Power banks: do tax equity investors add value to renewable power projects?

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Abstract

We characterize a novel agency conflict within the capital structures of renewable power plants. In 656 U.S. plants from 2006-2024, wind (solar) plants, for which tax equity returns depend (do not depend) on production quantity, produce 6-9% (no) closer to capacity until the tax equity investor's exit. Two natural experiments suggest increased production is not due to selection nor due to relaxing financial constraints. Wind plants with tax equity have lower revenue per megawatt-hour produced, reducing common equity returns. Tax equity's distortionary effect is attenuated by back-levered debt held by equally sophisticated investors and secured by the sponsor's equity position.

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1 Introduction

Infrastructure investment around the world faces challenging financing frictions due to the confluence of high fixed costs and the involvement of the public sector. When ownership is shared, governments and private investors can have conflicting incentives which may result in under-investment in infrastructure through a variey of mechanisms (Grossman and Hart (1986), Cai (2003), Acharya, Parlatore, and Sundaresan (2025)). A wide spectrum of project finance structures has evolved in response to these issues—ranging from full government ownership and control to private ownership with limited government funding.[1] As infrastructure investment increases in public priorities such as the low carbon transition or replacing aging roads and bridges, it is important to understand the role that private financing plays in facilitating or slowing investment.

In this paper, we study a particular financing structure with heavy private ownership that has surged in popularity for utility-scale green energy in the US: *tax equity*. Governments around the world use tax credits to encourage private investors to finance public goods. In the U.S., where investment in clean energy in 2024 was $500 billion, the tax code provides incentives that amount to 30-50% of the plant's construction cost. Project sponsors without enough taxable income to use these credits often turn to "tax equity" investors, traditionally large banks with high taxable income, who provide additional financing in return for the tax-related cash flows. In the U.S. in 2024, about $28 billion of tax equity capital was raised, according to Norton Rose Fullbright, and this number is projected to grow in 2025. Since the tax equity investor is compensated principally by the government and little from the overall project returns, their objectives may conflict with those of other stakeholders.

We study a sample of 656 solar and wind plants financed with external project finance to assess how and why the use of tax equity can positively or negatively impact project outcomes. We examine wind plants, where the tax credits scale with production quantities (production tax credits or PTC), separately from solar plants where the tax credits (invest-

[1] We discuss the range of existing ownership structures in Appendix A and Figure 1.

ment tax credits or ITC) and thus the tax equity investor's returns do not vary directly with production.[2] First, we describe how plant outcomes, primarily energy output and price, are a function of physical plant characteristics like wind speed and turbine size. Next, we find that wind plants receiving tax equity financing generate 6-9% more electricty as a share of their capacity and sell this electricity at lower prices conditional on physical characteristics. We find that ownership structure is unrelated to output outcomes for solar plants where the tax equity investor's returns do not increase with additional production.

We propose and test three mechanisms through which tax equity may affect project outcomes: (1) project selection and screening, (2) relaxation of financial constraints, and (3) monitoring or contracting. Our evidence supports the role of monitoring or contracting, and we find limited evidence for the importance of the other two channels. Our evidence points toward production quantity incentives of tax equity investors creating a novel agency conflict that changes the performance and decreases value of the underlying asset.

We test for causality in five ways. First, the change in wind plant production and prices is only apparent during the tax equity investor's holding period (10 years). Second, the effect is strongest for tax equity provided by the most frequent and sophisticated tax equity providers. Third, we examine instances where plants have very low monthly production and find a strong negative association between low production months and the presence of tax equity. This is consistent with additional effort toward attaining best practices in maintenance preventing these occurrences in tax equity wind plants. Fourth, we contrast the operational changes observed in wind plants with the lack of a tax equity impact for solar plants.

Fifth, we present two complementary natural experiments where tax equity either was not used due to the availability of cash grants, or was used due to the the presence of a

[2]A production model with capital and utilization appears in Online Appendix B, providing structure regarding how the PTC and ITC incentives interact with the presence of a tax equity investor. Since the solar ITC's value is proportional to the plant's initial cost, increasing a plant's production on the margin has limited value to ITC tax equity investors unless they provide a lower-cost monitoring technology. Maximizing a plant's initial cost is also unhelpful because this porportionally increases the tax equity investors' initial investment.

negative tax position on other assets. The first natural experiment is the American Recovery and Reinvestment Act (ARRA)'s "Build Back Better" plan that was put in place after the financial crisis of 2007-2008 because traditional tax equity investors no longer had the taxable income to offset with tax credits. This plan offered developers of renewable energy projects the choice of a direct cash grant instead of a tax credit. We find that projects of sponsors who are sophisticated enough to attract tax equity in other years during the sample period but who received a grant are not more efficient than projects that receive neither tax equity investment nor a grant and for which the sponsor simply claims the tax credit. These results suggest that the presence of tax equity investors in the capital structure, and not simply their project selection ability or general sophistication, is associated with more energy generation. A second natural experiment occurred when the Southern Company experienced a large drop in taxable income, but not book income, in late 2018, forcing it into unplanned tax equity agreements for a portfolio of recently operational wind plants. The capacity factor relative to matched plants increased in the presence of the tax equity investors, consistent with a causal relation between tax equity investors' presence and electricity generation outcomes.

