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

Abstract: The rapid growth of utility-scale wind energy generation is a potentially important boon to rural economies in the United States. Yet most 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.

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). 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 generally finds only modest local benefits from the arrival of utility-scale wind power. [1] 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.[2] 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 turbines more likely?* This paper

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[1] Brown, *et al.* (2012) estimate that the arrival of the wind sector in the years 2000-2008 increased the median county's personal income by 0.2 percent and employment by 0.4 percent. De Silva, *et al.* (2016) estimate that the arrival of 100 MW of capacity generates a 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. Shoeib, *et al.* (2022) find that each additional MW capacity in a county will boost county per capita income by $37 using a mixed effect model, but their matching model shows no significant impact of wind development on per capita income. Brunner & Schwegman (2022) estimate an average increase of 5 percent in per capita income, by far the largest estimated impact in the literature.

[2] 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.

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 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.[3]

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 the Dutch Disease model of Corden and Neary (1982), with the wind energy sector as the booming sector.[4] The model is static, but the participation of external capital in the sector depends on the after-tax rate of return to capital. 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 them. 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. The rents the tax extracts from external capital provide additional income to residents of the county, income that increases demand for locally supplied retail

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[3] 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 are materially affected by changes in the viewscape. Broadly-distributed material benefits (including payments to those who live and work in the local towns) would presumably increase the breadth of local support for accepting the turbines.

[4] 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.

services. The consequences of this increase in demand follow the standard intuition of the Dutch Disease, 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.

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. 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 2.06 percent in the smaller of the two counties and by 0.45 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 10.11 percent and 2.09 percent, respectively. These benefits are the result of increased tax payments by the sector to local governments, which rise by a factor of ten 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 21.64 percent in the smaller county and by 4.04 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, 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 a renewable energy sector appears to be novel, relative to the resource rent literature, which has focused on non-renewable resources, especially petroleum.[5]

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. NREL (2014) was developed for this purpose and is used in many such studies. 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. 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. Our approach, a

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[5] See Lund (2009) and Smith (2013) for reviews of the resource rent tax literature. Gronbekk (2023) reports that Norway is considering a resource rent tax on wind-powered electricity generation. A key reason for the tax is to collect revenues to compensate localities that oppose more wind development. Our work is contemporaneous with these developments in Norway.

calibrated general equilibrium model, is better suited to tax policy analysis than is either econometrics or input-output modelling.[6]

Our work is tangentially related to the recent literature on the economic impact of place-based policies.[7] Federal subsidies to the wind sector, which were made especially generous in response to the global financial crisis (GFC), 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. 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.[8] 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.

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[6] 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.

[7] Neumark and Simpson (2015) review this literature. Popp, *et al.* (2020) study the impact of the entire set of green subsidies in the ARRA on local employment.

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

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 extensions. Section 5 uses a calibrated general equilibrium model to quantify the potential implications of a resource rent tax. Section 6 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 GFC 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.

Section 2.1 Policy context

The development of the utility-scale wind power sector has been generously supported by the United States federal government (CRS, 2020). The longest-lived subsidy has been the production tax credit (PTC), a per-unit production subsidy for electricity produced by renewable fuels. Since 2008, wind energy developers have had the choice to receive an up-front investment tax credit (ITC) instead of the PTC. As part of the federal government’s response to the GFC, Section 1603 of the ARRA authorized federal grants to subsidize investments in projects beginning in 2009 or 2010. The high cost of acquiring external capital during the GFC 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 2.2 Geographical context

Although our insights are mostly 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. 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) data on counties' total personal income 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 county size, these two counties are somewhat lower in the distribution of US counties. Both counties' per capita incomes are above the US median. White County is at the 55th percentile of US counties in population density; Benton County the 32nd percentile.

In order to understand the role of agriculture in the two counties, 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. 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. 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 operational installed capacity. 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 was clearly large, even in the context of a much larger US market.

In order to put the size of the sector in further context, 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 $178.6 million in Benton County and $105.4 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.

