.[44]

The arrival of the wind sector requires an inflow of foreign capital services and intermediate goods to support the boom in the wind sector. The resource movement effect occurs as a shift of labor and land away from the other local sectors and into the production of wind energy. Higher incomes in the county lead to increased purchases of local retail. Relative to the standard Dutch Disease model the real exchange rate appreciation is muted because locals purchase retail services outside the county. The reliance of all sectors on intermediate inputs that are purchased outside the county at fixed prices also dampens Dutch Disease effects.

The arrival of the wind generating electricity sector generated increased revenues to these counties' governments, in the form of property taxes and in the sector's other payments to local governments. We capture these flows in the model with *ptax*. We calibrate this rate so that the wind sector's arrival generates tax revenues that are broadly consistent with what has been observed in the two counties. Table 4 in Bednarikova, et al. (2020) reports the sector's payments of property taxes to the two counties for the years 2010-2019. These grew steadily over the period reaching $4.3 million and $2.3 million in 2019 for Benton and White Counties, respectively (both counties had offered generous abatements in the early years, which sharply reduced revenues in the earliest years). We calibrate *ptax* to 0.002, which causes our model to produce annualized property tax payments that are somewhat lower than the 2019 annual figures, but much higher than in an average year.[45]

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[44] The price is fixed on external markets throughout all exercises. Defining units such that $P_E = 1$ simply allows all initial relative prices to be set to 1.

[45] We calibrate the model to relatively high annualized tax payments in order to be conservative. The industry made other payments to the counties that were outside the property tax system. White County, for example, received $7.5 million dollars of economic development payments during the early years of these projects' life, when the abatement limited property tax payments by the industry. Our calibrated rate is below the actual property tax rates in the counties, because the large tax abatements the two counties awarded reduced the revenues they would otherwise have collected.

Counterfactual 2. Taxing resource rents

The key policy variable that we change in our second exercise is *tax,* a proportional tax on the resource rents. We consider tax rates from 0-100. Conceptually, a 100% tax on the rents is optimal, but two practical considerations intervene. First, because we use a single policy instrument to tax rents accruing to two different agents, an exhaustive rent tax is not incentive compatible for at least one of the two agents. This issue is compounded by changes in factor prices induced by the wind's arrival. Notably, the market return to land (net of the rents) falls with the sector's arrival (the spending effect dominates the resource movement effect in this regard). A rent tax that extracts the entirety of landowners' rent is thus not incentive compatible, and landowners' consent is critical for wind energy production.

We wish to only consider rent taxes that are fully incentive compatible. In the representative agent model, a 99 percent rent tax is incentive compatible because the recycled tax revenue offsets losses that accrue to land.[46] In the multiple agent model, we must choose lower rent tax rates so as to insure participation in the sector by landowners. For each parameterization we consider, we search for the largest possible rent tax that maintains the utility of landowners at the levels of utility they achieved prior to the arrival of the wind sector.[47]

Robustness exercises

The rent tax creates a sizable pool of funds that can be used to favor any one of the local factors. We hypothesize that the allocation that would generate the greatest political support for wind energy is one that targets the factor that is the primary source of income for the largest number of voters, labor. In order to estimate the maximal gains for labor, we allocate all the rent tax revenue that accrues from an incentive compatible rent tax to labor. Our policy variables for this exercise are θ_f. We set $\theta_f = 1$ for labor, and $\theta_f = 0$ for all other factors.

[46] In all exercises we consider outside capital continues to the participate in the wind sector. The price of capital determined in markets outside the county is P_K^E, which remains fixed across all scenarios. The rents that accrue to capital in the wind electricity sector are excess returns to outside capital. In our model, capital services are endogenously provided to the wind sector at that rate so long as we set the rent tax rate below 100%.

[47] Prudence would suggest that actual rent tax rates be set somewhat lower than the maximum estimated incentive compatible tax rate, in order to ensure that critical factors of production choose to participate. For example, Australia's short-lived 2012 Mineral Resource Rent Tax was set at only 30% of the estimated supernormal profits earned by the sector. We report results for the maximum incentive compatible tax rate in order to illustrate an upper bound on the local benefits that accrue from taxation.