Taken together, our results suggest that tax equity investors' presence in the capital structure, whether through up-front contracting or periodic monitoring, is necessary for the effect and that it is not due to the selection of plants with attributes that are associated with higher production. We have shown that tax equity investors benefit from increased production and do not proportionally bear the costs of maintenance, and we have found that tax equity-funded wind plants produce more while solar plants have production that is not distinguishable from non-tax-equity-financed projects. A calibration that combines the increase in quantity produced with the decline in price for average sale estimates that these operational changes decrease the return on invested capital by 4.1% on average, which is of the same magnitude as that of other agency problems [Morellec, Nikolov, and Schürhoff (2018)]. This reduction in returns, like an increase in hurdle rate, represents a headwind to the investment that the government is trying to incentivize.

In a final test, we examine the effects of the presence of long-term debt in the capital

structure. In tax equity-funded plants, long-term, "back-levered" debt has claims on the cash equity's portion of the project, so they should be especially sensitive to costs that are disproportionally borne by the project sponsor. Moreover, back leverage is provided by large banks with the same level of sophistication as tax equity investors. If the increased production associated with tax equity investors decreases the value of the equity stake on the net, we expect the presence of back-levered debt to attenuate the effect of tax equity on production. On the other hand, if the increased production associated with tax equity increases the value of cash equity, we would expect no interaction effect, or possibly a positive interaction effect of back-levered debt on production. We find that the presence of long-term back-levered debt in the capital structure almost entirely attenuates the effect of tax equity. This is consistent with a distortionary effect of tax equity's presence on production rather than an increase in project value.

The Inflation Reduction Act of 2022 allows for the transferability of ITC and PTC tax credits. Due to this change, tax equity investors may become more numerous and less sophisticated, with less ability to monitor or contract for high-quality preventative maintenance. On the other hand, sophisticated intermediaries may require the same contracts as traditional tax equity investors for the tax equity stakes they sell to third-party investors.[3] In untabulated results, we find no significant effect of wind tax equity on performance for plants with COD dates in 2024 or later, after which the transfer market began to grow, but this may be due to insufficient power in this subsample.

2 Related literature and this paper's incremental contribution

This paper contributes to the literatures on agency conflicts, project finance, and tax incentives by analyzing the unique role of tax equity investors in renewable energy projects.

[3]The mandate issued on January 27, 2025 by the Office of Management and Budget (OMB) aims to pause cash outlays and assistance through grant and loan programs, not tax credit claims.

Our paper identifies a novel agency conflict between tax equity investors and traditional equity investors. Our finding that tax equity investors' bargaining power enables up-front contracting on onerous terms contributes to the literature on how concentrated capital providers affect firm value. Unlike traditional creditors [Jensen and Meckling (1976), Rajan (1992)], preferred equity holders [Ewens, Gorbenko, and Korteweg (2022)], or large shareholders [Dann and DeAngelo (1983), Burkart, Gromb, and Panunzi (1997), Pagano and Röell (1998), Crane, Michenaud, and Weston (2016)], all of which can diminish firm value in their efforts to claim a larger share of it, tax equity investors have revenues that are provided by the government and tied to production volume, creating exogenous incentives for production with less regard to expense. We show that even in the absence of substantial claims on the project's cash flows or of explicit voting rights as in other work, this agency conflict results in harm to other investors in the project. The discipline imposed by back-levered creditors aligns with Morellec, Nikolov, and Schürhoff (2018)'s finding that creditors counteract general agency distortions, but here, the discipline comes from counteracting tax equity investors rather than by reducing the availability of cash.

This paper also contributes to the literature on infrastructure finance [Esty and Megginson (2003), Esty (2004), Leland (2007), Reinartz and Schmid (2016), Detemple and Kitapbayev (2019), Andonov, Kräussl, and Rauh (2021), Andonov and Rauh (2022)], which amounted to $799.16 billion in 2024 and has been growing at more than 10% per year according to IJ Global. In particular, Williamson (1988) shows that redeployable assets are best suited to debt governance, which functions via rules, in contrast to equity governance's reliance on control. Consistent with this hypothesis, in this setting with highly redeployable assets, the observed structure of tax equity contracts isolates the tax benefits, with substantial initial contracting but without day-to-day control rights. As is common in project finance settings, our sample comprises transparent assets with observable production and characteristics, a common industry, and a uniform set of contracts. While prior work emphasizes project finance as a solution to agency costs [Esty and Megginson (2003), Esty (2004)], our paper reveals the limitations of project finance in this regard when combined

with government incentives.