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.[9] In the model firms make an annualized output 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 the rents.

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[9] 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 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.

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.[10]

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.[11] 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

$$E \leq aVh. \tag{1}$$

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

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

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[10] The Latin term for wind is *ventum*, so we use V to indicate variables relating to the wind. Similarly we use T (*terra*) to denote variables related to land.

[11] 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.

where P_E is the fixed price of electricity per MWh, S a per unit production subsidy from the federal government, $C^E(\overline{IP}, 1)$ a unit cost function in the electricity sector given a vector of prices for market-supplied inputs $\overline{IP}$, and $(P_E + S - C^E(\overline{IP}, 1))E$ 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

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

and

$$aVh \geq E \quad \perp \quad P_V \geq 0 \tag{4}$$

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 $C^E(\overline{IP}, 1)$ 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

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

where the α terms 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.[12]

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[12] 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.

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 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.[13] 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:

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

The PE 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 PE model requires data-driven choices of its input parameters, given observed values of the equilibrium.[14]

Section 3.1. Calibration of the PE 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. County-level estimates of output 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 these counties. 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

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[13] In practice the allocation of rents is determined by contracts that outside capital negotiates with the landowners.
[14] Calibration of the GE model also involves price normalizations.

figures to be inclusive of rents, and use available data on factor quantities 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.[15] 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. We use the median price as the price relevant to our calibrations.

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.

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[15] 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.

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.[16] 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 the rate of return assumed in Tegen, *et al.* (2012) fully compensates outside capital for its opportunity costs.

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 grants from section 1603 of the ARRA. 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 the cost of labor associated with O&M, we extrapolate backward local estimates of direct labor employed by the industry in Benton and White counties and of estimated compensation costs in the industry.[17] These calculations imply labor costs of \$1.84/MWh in

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[16] 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."

[17] We collect annual salary data for wind technicians from Indeed.com, approximately \$60,000/year. Bednarikova (2020) reports locally-sourced data on 2020 employment levels for our two counties. We require employment data

Benton County and $1.67/MWh in White County. We assume that these are normal factor payments, without any embedded rents.[18]

Landowners in the region who had turbines installed on their land in 2007-2010 receive payments of approximately $6000-$7000 per turbine annually.[19] 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 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 and Cook (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. This accounts for either higher rates of land use, or additional costs of allowing turbines that put the opportunity cost of land above the cash rental rate.

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

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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.

[18] 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 dangers of turbine maintenance.

[19] 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.

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.[20]

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. As noted above, landowner rents are (conservatively) \$1/MWh. Together these imply total rents in the sector of \$9.72/MWh and model parameters of $\gamma_K = 0.897$, and $\gamma_T = 0.103$.

In order to move to quantitative exercises we also need to calibrate the electricity generation sector's cost function $C^E(\overline{IP}, 1)$. 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, we 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

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[20] Tegen, *et al.* also include payments to governments in the O&M costs. These payments turn out to be 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.

White County. This leaves intermediate shares of $\alpha_M = 0.11$ 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 the approach reviewed in Markusen (2021).[21] 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. The simple structure also facilitates straightforward calibration, and allows us to see model mechanisms operating clearly.

The model structure follows the Dutch Disease model that Corden and Neary (1982) developed to understand the short- to medium-term effects, on a small open economy, of a "boom" in a single tradeable sector.[22] The textbook model has three sectors – a non-tradeable sector, a "booming" tradeable sector, and a "lagging" tradeable sector. Each sector employs a sector-

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[21] The article summarizes a more in-depth pedagogical treatment in the "teaching" section of Markusen's web page: https://spot.colorado.edu/~markusen/teaching.html. The approach was first developed by Matthiessen (1985) and extended by Rutherford (1995).

[22] This model is usually used to analyze economic developments in much larger political units, but a number of papers have used the framework to study local economies. Kwon and Sorenson (2021), for example, find Dutch Disease effects in high-tech clusters like Silicon Valley. Maniloff and Mastromonaco (2017) review competing findings regarding the local effects of oil extraction.