Factor price changes in the Dutch Disease model mean that some factors are worse off after the "boom," especially specific capital in the lagging tradeable sectors. We also conduct a thought experiment where we allocate revenue from the resource rent tax across the factors to ensure a Pareto efficient outcome; that is, one in which no *local* factor is made worse off by the arrival of the sector and the imposition of the tax. In this exercise we calculate the values of θ_f that are required to maintain the utility of all factors at their benchmark levels. These allocations do not exhaust available rent tax revenues, and we allocate the remainder to labor by choice of θ_L.

Next, we note that a model assumption that labor is intersectorally (but not geographically) mobile may not be fully appropriate in the context we study. In particular, it seems likely that the skilled workers employed in the wind sector are notably different than those employed in the other sectors, and may be drawn into the county from outside.[48] If the sector were to import all of its workers, the resource movement effect would be largely neutralized (the sector still draws a small amount of land away from agriculture). In order to consider this possibility, we simulate a counterfactual analysis that includes an endogenous expansion of the local labor force.

Section 5. Results

In our first exercise we use the representative local agent model to consider the effects of the arrival of the wind sector on each county. Results for Benton and White Counties are reported in columns 1 and 3 of Table 3, respectively. In the same table, we report results that consider both the arrival of the wind sector and the application of a near exhaustive (99 percent) resource rent tax. These results are reported in columns 2 and 4. The model is solved in levels but results are represented in percentage changes. Calibration methods à la Markusen are such that all model variables are normalized to 1 in the benchmark. Counterfactual values of prices and quantities are reported at their new equilibrium level of $1 \pm \%\Delta$.

The results in columns 1 and 3 show that the wind sector's arrival generates effects that are consistent with the Dutch Disease model. The wind sector's arrival generates a positive shock to demand for the model's mobile factors, labor and land. The resource movement effect sees these factors move out of the pre-existing sectors, reducing the quantity of outputs and the factor prices

[48] Ours is a steady state model. One might expect that over time, local labor could be trained to do the turbine maintenance jobs that dominate the sector's steady state labor demands. Qualification for turbine maintenance jobs requires only two years of specialized training, followed by one year of on-the-job training (DOE 2021).

earned by sector specific capital in those sectors. The spending effect occurs – as can be seen by rising prices in the retail sector - but these effects are muted by substitution toward the output of an external retail sector. The largest positive net effects are on a) the factor price of labor (up 5.2 percent in Benton County), and b) purchases of outside retail (up 4.2 percent in Benton County). The sectors that pre-existed the arrival of the wind sector shrink, on net. The most negatively affected sector is manufacturing, which is a lagging sector that loses from both the resource movement and spending effects. Both the quantity of output and the factor price of sector specific capital in the manufacturing sector fall by 5.2 percent in Benton County. The other two sectors shrink, but less than does manufacturing. The representative agent sees a 1.1 percent increase in welfare in Benton County and an increase of 0.2 percent in White County. Property tax revenues collected from the wind sector in our model amount to $3.64 million in Benton County and $2.17 million in White County.

In the representative agent model, the redistribution of rents from landowners to other local residents is immaterial to the welfare calculations, so an exhaustive resource rent tax offers the biggest improvement in welfare. In columns 2 and 4 we report results from an experiment in which a 99% tax is imposed on rents for Benton and White Counties, respectively. The results from this experiment include the effects of the wind sector's arrival, so one can gauge the effect of the rent tax by comparing results in columns 2 and 4 with their counterparts in columns 1 and 3. The main channel by which the rent tax affects the two counties is that it gives the representative agent more income. This leads to a large spending effect (retail prices rise, relative to the no-tax scenario, as do the quantities of domestic retail services offered.) Higher domestic retail prices lead to even more purchases of imported final consumption goods. Welfare is much higher in this scenario (up 9.1 percent in Benton County and 2 percent in White County). The larger spending effect aggravates the negative consequences of the boom on the lagging sectors. Because it is relatively labor intensive, manufacturing suffers more than agriculture from the larger spending effect, as labor moves from the manufacturing to the retail sector.