Lastly, we contribute to the empirical work studying the costs and benefits of subsidies and tax expenditures [Surrey (1973), Auerbach and Summers (1979), Denes, Howell, Mezzanotti, Wang, and Xu (2023)]. Several studies perform cost-benefit analysis of renewable energy subsidies [Aldy (2013), Borenstein and Kellogg (2022), Johnston (2019), Aldy, Gerarden, and Sweeney (2021)], but these papers do not consider tax equity or its incentive-driven costs. This is an important gap in the literature, given that tax equity comprises roughly half of the capital cost of these projects. Telmer and Wu (2024) study tax equity theoretically to determine how the tax benefits are allocated between the tax equity investor and the sponsor. In a related empirical exercise focusing on US utility-scale wind production tax credits, Kay and Ricks (Forthcoming) find that production declines on average after the 10-year PTC window and use this decline to calibrate a model of optimal taxation. In contrast, our results show that production as a share of capacity declines differentially for plants financed with tax equity relative to those plants without tax equity after the PTC period ends. We show that the incentives of tax equity investors lead to operating changes that decrease the value of the sponsor equity claim, thereby decreasing the effectiveness of the tax subsidies.

3 Investment and Production Tax Credits

The Investment Tax Credit (ITC) has been primarily used by solar projects and accrues in the year that the plant is placed in service and then vests over 5 years. The Production Tax Credit (PTC) is available for wind, nuclear, and hydrogen projects, amounting to 1-3 cents per kilowatt-hour produced over 10 years. Figure 2 presents a project timeline and a typical tax equity deal structure. Negotiations begin as the project is developed, and closing occurs at the commercial operations date (COD). Yields on tax equity are typically between 6 - 7.5%.[4] Tax equity investments are relatively low-risk due to their 'back-levered' structures

[4] Norton Rose Fulbright Cost of Capital: 2024 Outlook.

that have priority over the project's debt. Additional details about tax equity structures appear in Online Appendix A.

In contrast to the ITC, the PTC creates an agency conflict between the tax equity investor and the cash equity sponsor because the PTC pays tax equity investors proportionally to the plant's electricity production. Thus, the PTC investor benefits from maximizing production regardless of the price the electricity is sold for or the costs associated with maintaining peak production. Although solar and wind fuel is free, plants require performance monitoring, inspections, preventative maintenance, and addressing outages quickly to run optimally, and O&M expense represents a large part of the levelized cost of equity (LCOE), a comprehensive measure of the cost to create one unit (MWh) of energy over the life cycle of a plant. In its 2023 *Levelized Cost of Energy Analysis*, Lazard estimates that O&M expense comprises 11.5%-12.5% of levelized cost of energy (a comprehensive measure of the cost to create energy over the life cycle of the plant) for utility-scale solar and 16.7%-17.3% of LCOE for utility-scale wind. In a survey of industry professionals and the literature, Wiser, Bolinger, and Lantz (2019) estimate that a broader measure of O&M costs, including unscheduled maintenance, represents 25-35% of LCOE and that its share is growing. An operation and maintenance (O&M) provider, which can be the original equipment manufacturer (OEM), the developer, or a third party, is chosen during construction with contracts ranging from 5 to 10 years. O&M contracts with OEM providers are significantly more expensive[5] and result in increased performance.[6]

Whether the use of tax equity would have any impact on firm operation is not ex ante obvious. In the U.S., the reasoning behind the use of tax credits instead of cash grants to developers is that tax equity investors contribute selection and monitoring expertise to the

[5]Estimates for the discount in turbine O&M fees associated with switching to self-provision from an O&M contract range from 19% [Ford (2018)] to 30% [Briggs (2017)]

[6]In a survey of professionals, Wiser, Bolinger, and Lantz (2019) find that switching away from an O&M contract with OEM providers is associated with a decrease in the share of time a turbine is available to spin if the wind blows from over 97% to 92% and is based on a cost-benefit analysis by the plant operator. Moreover, Wiser, Bolinger, and Lantz (2019) emphasize that O&M practices have a direct effect on wind turbine component reliability, turbine performance, and wind plant availability. Similarly, in data from 2,200 solar photovoltaic systems, the National Renewable Energy Lab (2020) finds that 8.3% of lost energy production could be avoided through optimal operations and maintenance.

projects, which might manifest as more production in the cross section, but should have similar impacts on wind and solar plants. A 2019 Congressional Research Service report explains that "[e]ffectively, the tax equity mechanism outsources a portion of the oversight and compliance monitoring to investors in exchange for a financial return." [Keightley, Marples, and Sherlock (2019)]. One banker warned that paying developers with cash grants instead could create incentives to build "not great projects" in poor locations or with inferior designs.[7] Tax equity structures require financial sophistication to execute, and a large proportion of tax equity investment comes from just five large banks during our sample period.