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, and their net effects on the economy, depends on model parameters.

The booming sector here is the wind energy sector. Reflecting local realities, we use two lagging tradeable sectors (manufacturing and agriculture) rather than one. We split these sectors 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 and government employment. Labor 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.

Section 4.1. Model Equations

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.[23]

Each sector's cost function is assumed to be Cobb-Douglas with cost share parameters for labor, land, sector-specific capital and imported intermediates. 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 are locally supplied. In the case of intermediates (7) determines the quantity used. In the case of locally supplied factors, The variational inequality associated with market clearance is:

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

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 price of the factor input.[24]

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

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

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[23] (6) follows from profit maximization that chooses Q^s, given P^s and $\overline{IP}$.

[24] 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 are the inputs that are not factors of production.

where P_{US}^{s} is the (fixed) price in the broader U.S. market, PFX is the "price of foreign exchange" variable, and X^{s} the quantity of good s exports.[25] An equivalent condition applies to electricity exports. The arbitrage condition that determines quantities of imported intermediates is similar:

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

with $P_{i,US}$ the price on the broader U.S. market, P_i the local price, and M_i the quantity of sector *s* intermediates purchased outside the county. Conditions analogous to (10) determine the quantity of intermediates (M^{E}) and capital services (K^{E}) imported by the electricity sector.[26] Imports of final retail (Q_{US}^{r}, 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.

Section 4.2 Income and welfare

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

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

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[25] The variational inequality in (9) relates to profit maximization of perfectly competitive 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 be one. We choose PFX as the model numeraire, and set it to one throughout all exercises.

[26] The arbitrage condition involving K^{E} disciplines participation in the wind-energy sector by external capital. Capital's return includes the normal factor return and the rent that it receives. Any local taxation of capital that would cause the after-tax return to capital to fall below the after-tax return in the broader U.S. would shut down participation by capital, shutting down the sector.

The resource rent instrument is *tax*, an *ad valorem* tax on rents. *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).

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

where $\theta^r$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.[27]

The market for the locally-supplied final retail clears with local supply equal to local (Hicksian) demand:

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

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[27] This formulation of household welfare is unfamiliar to many, but is extremely useful in modeling optimizing behavior by multiple households as we do here.

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:

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

Section 4.3. Trade balance

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 reduced 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 transfer payments from outside the county, and is held fixed. $\sum_s IP^s M^s$ and $IP^E M^E$ represent purchases of intermediates by the preexisting and the wind energy sectors, respectively. $PK^E K^E$ represents payments for the factor services of wind energy capital. $\gamma_K(1 - tax)P_V aVh$ is the economic rent, net of taxes, paid to external capital.

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 11). A positive tax also reduces the county's rent payments to external capital (16). The new income from rent taxes is balanced by increased purchases of either outside retail ($P_{US}^{r} Q_{US}^{r}$) or intermediates for use by the preexisting sectors ($\sum_s IP^s M^s$). There is also 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 production sectors affect factor prices.

Section 4.4 Extension to multiple local agents

So far, the model assumes a representative local agent who 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. 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.[28]

In terms of model equations, the shift to a multiple agent version of the model is simple. Each of the five locally supplied factors is given its own income equation. That equation appears as

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

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

This 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

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[28] 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.

accrues to each factor f with $\sum_f \delta_f = 1$. 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 4.5 Calibration of the GE model.

Following Markusen (2021), we calibrate the model's cost and expenditure shares by construction of a social accounting matrix (SAM). 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. Since this exercise is rather involved, and only tangential to the main lessons of the paper, we relegate the details to Appendix A.

Model calibration also requires a choice of consumers' elasticity of substitution, σ. $\sigma=5$ is a common choice in the international trade and the economic geography literatures. In our preferred estimates, we use $\sigma=5$. But we also estimate with $\sigma \cong 1$, a Cobb-Douglas parameterization, and show that smaller values of σ magnify the Dutch Disease.[29] 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 county GDP, and award the same share of transfer income and of property tax revenue to that factor. This share is δ_f.