Table 3. Effects of wind sector arrival and 99% rent tax, representative agent model

	Benton County		White County	
Variable	Wind sector arrival	Wind sector plus 99% tax	Wind sector arrival	Wind sector plus 99% tax
P^{ag}	1.000	1.000	1.000	1.000
P^{mfg}	1.000	1.000	1.000	1.000
P^{rtl}	1.015	1.032	1.002	1.007
Q^{ag}	0.981	0.979	0.992	0.992
Q^{mfg}	0.948	0.928	0.994	0.988
Q^{rtl}	0.969	0.995	0.998	1.006
FP_L	1.052	1.074	1.005	1.012
FP_T	0.996	0.994	1.000	1.000
FP_{K-ag}	0.981	0.979	0.992	0.992
FP_{K-mfg}	0.948	0.928	0.994	0.988
FP_{K-rtl}	0.984	1.027	1.000	1.013
Q_{US}^{r}	1.042	1.165	1.009	1.043
U_{rep}	1.011	1.091	1.002	1.020
Tax revenue from wind energy	\$3.64 million	\$26.94 million	\$2.17 million	\$16.09 million

Table notes: P^s is price of the pre-existing sector/good s, Q^s is locally produced quantity of the good/sector, FP is the factor price, Q_{US}^{r} is the quantity of imported retail and services purchased, and U_{rep} is the utility level of the representative consumer. Results assume $\sigma = 5$ in the consumer's expenditure function (eq. 12). The wind sector's arrival generates property tax revenue, which appears in all scenarios. Tax revenues in columns 2 and 4 also include revenues from rent taxes.

The mechanism that produces higher incomes for the representative household is the rebating of tax revenues. The final row of Table 3 shows that annual tax revenues collected from the wind sector in each county rise by a factor of approximately seven when the resource rent taxes are added to the property tax payments.

As in Corden and Neary, the only information about the distributional effects of the policy in this exercise arises from factor price movements. Because there are economic rents in the model, a realistic discussion of distributional effects should also consider how the distribution of rents affects the real incomes of factor owners. Assigning factor incomes to distinct agents allows us to better understand these consequences. The multiple agent model also allows us to clarify our scenarios in terms of incentive compatibility for particular factor owners, especially landowners. Since landowners' decisions to allow turbines on their property is central to the wind electricity sector's viability, we constrain the taxes we consider to those which leave landowners with levels of utility that existed prior to the arrival of the sector. Incentive compatible tax rates depend on the assumed elasticity of substitution between local and external retail sector outputs. In order to investigate the sensitivity of results to assumptions about this parameter, we consider two scenarios, a Cobb-Douglas parameterization and our standard assumption that $\sigma = 5$.[49] The maximum incentive compatible tax rate varies over these scenarios, and we report results for that rate under each parameterization.

The results from these exercises are reported in Table 4. Columns 1 and 3 report results for the Cobb-Douglas scenario, and columns 2 and 4 for $\sigma = 5$. In all experiments, the utility of landowners is unchanged from the benchmark due to our choice of rental tax rates. Under Cobb-Douglas, the incentive compatible tax rate is 35 percent for Benton County and 68 percent for White County. For $\sigma = 5$, the largest incentive compatible tax rates are 63 and 82 percent, respectively.

The much lower tax rates under Cobb-Douglas arise because Dutch Disease effects are much more pronounced under Cobb-Douglas. Since consumers cannot easily substitute towards the external retail good, the spending effect causes a larger expansion of the domestic retail sector in Cobb-Douglas than in the CES model. This expansion occurs at the expense of the other domestic sectors. The factor price of land falls more in equilibrium (because the spending effect draws labor from the agriculture sector), so landowners must be allowed to retain a larger portion of the rents under Cobb-Douglas if their benchmark utility is to be maintained. This limits the size of the incentive-compatible tax rate. Further evidence that the spending effect has more bite in the Cobb Douglas scenario can be seen in the larger changes in the domestic retail price, P^{rtl}, the somewhat larger changes in local retail quantities and the higher price of sector specific retail capital in the Cobb Douglas scenario. The mechanism for the larger spending effect under Cobb-Douglas is also clear from the table, imported retail grows substantially less than when $\sigma = 5$. The larger domestic retail sector in the Cobb-Douglas scenario also supports higher factor prices for labor.