Tax equity investors have bargaining power because tax equity dollars are in short supply. Although they do not operate the plant, tax equity investors can rely on a combination of contractual agreements, monitoring, and warranties to ensure a desired level of maintenance effort. For example, a tax equity investor can require third-party O&M agreements and that the sponsor keep a given level of cash on hand to pay for unexpected maintenance. Moreover, tax equity investors often require detailed operational and financial reporting from the project owner. If the plant owner fails to fulfill its maintenance obligations, the tax equity agreement typically includes remedies such as withholding distributions, accelerating payments due to investors, or replacing the plant operator ("step-in rights").

4 Data

Data on the project finance transactions of renewable power projects are from IJ Global from 2007 through the third quarter of 2024. This paper focuses on U.S. onshore solar and wind power plants, which are numerous and have standardized and transparent revenues and expenses. IJ Global covers plants financed through project finance and excludes projects financed directly from utilities' balance sheets (traditional corporate finance) that require no project-specific external financing. The advantage of project finance is that the entity or special purpose vehicle (SPV) is self-contained with all claims on easily observable assets.

[7] US renewables look to plug funding gap as pandemic hits tax incentives, Financial Times, December 12, 2020.

IJ Global lists the power plants' location, capacity and type, and the name of the SPV. Financings can be for portfolios of plants or, most commonly, for individual plants. IJ Global provides the names of the investors and often the dollar amounts of their investments. IJ Global misses some tax equity investments negotiated after the initial project financing is in place. We search the Web for each plant and the keyword "tax equity" to find tax equity closing announcements and the associated tax equity investors and amounts or to confirm that there are none. The media mentions appear in trade journals and/or on the websites of plants, developers, and utilities. To isolate the effects of tax equity cleanly, we remove from the sample the rare cases in which the tax equity provider also provides debt or traditional equity.

We create an indicator for whether each plant has *Tax Equity*. Using the name of the tax equity investor(s), we classify them into *Bank5TaxEquity*, for the top five providers of tax equity during the sample period (JP Morgan, Bank of America, Wells Fargo, Credit Suisse, and US Bank), *FinTaxEquity* for other financial institutions, banks, insurance companies and funds (for example, PNC), *EnergyTaxEquity* for entities whose primary business includes energy (for example GE and Siemens), and *CorpTaxEquity* for corporations whose primary business is not energy (for example, Google and Apple). The indicator *UnknownTaxEquity* signifies that the name of the tax equity investor is not available.

We hand-match the IJ Global financing data by name to the U.S. Energy Information Administration (EIA) list of functioning, planned, and retired power plants in Form EIA 860. This form provides the current capacity and the year and month the plant begins operations. EIA Form 923 provides data on the annual power production of each plant and revenues from sales of electricity. This form also provides details about the power plants: capacity, location, and the existence of a power purchase agreement (PPA). Power purchase agreements reduce risk to the project as the output is contracted for in advance.

Definitions of "utility-scale" plants vary widely from over 1 to over 50 MW. We limit the data to plants 20 megawatts (MW) or greater, though our empirical results are similar with a threshold of 5, 10, or 50 MW instead. Less than 10% of plants below 20 MW receive

tax equity financing according to IJ Global, and the 20 MW threshold is consistent with the definition used by the Inflation Reduction Act of 2022.

The IEA lists 1,977 20 MW or larger wind and solar plants reaching their COD in the U.S. between 2006 when the first tax equity financing appears in the IJ Global data, and November 2024. The plants that we do not match are either government-owned, financed using internal corporate finance, or financed with project finance but not identified by IJ Global. In the latter case, the financing could be missing, or the asset is not identified precisely enough by IJ Global for us to match to a unique plant. We also exclude four solar thermal plants (none of which have tax equity) because the technology is significantly different from PV solar plants, is still experimental, and tends to underperform traditional PV plants. Projects in our data have a mean of 1.14 plants, a median of 1 plant, and a maximum of 9 plants. Our final sample comprises 327 solar and 329 wind plants. Figure 3 shows how many plants with a capacity of 20 MW or larger came into service in each year of the sample period and how many are in this paper's sample. Figure 4 illustrates the prevalence of tax equity for various plant size categories and shows a distinctly positive relation between plant size and the presence of tax equity.