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

Section 4.6 Equilibrium in the calibrated model.

The calibration and simulation methods are typical of models of this kind; the approach is outlined in Markusen (2021). 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 indices 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 percentage changes in the price and quantity indexes. 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). Another application of Walras' Law, ensures consistency of the counterfactual equilibrium.

Section 4.7 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. 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 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 benchmark calibration, V = 0. 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.[30]

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 local retail purchases and higher retail prices. Relative to the standard Dutch Disease model this effect is muted because locals purchase retail services outside the county.

The arrival of the wind-generating electricity sector produces increased tax revenues for the county government, in the form of property taxes or other payments. We capture these flows 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 0.02,

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[30] 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 one.

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.

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 to 100 percent. Conceptually, a 100 percent 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 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 incentive-compatible rent taxes. In the representative agent model, a 99 percent rent tax qualifies because recycled tax revenues are more than sufficient to offset landowners' losses. In the multiple-agent model, we must choose lower rent tax rates to insure landowners' participation.[31] 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.[32]

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[31] In all exercises we consider outside capital continues to the participate in the wind sector.

[32] 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. 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. According to Gronbekk (2023), the resource rent tax rate proposed for wind energy in Norway is 40 percent.

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.[33]

In robustness analysis 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. If the sector were to import all of its workers, the resource movement effect would be largely neutralized. 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 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.

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[33] Reallocating these funds changes relative welfare levels without affecting other outcomes. In unreported work we show that the arrival of the wind sector and the imposition of taxes can generate a Pareto improvement because new tax revenues are more than sufficient to compensate all losing households.

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 factor, labor. The resource movement effect sees rising wages cause pre-existing sectors to reduce labor inputs, reducing the quantity of outputs and the factor prices earned by sector-specific capitals. The spending effect occurs – as can be seen by rising prices in the retail sector - but these effects are muted by consumers' substitution toward external retail. The largest positive net effects are on a) the factor price of labor (up 5.53 percent in Benton County), and b) purchases of outside retail (up 5.76 percent in Benton County). The most negatively affected sector is manufacturing, a relatively labor-intensive 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 5.52 percent in Benton County. The other two sectors shrink, but by less than manufacturing. The representative agent sees a 2.06 percent increase in welfare in Benton County and an increase of 0.45 percent in White County. Property tax revenues collected from the wind sector in the calibrated model amount to $3.01 million in Benton County and $1.79 million in White County.

In columns 2 and 4 we report results from an experiment imposing a 99 percent tax on rents in 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 10.11 percent in

Benton County and 2.09 percent in White County). The larger spending effect aggravates the negative consequences of the boom on the lagging sectors.

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 ten when the resource rent taxes are added to property tax payments.

Extensions and Robustness

Results from our extensions and robustness exercises are too lengthy to report in detail here. So we summarize, and direct the reader to Appendix B for detailed results. Our multiple-household model reveals significant distributional consequences of both the wind-generating sector's arrival and the resource rent tax. In order to be incentive-compatible for landowners, rent taxes must be lower than in the representative agent model. When we reduce σ, Dutch Disease effects are stronger, meaning even lower (though still quite high) incentive-compatible tax rates. Lower tax rates imply lower tax revenues, which means that the rent taxes generate smaller (but still large) increases in local welfare. Allocating all the revenues to labor leaves county workers much better off in all exercises.

When we consider the possibility that the arrival of the wind sector generates an offsetting increase in the labor supply, Dutch Disease effects are substantially reduced. Since factor prices changes are muted, larger incentive-compatible resource rent taxes are feasible. These larger rent taxes generate larger increases in local welfare.

Section 6. 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, 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. 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.

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.

We report results for exhaustive rent taxes and for somewhat smaller 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.

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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)	$176.8 million	n/a	$105.4 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.

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 and Cook (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.