[49] Our Cobb-Douglas representation retains the CES form, but imposes an elasticity of substitution of 1.0001, which is effectively Cobb-Douglas.

Table 4. Results for factor specific real incomes, incentive compatible taxation, and alternative substitution possibilities.

	Benton County		White County	
Variable	Wind sector plus 35% tax, $\sigma \approx 1$	Wind sector plus 63% tax, $\sigma = 5$	Wind sector plus 68% tax, $\sigma \approx 1$	Wind sector plus 82% tax $\sigma = 5$
P^{ag}	1.000	1.000	1.000	1.000
P^{mfg}	1.000	1.000	1.000	1.000
P^{rtl}	1.045	1.026	1.010	1.006
Q^{ag}	0.978	0.980	0.991	0.992
Q^{mfg}	0.914	0.935	0.984	0.989
Q^{rtl}	1.013	0.986	1.011	1.005
FP_L	1.089	1.066	1.015	1.011
FP_T	0.992	0.995	0.999	1.000
FP_{K-ag}	0.978	0.980	0.991	0.992
FP_{K-mfg}	0.914	0.935	0.984	0.989
FP_{K-rtl}	1.059	1.011	1.021	1.011
Q^r_{US}	1.059	1.120	1.021	1.037
U_L	1.106	1.161	1.030	1.035
U_T	1.000	1.000	1.000	1.000
U_{K-ag}	0.970	0.979	0.988	0.991
U_{K-mfg}	0.933	0.953	0.984	0.989
U_{K-rtl}	1.016	0.997	1.010	1.004
U_{rep}	1.039	1.062	1.015	1.017
Tax revenue from wind energy	$9.52 million	$17.15 million	$11.05 million	$13.33 million

Table notes: P^s is price of the pre-existing sector/good s, Q^s is locally produced quantity of the good/sector, FP is the factor price, Q^r_{US} is the quantity of imported retail and services purchased, and U_{rep} is the utility level of the representative consumer. Columns 1 and 3 assume Cobb Douglas preferences in the consumer's expenditure function (eq 12). Columns 2 and 4 use $\sigma = 5$ instead. The applied rent tax rate is the largest that leaves landowners at benchmark utility levels. Tax revenues include both property and rent tax revenues.

The allocation of income from the resource rent tax is a political, not an economic, decision. Since our thought experiment involves maximizing political support for allowing the industry to locate in the county, we allocate the revenues collected from the tax to give the largest benefit to most broadly held factor of production, labor.[50] The size of the allocation to labor is increasing in

[50] We are imagining something akin to the dividend payment from the Alaska Permanent Fund to Alaska residents. The closest analogue in our model would be payments to labor.

the tax. These larger allocations are the reason why the utility of labor owners is larger in the $\sigma = 5$ than in the Cobb-Douglas scenario, even though the increase in labor's factor price is smaller. The larger value of σ allows a higher tax rate; it also allows consumers more flexibility to substitute consumption of the imported final retail good for the domestic good, reducing the real exchange rate appreciation attributable to the spending effect. In total, the higher rent tax rates in the $\sigma = 5$ scenario produce welfare gains of 16.1 and 3.5 percent for labor in Benton and White Counties, respectively.