The clean energy package within the American Recovery and Reinvestment Act of 2009 modified Section 1603 of the tax code to offer developers of renewable energy projects the option to receive direct grants instead of tax credits. The program began on July 31, 2009, was renewed in 2010, and expired on December 31, 2011. In all, 252 wind projects and 4,404 solar projects qualified for the program, according to Aldy (2013), who provides a preliminary evaluation of the program. Although he notes that developers might still use tax equity if they could not use the depreciation from the project, which could amount to an additional 10% of project cost, one could expect that developers would be less likely to use tax equity during this period. From Treasury.gov, we collect data on Section 1603 grants and match them to our sample by plant name. These list the date and the amount disbursed. In our sample, these plants went into service between 2008 and 2013.[8]

[8]The single plant with a COD of 2008 in the EIA Form 860 was part of a four-part wind project, where

Hourly weather conditions for all 546,203 weather stations in the United States from the NSRDB are available for bulk download through 2022. For each plant, we identify the closest weather station and compute the average weather values in the ten years prior to the financing date and in each of the operating years and months of the plant. The measure of solar input that we use is average direct normal irradiation (DNI), the most direct measure of sunlight hitting a surface. Average monthly *Windspeed* for wind plants is collected from the NSRDB and is available through 2022. Figure 5 presents the solar and wind plant projects that achieved COD over the sample period. These figures show that wind plants have appeared steadily over the sample period, while solar plants have appeared mostly after 2011. The figure also shows the proportion of projects each year that have tax equity or a Section 1603 grant. This figure shows that tax equity was almost never used when the Section 1603 grants were available. Exceptions were likely due to a contract signed ahead of time and/or to the need by some developers to monetize depreciation tax benefits as well as the ITC or PTC. Figure 5 shows that many wind plants came into service in 2012, as a historically large 2.2 cent per kilowatt hour production tax credit was set to expire that year (it was ultimately extended).

Table 2 presents summary statistics for the 656 plants in the sample. Panel A presents plant-level data, and Panel B presents time-series data. In each panel, the first two columns present all plants, while columns 4-6 present solar plants, and columns 7-9 present wind plants.

Panel A summarizes the plant characteristics. Solar projects average 105.9 MW in capacity, while wind projects average 172.7 MW. 58.7% of solar projects receive tax equity while only 49.5% of wind projects do, perhaps due to the uncertainty of the amount of electricity that will be produced and, thus, the amount of production tax credits that the tax equity investor will receive. Solar and wind projects are roughly equally likely to be associated with power purchase agreements at the time of COD: 52.9% vs. 56.5%, respectively. Panel A also lists the types of tax equity investors in our data in the subset of deals for which this

the subsequent parts received a crisis grant and had CODs of 2009.

information is available. Some projects have more than one tax equity investor, and thus the investor category totals add up to more than 54.1%. The top five banks are involved in at least 16.5% of deals, or 52% of tax-equity-funded deals for which the tax equity investor is known, throughout the sample period. Another major type of investor is in the energy industry. These are often the suppliers of the turbines or other equipment for the project. For 22.6% of deals (42% of tax-equity-funded deals), the identity of the tax equity investor is not known.

We also collect plant characteristics from EIA Form 923 to capture the physical characteristics that determine energy generation outcomes. For solar plants, these include characteristics of the panels: *CrystallineSilicon* (72.4% of solar plants), *SingleAxisTracking* (84.5% of solar plants), *DualAxisTracking* (1.41%), all of which should theoretically be associated with higher performance as a share of total capacity. *StorageRatio* is the capacity of any battery storage divided by the maximum capacity of the plant. This ratio is less than 1% for solar plants, and is almost always zero for wind plants.

In its annual reports on land-based wind, the Lawrence Berkeley National Laboratory distinguishes two main drivers of wind plant performance in addition to wind speed. The first is "specific power," which is the ratio of its nameplate capacity to its rotor's swept area measured in watts per square meter (W/m^2) Swept area is equal to $\pi(D/2)^2$, where D is the diameter in meters of the turbine blades. Since specific power is inversely related to performance, we create the variable *InvSpecificPower*. The data on the length of the turbine blades and their maximum output is collected from EIA 923 Wind and supplemented with hand-collection from Power-technology.com. Table 2, Panel A shows that *InvSpecificPower* averages 3.912 for wind plants in our sample. A second driver of wind plant performance is *TurbineHubHeight*. Turbine hub heights are collected from the EIA form 923 subsection on wind plants. Using web searches, we correct several errors where turbine heights are reported in meters instead of feet as required by Form 923. Turbine hub heights average 299.4 feet in our sample.

We further supplement the EIA 923 data with hand-collection from the profiles of a subset

of the plants that are available at power-technology.com. From these profiles, we collect the names of the Operations and Maintenance (O&M) providers along with the names of the developers and suppliers of solar panels or wind turbines (EIA Form 923 also provides the names of turbine suppliers). The variable *TopSupplier* indicates that the plant uses the top supplier of solar panels (First Solar) or of wind turbines (GE) in our data. GE is known for producing high-quality wind turbines.[9] Table 2 shows that 15% of solar plants have First Solar panels and 47.4% of wind plants have GE turbines. *TopDev* is an indicator for whether the plant is developed by one of the top 3 developers in our sample. For solar plants, these are First Solar, Recurrent Energy, and SunEdison, and for wind plants, these are Invenergy, RES Americas, and EDF. Panel A of Table 2 shows that the top 3 developers build 19.8% and 19.2% of the solar and wind plants, respectively.