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

	Benton County		White County	
	(1)	(2)	(3)	(4)
Variable	Wind sector arrival	Wind sector arrival with 99% tax	Wind sector arrival	Wind sector arrival with 99% tax
P^{ag}	0	0	0	+ 0.21
P^{mfg}	0	0	0	+ 0.21
P^{rtl}	+ 1.69	+ 3.43	+ 0.26	+ 0.93
Q^{ag}	- 1.91	- 2.12	- 0.78	- 0.84
Q^{mfg}	- 5.52	- 7.47	- 0.64	- 1.20
Q^{rtl}	- 2.76	- 0.22	- 0.06	+ 0.60
FP_L	+ 5.53	+ 7.63	+ 0.61	+ 1.36
FP_T	- 0.44	- 0.65	0	+ 0.16
FP_{K-ag}	- 1.91	- 2.12	- 0.78	- 0.63
FP_{K-mfg}	- 5.52	- 7.47	- 0.64	- 1.00
FP_{K-rtl}	- 1.11	+ 3.2	+ 0.20	+ 1.53
Q^r_{US}	+ 5.76	+ 16.5	+ 1.26	+ 4.26
U_{rep}	+ 2.06	+ 10.11	+ 0.45	+ 2.09
Tax revenue from wind energy	\$3.01 million	\$29.73 million	\$1.79 million	\$17.87 million

Table notes: Reported values are percentage changes in associated variables. P^s is price of the pre-existing sector/good s, Q^s is locally produced quantity of the good/sector, FP_f is the price of factor f, Q^r_{US} 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. 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.

Appendix A. Construction of the Social Accounting Matrices

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. This information is typically summarized in a Social Accounting Matrix (SAM)**.** We use data from various sources to construct our 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.[34] From the tables, we collect each aggregate sector’s measure of output, and subtract tax payments. For each sector, the labor share is calculated as payments to

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[34] 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.

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.[35]

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

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[35] 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.

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 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.).[36] 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

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[36] 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.

approximately half of total spending. The calculations here are sufficient to produce the SAM for each county. Tables A1 and A2 report the SAMs for Benton and White Counties respectively.

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*						50,154,214*
Mfg Capital		-19,277,282*					
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*
Ag Capital	-4,344,913*						184,474,284*
Mfg Capital		-76,973,990*					
Retail Capital			-103,155,381*				
Intermediates	-119,919,610*	-269,408,963*	-183,885,683*		573,214,256*		
Gross output	173,796,537*	427,633,274*		-601,429,811*			
Final Retail			448,501,658*		281,771,342*	-730,273,000	
Welfare activity						730,273,000	-730,273,000
Balance of payments				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.

Appendix B. Model extensions and robustness.

The only information about the distributional effects of the policy in the representative agent model arises from relative factor price movements. Because there are economic rents, a realistic discussion of distributional effects should also consider how taxing rents affects the incomes of other 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 $\sigma = 5$.

The results from these exercises are reported in Table B1. 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 49 percent for Benton County and 69 percent for White County. For $\sigma = 5$, the tax rates are 74 and 86 percent.

The much lower tax rates under Cobb-Douglas arise because Dutch Disease effects are much more pronounced. Since consumers cannot as easily substitute towards the external retail good, the spending effect causes a larger expansion of the domestic retail sector than in the CES model. This expansion occurs at the expense of the other local 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.

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.[37] The size of the allocation to labor is increasing in 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

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[37] 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.

rates in the $\sigma = 5$ scenario produce welfare gains of 21.64 and 4.04 percent for labor in Benton and White Counties, respectively.

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 representative agent. This mechanism offers one explanation for local opposition to turbines. It is possible, however, that the model overstates the harm done to lagging sectors, because the baseline model does not allow immigration into the county. All labor used in the wind sector must be drawn away from the pre-existing sectors. 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 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 preexisting 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 B2. 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 (22.50 percent in Benton County and 3.90 percent in White County). These estimates are quite similar to those in Table B1, which presume that the wind sector may only draw labor away from other local sectors.

Table B1. Results for factor-specific real incomes, incentive compatible taxation, and alternative substitution possibilities.