Section 6. Robustness

Pareto improvement

While the scenarios in Table 4 are constructed to be sure that landowners do not suffer from the wind sector's arrival, the model still produces losses for owners of factors that are specific to the pre-existing sectors. Owners of manufacturing-specific capital suffer the most, as higher prices for local labor draw workers out of this relatively labor-intensive sector. In our next exercise we ask whether there is an allocation of tax revenues that can support a Pareto improvement over the benchmark equilibrium. In short, the exercise is to reallocate funds from the rent tax away from labor, and to the owners of factors whose welfare falls when the wind sector arrives. We present one of the many Pareto improving allocations, the one that retains the highest utility for labor, conditional on all other factors achieving their benchmark utility level. We use the $\sigma = 5$ parameterization for consumer behavior, and apply the same taxes that we applied in Table 4.

The results of this exercise are reported in Table 5. In both counties approximately 1/10 of the tax revenues must be reallocated in order to achieve a Pareto improvement over the equilibrium without a wind energy sector. Manufacturing capital requires the largest share of the payments to be made whole. The other specific factors require only small payments. After the reallocation the utility of labor is 14.5 percent higher than in the benchmark for Benton County, and 3.3 percent higher than in the benchmark for White County.

Table 5 Tax revenues and utility in a Pareto efficient equilibrium

	Benton County		White County	
Rent tax rate	63%		80%	
	Share of tax revenues	Utility	Share of tax revenues	Utility
Labor	0.880	1.145	0.938	1.033
Land	-0.001	1.000	-0.0001	1.000
Ag Capital	0.009	1.000	0.005	1.000
Mfg Capital	0.102	1.000	0.105	1.000
Retail Capital	0.009	1.000	-0.048	1.000
Rent tax revenue	$17.15 million		$13.01 million	

Table notes: Share of rent tax revenue paid to each factor (δ_f) and levels of utility achieved in an equilibrium that is a Pareto improvement over the benchmark scenario. Other model outcomes (e.g. prices and quantities) are consistent with those reported in Table 4. This is just one of many Pareto improving outcomes, since any redistribution of revenues from labor to other factors that generates $U_{labor} \geq 1$.

Geographic mobility of wind-sector labor

The Dutch Disease model is useful for our purposes because it allows for the possibility that the wind sector's arrival has negative distributional consequences, even as the wind sector improves the welfare of the counties' representative agents. This mechanism provides another explanation for the opposition to turbines in many counties. It is possible, however, that the model overstates the harm done to lagging sectors, because the baseline model leaves no possibility of migration from outside the county. All labor used in the wind sector must be drawn from other sectors producing in the county. One might expect that the wind industry workers have a different skill set than those in other sectors, and would not choose to work in the county if they were not employed in this particular sector. We use our model to investigate this possibility, treating wind industry labor as immigrants to the county.

Conceptually, our goal is to neutralize the resource movement effect, assuming that the wind sector's labor services are provided by non-citizens of the county in question. These workers should enter the economy, their income should support local spending on final goods, but we wish to exclude the income they earn from our calculated changes in local utility.

Since the calibration of the model is defined not in units of labor but in $US equivalent quantity units, this exercise is somewhat difficult to implement. What we do is the following: we simulate the wind sector's arrival as usual. This leads to higher equilibrium wages. A portion of the wage increase is due to the labor demand shock from the wind sector's arrival; the other portion is due to the spending effect. In order to offset the first effect - the resource movement effect - we gradually add quantity units of labor to the county's labor supply (recalculating the equilibrium as we go) until the percentage change in the total wage bill for the non-wind sectors (relative to the baseline) equals the percentage change in P_L. This condition implies unchanged quantities of labor supplied to these sectors. We calculate utility by dividing income (net of the wind sector wage bill) by the true cost of living index (PU). In the case where we consider wind taxes, we rebate the tax revenues to locally-owned factors, calculating separately the change in labor income for labor employed outside the wind energy sector. This exercise treats the wind sector workers as completely new to the economy; their income is spent locally, but they receive no income from the resource rent tax.

The results of this exercise are reported in Table 6. It is clear that nullifying the resource movement effect generates much smaller movements in factor prices. This translates into much smaller effects on welfare, both positive and negative. When we turn to the evaluation of wind taxes, we see that allowing imported labor allows larger incentive-compatible rent taxes. The larger incomes that arise from higher rent taxes generate relatively large welfare gains for resident labor (17.2 percent in Benton County and 3.4 percent in White County). These estimates are quite similar to those in Table 4, which presume that the wind sector must draw labor from other local sectors.