Table 2, Panel B summarizes the plant-level cross-sectional averages of the time-series variables. The variable *CapacityFactor* measures the monthly production scaled by the theoretical capacity of the plant. Although the same term is used, capacity factors for solar and wind plants differ from those of plants that burn fuel. Instead of measuring the efficiency of extracting energy from fuel, wind and solar capacity factors are expressed as a fraction of the performance that would be observed if the sun shone on the panels 24 hours a day with no cloud cover or the wind constantly turned the turbines at their maximum speed. Using the EIA data on generators within each plant, we adjust for cases where plants come online progressively or otherwise change their capacity over time. We also remove the first month of production because the exact date or the beginning of operations is not known. Panel B shows that average capacity factors are higher for wind plants at 0.359 compared to solar plants at 0.251. This is consistent with Andonov and Rauh (2022), who include balance-sheet-financed plants and report average capacity factors of 0.328 and 0.241 for wind and solar, respectively.

The variable R_S is the annual ratio of revenue from sales of electricity to the amount of electricity sold, using EIA data from Form 923. Revenues are from the sale of electricity,

[9] Source: S&P Global

capacity, and renewable energy certificates. We retain plants that sell at least half of the electricity they produce. Most of our sample plants are in this subsample, as the 25th percentile plant sells 100% of output. EIA 923 annual revenue data are noisy, particularly in 2021. We believe that this may be in part because revenue data are supposed to be reported in thousands of dollars, but there may be unit errors in reporting. To mitigate the effects of reporting errors, we remove observations of R_S that are either less than 1/10th or more than 10 times the median price for that plant type and year. Table 2, Panel B shows that solar plants charge about one-third more for electricity on average than wind plants. This is partly because solar electricity is generated at peak usage times during the day and benefits from the associated high rates. This is also partly due to the different geographic distribution of plants depending on where wind and solar are each more efficient. Panel B of Table 2 also presents statistics on plant ownership: 27.1% of solar plants in our sample are private equity owned, while 35.6% of wind plants are. Developers retain some ownership in 36.1% of solar and 48.9% of wind plants. Utilities have some ownership of 12.5% of the solar plants and 23.4% of the wind plants. Recall that plants for which the construction is financed wholly from utilities' balance sheets are not in the sample.

5 Determinants of plant capacity factors

We now describe how the plant characteristics that we observe determine energy generation outcomes. Table 3 presents estimates from OLS regressions of *CapacityFactor*, energy generation as a share of nameplate capacity, on plant characteristics. The first four columns are restricted to the sample of solar plants, and the last four columns are restricted to the sample of wind plants.

Unsurprisingly, a strong predictor of the monthly solar plant capacity factor is the average DNI, our publicly available measure of sunlight, during that month. In column 1, a one-standard-deviation increase in *DNI* (49.18) is associated with an increase in the solar plant capacity factor of 0.0432 (0.000878×49.18), while the mean capacity factor of a solar plant

is 0.251. This size of the effect shrinks to 0.0165 (0.000335 × 49.18) when controlling for balancing authority × state × time fixed effects, which capture some weather effects, in column 2. Another strong predictor of solar plant performance is whether it has single-axis tracking or dual-axis tracking, although the dual-axis tracking technology is reportedly less reliable.[10] Dual-axis tracking does become insignificant once we control for the supplier, operator, and ownership indicators in columns 3 and 4, but the single-axis tracking indicator and DNI both remain positive and statistically significant.

We now turn to wind plants in the last four columns in Table 3. The annual land-based wind market reports of Lawrence Berkeley National Laboratory distinguish three primary drivers of wind plant capacity factors: wind speed, the inverse of specific power, and turbine hub height. We find that a one-standard-deviation higher *Windspeed*, 0.949, is associated with performance that is higher by 0.0223-0.0472 depending on the specification, with all estimates positive and statistically significant at the 5% level. According to Table 2, Panel B, the average capacity factor of wind plants is 0.359 with a standard deviation of 0.0739. *InvSpecificPower* is also strongly related to performance. A one standard deviation increase in *InvSpecificPower*, 0.784 according to Table 2, Panel A, is associated with a $0.0198 \times 0.789 = 0.016$ higher capacity factor, using the coefficient from Table 3, Column 6. Turbine hub heights are not significantly related to performance in our sample while controlling for other factors related to the supplier, operator, and other physical characteristics. This could be because they are largely determined by the specific power of the turbines.

Other indicators that are significantly associated with wind plant performance are *Top-Supplier* (with coefficients of 0.0186-0.0239), and *SupplierisOM* (0.0334-0.0343). Performance is higher when the operations and maintenance provider has additional skin in the game. The estimates for the *logCapacity* control are also negative and statistically significant across all specifications.

[10] Source: Solarfeeds.com

6 Tax equity investors and project capacity factors

This section examines whether tax equity investors are associated with plant capacity factors while controlling for plant characteristics that are significantly related to performance.