	Benton County		White County	
	(1)	(2)	(3)	(4)
Variable	Wind sector arrival with 49% tax, ($\sigma \approx 1$)	Wind sector arrival with 74% tax, ($\sigma = 5$)	Wind sector arrival with 69% tax, ($\sigma \approx 1$)	Wind sector arrival with 86% tax ($\sigma = 5$)
P^{ag}	0	0	0	0
P^{mfg}	0	0	0	0
P^{rtl}	+ 5.54	+ 3.17	+ 1.33	+ 0.81
Q^{ag}	- 2.37	- 2.09	- 0.94	- 0.87
Q^{mfg}	- 9.79	- 7.18	- 2.16	- 1.52
Q^{rtl}	+ 2.82	- 0.59	+ 1.19	+ 0.42
FP_L	+ 10.25	+ 7.32	+ 2.09	+ 1.46
FP_T	- 0.91	- 0.62	- 0.15	- 0.09
FP_{K-ag}	- 2.37	- 2.09	- 0.94	- 0.87
FP_{K-mfg}	- 9.79	- 7.18	- 2.16	- 1.52
FP_{K-rtl}	+ 8.52	+ 2.57	+ 2.53	+ 1.24
Q_{US}^{r}	+ 8.52	+ 16.22	+ 2.53	+ 4.55
U_L	+ 14.73	+ 21.64	+ 3.46	+ 4.04
U_T	0	0	0	0
U_{K-ag}	- 2.57	- 1.40	- 1.17	- 0.81
U_{K-mfg}	- 6.78	- 4.32	- 0.02	- 1.24
U_{K-rtl}	+ 3.62	+ 1.27	+ 1.07	+ 0.56
U_{rep}	+ 6.02	+ 8.08	+ 1.54	+ 1.85
Tax revenue from wind energy	$16.17 million	$25.68 million	$12.99 million	$15.75 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_f is the price of factor f, Q_{US}^{r} is the quantity of imported retail and services purchased, and U_{rep} is the utility level of the representative consumer. Values in the associated rows are percentage changes in each variable. Results assume $\sigma = 5$ in the consumer's expenditure function. 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.

Table B2. Results assuming endogenous labor supply (and no resource movement effect)

	Benton county		White county	
	(1)	(2)	(3)	(4)
Variable	Wind arrival with endogenous labor	Endogenous labor and 98% tax	Wind arrival with endogenous labor	Endogenous labor and 92% tax
P^{ag}	0	0	0	0
P^{mfg}	0	0	0	0
P^{rtl}	+ 0.83	+ 2.55	+ 0.18	+ 0.67
Q^{ag}	- 1.40	- 1.61	- 0.73	- 0.79
Q^{mfg}	- 0.69	- 2.74	- 0.16	- 0.77
Q^{rtl}	+ 1.75	+ 4.41	+ 0.38	+ 1.10
FP_L	+ 0.66	+ 2.67	+ 0.15	+ 0.73
FP_T	+ 0.66	- 0.15	+ 0.05	- 0.01
FP_{K-ag}	- 1.40	- 1.61	- 0.73	- 0.79
FP_{K-mfg}	- 0.69	- 2.74	- 0.16	- 0.77
FP_{K-rtl}	+ 2.59	+ 7.07	+ 0.57	+ 1.77
Q_{US}^{r}	+ 6.02	+ 18.43	+ 1.31	+ 4.52
U_L	+ 1.20	+ 22.50	+ 0.20	+ 3.90
U_T	+ 4.38	0	+ 2.35	0
U_{K-ag}	- 0.06	- 0.88	- 0.35	- 0.68
U_{K-mfg}	+ 0.35	- 1.51	+ 0.03	- 0.66
U_{K-rtl}	+ 2.25	+ 4.09	+ 0.50	+ 0.99
Tax revenue from wind energy	$3.01 million	$21.23 million	$1.79 million	$16.73 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_f is the price of factor *f*, Q_{US}^{r} 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.