Economic rents in more recent circumstances

The sector's pace of technological change makes it difficult for us to calculate rents in more recent years. Stehly and Duffy (2021) provide the most recent detailed information on the levelized costs of energy for onshore wind. But these estimates assume 2.8 MW turbines. The most recent projects in the counties we study use 3.6 MW turbines, which should have lower costs of producing electricity. When we replicate the calculations from Table 2 we calculate negative rents. It is likely that this arises because we compare PPA contracts for 3.6 MW turbines with production cost estimates for 2.8 MW turbines.

Table 6. Results assuming immigration (and no resource movement effect)

Variable	Benton – Wind imported labor	Benton - Tax rate of 78%	White – Wind imported labor	White - Tax rate of 85%
P^{ag}	1.000	1.000	1.000	1.000
P^{mfg}	1.000	1.000	1.000	1.000
P^{rtl}	1.006	1.020	1.001	1.006
Q^{ag}	0.986	0.985	0.993	0.992
Q^{mfg}	0.995	0.979	1.000	0.993
Q^{rtl}	1.013	1.035	1.003	1.010
FP_L	1.005	1.021	1.001	1.006
FP_T	1.001	0.999	1.001	1.000
FP_{K-ag}	0.986	0.985	0.993	0.992
FP_{K-mfg}	0.995	0.979	0.999	0.993
FP_{K-rtl}	1.019	1.055	1.004	1.015
Q^r_{US}	1.045	1.142	1.010	1.039
U_L	1.002	1.172	1.000	1.034
U_T	1.035	1.000	1.022	1.000
U_{K-ag}	0.991	0.984	0.995	0.992
U_{K-mfg}	0.996	0.980	0.999	0.992
U_{K-rtl}	1.010	1.025	1.002	1.007
Tax revenue from wind energy	\$3.64 million	\$21.23 million	\$2.17 million	\$13.82 million

P^s is price of the pre-existing sector/good s, Q^s is locally produced quantity of the good/sector, FP is the factor price, Q^r_{US} is the quantity of imported retail and services purchased, and U_f is the utility level of the representative household holding factor f. The wind sector's arrival generates property tax revenue, which appears in all scenarios. Tax revenues in columns 2 and 4 also include revenues from rent taxes.

While it is unlikely that the industry is installing turbines that are not economically viable, it is still quite likely that recent projects are earning much smaller economic rents than did the projects initiated during our period of study. PPA prices are much lower. The costs of generating electricity with competing sources of energy (especially solar and natural gas) have fallen substantially.[51] Subsidies to the sector are less generous. Section 1603 is no longer operative; and the PTC pays lower rates than previously and only does so during the first ten years of the project's lifetime. Costs of production have also come down substantially, but it is unlikely that they have fallen as rapidly as the revenue side of the equation. Thus, in our view it is unlikely that rents are as large as they were in the time period we consider. Rents could, however, easily

[51] See Wiser, *et al.* (2021), section 8.

rise again – through further improvements in wind generating technologies, through higher electricity prices, through legislation putting a price on carbon, or through larger federal subsidies. All of these are possible, which makes the construction of a legal infrastructure for taxing resource rents a useful effort. Solar energy is also likely to generate resource rents through similar mechanisms, both now and in the future.

Section 7. Discussion

It is useful to distinguish the form of our proposed tax from other taxes that have been applied to the sector. The most common form of local taxation of the industry is via property taxes. Revenues from property taxes vary substantially over the length of the project, as the turbines owners depreciate out the capital. The counties we study gave large property tax abatements that substantially reduced their tax take from these projects in the beginning of the project lifetimes. Resource rent taxes offer the possibility of higher revenues, and of steadier revenue streams for county governments throughout the life of industrial scale wind projects.