Table 4, Panel A examines whether tax equity is associated with plant capacity factors conditional on other observable characteristics. The sample period includes January 2007-November 2024, the months for which plant capacity factors are available from the EIA. Recall that Table 2 shows that the mean capacity factor is 0.305; 0.251 for solar plants, and 0.351 for wind.

Figure 6 plots capacity factors of solar and wind plants. The left side of Panels A, B, and C presents solar plants, and the right side presents wind plants. Panel A plots performance against age and shows a distinct downward trend in capacity factors over time for both types of plants. Panel B plots performance by month of the year and shows distinct seasonality, with performance peaking in the summer for solar plants and in the winter for wind plants. Panel A reflects the seasonality of Panel B because the most frequent month of the COD for both types of plants is December. Thus, regressions control for both plant age in months fixed effects as well as balancing authority-by-state-by-month fixed effects. In Panels A and B of Figure 6, there is evidence that the solid line, designating the tax equity plants, is frequently above the dashed line, designating the non-tax-equity plants. Panel C plots the distributions of *CapacityFactor* for solar and wind plants and shows that the distribution for tax equity-funded wind plants is shifted to the right compared to the distribution for non-tax-equity-funded wind plants.

Matching the visual patterns in Figure 6, Columns 1-3 of Table 4 Panel A show no association between plant capacity factors and tax equity for solar plants, but *CapacityFactor* is higher by 0.0164 when tax equity is present for wind plants in column 4.

Next, we investigate whether the relation between tax equity and capacity factor is different if the tax equity investor is *In* the project (typically, in the first five years for solar and the first ten years for wind) or if they have exited the investment and are *Out*. While we

do not observe when the tax equity investor exits the project, there are penalties for exiting the deal prior to the end of these holding times. Also, deals tend to be structured so that the benefits to staying in the deal are small for the tax equity investor once the minimum investment period is up and they have realized their contractual return. All wind deals and most solar deals are structured as yield-based partnership "flips" in which tax equity investor ownership becomes small after the point where they realize their contractual return. Other structures in solar are economically similar.[11]

Columns 5-7 show that the association for wind plants is stronger during tax equity's *In* period, and the coefficient increases to 0.0203-0.0324 depending on the specification. The presence of tax equity is associated with a capacity factor that is higher by 6%-9% of the mean of 0.359 and 27%-44% of the standard deviation of 0.0739 for *CapacityFactor* from Panel B of Table 2. In order to make direct comparisons of wind and solar plant outcomes with tax equity investors, we include a stacked regression with all plants in column 8. This specification allows us to test whether the $TaxEquityXInXWind$ is statistically distinguishable from $TaxEquityXInXSolar$. A Wald test for differences in coefficients rejects the null of no difference with an F-stat of 17.71 and a p-value of 0.000, which provides evidence that wind plants with tax equity investors receiving production tax credits are operated differently than solar plants with tax equity investors receiving investment tax credits, which is consistent with the differences in incentives for PTC tax equity investors as detailed in Online Appendix B.

Table 4, Panel B examines wind plants in more detail. The first four columns examine the effect from Panel A with varying fixed effects, with Column 3 reflecting the results of Panel A and Column 4, and we observe that the coefficient is stable across these specifications. It is possible that the observed effect of tax equity is actually driven by developer sophistication, which influences both plant performance and the likelihood of securing tax equity financing. In column 4, we insert fixed effects for the 358 developers in the sample. Often, more than one developer is involved. This only increases the magnitude of the coefficient on *TaxEquity*.

[11] See Online Appendix A for more information.

The positive effects of tax equity on plant performance could be simply due to the alleviation of the cash equity sponsor's financial constraints, which may result in development choices in favor of higher plant quality. We test this possibility by examining tax credit bridge loans. Instead of tax equity, a liquidity-constrained sponsor can opt for a bridge loan to fund development costs while awaiting the tax credits that come when the plant is operational. In this case, the lender does not take project risk as the tax equity investor does. These loans are identified as "ITC Bridge Loan" or "Tax Credit Loan" in the IJ Global data. We call this indicator *TCBridgeLoan*. Table 2, Panel A shows that 3.36% of solar plants have such loans, while 4.56% of wind plants do. We also create an indicator variable for whether the plant received a bridge loan during the Section 1603 period when grants could be in lieu of tax equity. *CrisisBridge* indicates that the plant received a bridge loan while anticipating reception of the the grant. Panel A shows that 1.2% of solar plants and 0.6% of wind plants have such a loan.

Column 5 of Table 4, Panel B shows that *TCBridgeLoan* and *CrisisBridge* are not positively related to wind plant capacity factors. Thus, tax equity's alleviation of a sponsor's liquidity constraints at the time of construction and the potential resulting positive effects on plant quality are not likely to be behind the positive relation between tax equity's presence and capacity factor.