The state of Texas recently imposed an output tax on wind generated electricity (Sixel, 2020; Baltz, 2021). Taxes on the quantity of electricity produced discourage production, and are therefore not economically efficient. A well-structured resource rent tax would not reduce investments in wind energy. In our view, the tax could potentially increase wind energy production, by making the industry more palatable to local communities, thereby limiting the degree to which land use restrictions preclude wind energy production altogether.

Resource rent taxes are typically operationalized as a proportional tax on supernormal profits. In the case of wind energy, taxes would be assessed at the level of individual projects or farms. Inframarginal projects earn excess returns, and those profits would be taxed. Marginal projects earning only a normal return would not pay resource rent taxes, and therefore not be deterred from production. This is the manner in which resource rent taxes can be efficient.

One practical difficulty that arises in the assessment and calculation of resource rent taxes revolves around the issue of what represents "normal" profits. Taxation of rents linked to petroleum and other mineral taxes has proven difficult in real-world settings. It is our view that the US electricity sector is already well-structured for the calculation of project-specific supernormal profits. A long history (and well-developed body of case law) have resolved most issues regarding the calculation of normal returns to capital on investments undertaken by regulated utilities. Similar metrics could be applied to the independent power projects that are most relevant to the setting we consider.

Section 8 Conclusion

In this paper we develop a partial equilibrium model of the wind-generated electricity sector and integrate it into a general equilibrium model that allows us to study the local economic impact the sector on a rural community. Factor services supplied by the wind itself and generous federal subsidies are sources of economic rent, which is divided between external suppliers of capital and local landowners. The existence of resource rents opens up the possibility that state or local tax policy could improve aggregate local welfare and mitigate the distributional consequences of the sector's arrival on a rural community. The general equilibrium model allows us to investigate the consequences of the sector's arrival on a small open economy, and the way in which tax policy interacts with it.

In order to put the magnitude of these possible gains in context we consider the effects of wind energy investments undertaken in 2007-2010, and do so in the specific context of two Indiana counties that saw especially large growth in wind energy generation during that period. The gross output of the wind sector in these counties is quite large relative to the scale of the county economies, but the sector value added that is produced by locally owned factors is rather small in comparison. The existence of resource rents allows a role for taxation in the sector, taxation that need not, in principle, limit the sector's growth. We build and calibrate a general equilibrium model that allows endogenous outside investment in the wind sector, and demonstrate that the taxation of economic rents can magnify substantially the local economic benefits of the wind sector's arrival. The substantial funds that can be raised via rent taxes can also be used to compensate losses associated with the sector's arrival. These insights may offer an answer to the problem that has limited expansion of the industry, particularly in the Great Lakes region - local opposition to the presence of the industry has blocked a large number of economically viable projects.

We report results for exhaustive rent taxes and for smaller - but still quite large – rent taxes in several robustness checks. These should be considered exploratory efforts, rather than explicit policy recommendations. Rent taxes that are beyond their efficient levels would preclude investment in the sector. Our estimates suggest that rent taxes well below the exhaustive level would still generate substantial improvements in local welfare.

We view our paper as a contribution to the larger literature on the local economic impact of wind energy investments. Much of the literature to date consists of input-output modeling and econometric studies. Our general equilibrium approach allows us to investigate distributional issues and local tax policy analysis. The data requirements for such models is normally quite burdensome, but our assumption the small rural economies we study contain few relevant input-output linkages allows us to complete the task.

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Appendix. Social Accounting Matrices (SAMs)

A social accounting matrix (SAM) is a database that records all economic transactions of an economy between economic agents/institutions of an economy for a time period (Causape, Ferrai & McDonald, 2018). It can be used to perform economic accounting of a nation, a state or, as in this case, a county. A SAM is used to display the full circular flow of all income in the economy, from production to factor owners, household income to consumption, and back to production. In this paper, domestic (aggregated) production activities include agriculture, manufacturing and retail & services; factors of productions are comprised of land, labor, sector-specific capitals, and intermediates. SAMs are used as data sources for economy-wide models like this one. SAM represents payments/receipts for a given time period, e.g. a year. Essentially, calibration of a GE model for a county requires data from the county's SAM. In absence of shocks, such as taxation policies or an entrance of an external economic activity, the parameters of the model are estimated so that the model results replicate data of the SAM precisely (Cicowiez & Sanchez, 2012). Further explanations and examples of GE model calibrations can be found in Markusen's lectures notes.

A SAM is represented as a square matrix, and each column represents buyers, or expenditures, and each row represents seller, or receipts. Thus, each cell indicates the payment from a buyer to the associated seller. Therefore, each row sums up the incomes of an account, and each column sums up an account's expenditure. For each account, the row total equals column total. The consumption column shows payments from firms to households for their labor, land and capital. The welfare column represents payment from households to firms. In this paper, households only consume retail services, both domestic and imported retail services, as all agriculture and manufacturing outputs are exported. For more information regarding the technical features of SAM, refer to Lofgren et al. (2002).

We undertake similar calculations for the wind sector, and report these data in Table A3. This sector does not appear in the SAM, since its arrival is a shock to the county economies. Gross output is the value of electricity produced by the turbines in one year. The allocation of these revenues to factor owners is determined by calculations outlined in Section 3.1 using data from Table 2.

Table A1. Social accounting matrix for Benton County

	Agriculture	Manufacturing	Retail services	Exports	Imports	Welfare	Consumption
Land	-40,061,847	0	0				40,061,847
Labor	-4,713,158*	-20,348,242	-42,181,513				67,242,913*
Ag Capital	-3,927,632*						
Mfg Capital		-19,277,282*					50,154,214*
Retail Capital			-26,949,300*				
Intermediates	-108,402,645*	-67,470,487*	-48,040,057*		223,913,189*		
Gross output	157,105,282*	107,096,011*		-264,201,293*			
Final Retail			117,170,870*		153,908,130*	-271,079,000	
Welfare activity						271,079,000	-271,079,000
Balance of payments				264,201,293*	-377,821,319*		113,620,026*

Data sources: US input-output table (BEA, 2020); Census of Agriculture (USDA, 2007); Quarterly Census of Employment and Wages (BLS, 2007); Dobbins et al. (2007); Tegen et al. (2012); Wiser et al. (2021). Detailed explanation of the construction of this SAM appears in Section 4.2 of the paper. * indicates imputed values. Our calculations imply net transfer payments to residents of the county of $113,620,026, the figure in the lower right corner of the SAM.

Table A2. Social accounting matrix for White County

	Agriculture	Manufacturing	Retail services	Exports	Imports	Welfare	Consumption
Land	-44,318,117	0	0				44,318,117
Labor	-5,213,896*	-81,250,322	-161,460,594				247,924,812*
Capital ag	-4,344,913*						
Capital manufacturing		-76,973,990*					184,474,284*
Capital retail			-103,155,381*				
Intermediates	-119,919,610*	-269,408,963*	-183,885,683*		573,214,256*		
Implied value of output	173,796,537*	427,633,274*		-601,429,811*			
Retail output			448,501,658*		281,771,342*	-730,273,000	
Price of welfare						730,273,000	-730,273,000
Exchange rate				601,429,811*	-854,985,598*		253,555,787*

Data sources: US input-output table (BEA, 2020); Census of Agriculture (USDA, 2007); Quarterly Census of Employment and Wages (BLS, 2007); Dobbins et al. (2007); Tegen et al. (2012); Wiser et al. (2021). Detailed explanation of the construction of this SAM appears in Section 4.2 of the paper. * indicates imputed values. Our calculations imply net transfer payments to the economy of $253,555,787, the figure in the lower right corner of the SAM.

Table A3. Gross output for and input payments by the wind energy sector

	Benton County	White County
Land	504,331	301,274
Land rent	2,799,765	1,672,500
Labor	4,639,853	1,506,367
Wind capital	143,331,129	85,621,940
Intermediate	17,550,750	11,749,668
Gross output	166,026,065	99,179,250

Gross output and payments made by the wind energy sector. These data determine the size of the shock associated with the first counterfactual exercise, the arrival of the wind sector, and the distribution of wind sector revenues when it is operating.