Column 6 tests whether the type of sponsor is associated with the relation between capacity factor and the presence of tax equity. Sponsors like private equity investors may be more likely to understand and utilize these transactions to their full investment potential, while other sponsors may have less sophistication or more multidimensional objective functions. Moreover, private equity sponsors may have deep relationships with the large banks that frequently provide tax equity. The regression shows that the positive relation between *TaxEquity* and *CapacityFactor* is associated with private equity sponsors. Tax equity is not associated with incremental plant performance for utility owners or developers who remain owners.

Lastly, column 7 tests whether the type of tax equity investor is related to the plant's

realized capacity factor. The top 5 banks show statistically significant positive effects, with coefficients of 0.0282. The top five tax-equity-providing banks are the most sophisticated and frequent tax-equity investors. This points to some role for tax equity investors' expertise in either choosing the best plants, contracting, monitoring, or all of these.

We find no effects of private equity ownership on performance other than when it is associated with tax equity. Thus, even sophisticated cash sponsors like private equity sponsors do not choose higher production levels on their own, suggesting that the highest production levels may not be the value-maximizing choice for the entire plant.

6.1 Natural experiments

We have found that tax equity investors are associated with projects that are more efficient and that this is not due to the relaxing of the project sponsor's financial constraints but is associated with incentives for greater electricity production in wind plants. This result could be due to tax equity investors' expertise in selecting projects that will produce closer to capacity during their holding period or because they encourage higher production through contracting on and monitoring the sponsor's behavior during the holding period. This section examines two natural experiments to test whether tax equity investors likely monitor or contract to increase project production, in addition to purely selecting good projects.

6.1.1 Likely tax equity investments that instead received Section 1603 grants

Aldy, Gerarden, and Sweeney (2021) point out that developers were not required to apply for the Section 1603 grant rather than simply waiting to use the tax deduction. This means that those who put in the time to obtain the grant must have been likely to have used tax equity had the grant not been available, as they are less likely to have been able to utilize the tax credits on their own.

In Table 5, we select plants that received a Section 1603 grant and that also have cash sponsors that use tax equity at some point in other years of the sample period. Presumably, these sponsors would have been more likely to have used tax equity had they not obtained a

crisis grant. These projects are not more efficient than others, either. These results suggest that the association of tax equity investors with more efficient plants is not simply due to their selection criteria. It does not rule out that tax equity investors use more sophisticated plant selection criteria than we have examined so far, but the following natural experiment sheds light on this possibility.

6.1.2 Southern Company's unintended tax equity transaction

A second natural experiment provides a case where the equity sponsor did not intend to use tax equity but was forced to for an exogenous reason. In the second quarter of 2018, The Southern Company experienced losses of $1.1B due to construction cost overruns at one of its nuclear facilities and, as a result, found itself unable to use all of the tax credits on its portfolio of eleven wind plants. As a renewables-focused banker put it in an article in the industry magazine *Power, Finance and Risk*,[12] "They need to generate cash flows because of losses they're taking with their nuke... They need cash and someone to monetize those tax credits because their nuke has eaten up their tax capacity." While Southern Company's annual report noted that its financial performance and accrual income increased in 2018 relative to 2017 and it was not in financial distress, its taxable income was lower than anticipated earlier in 2018.

Southern Company quickly negotiated a tax equity transaction with Wells Fargo, JP Morgan, and Bank of America Merrill Lynch for eight existing wind plants. The transaction was announced on November 18, 2018, and closed before the year's end. The plants (CODs) are Kay Wind (2015), Grant Plains (2016), Grant Wind (2016), Passadumkeag (2016), Salt Fork (2016), Tyler Bluff (2016), Wake Wind (2016), and Bethel (2017).[13]

For each of these plants, we select all non-tax-equity funded plants in our sample that

[12] https://www.powerfinancerisk.com/pdf/PFR11122018

[13] Although the *Power Finance* article mentioned the entire portfolio of eleven functioning and in-development power plants, an announcement from the Southern Company excluded Cactus Flats (2018), Wildhorse Mountain (2019) and Reading (2020). See https://www.southerncompany.com/newsroom/business-leadership/southern-power-partnership.html

began service in the same year and month.[14] Figure 7 shows the average performance of both portfolios of plants. The solid line represents the Southern Company plants, and the dotted line represents the portfolio of matching plants. The vertical line indicates December 2018, when the tax equity transaction closed. This figure suggests that efficiency is generally higher for the tax-equity-funded plants. Table 6 presents t-tests of plant efficiency before and after the transaction. Columns 1 and 2 show that the difference in performance is significant only after the transaction. This suggests that the tax equity investors either monitor the plants or contract in advance to ensure that best practices in plant operation are followed during their holding period.

In this section, we have seen that tax equity is robustly associated with plant performance measured by capacity factor. The absence of an effect for tax credit loans and for the *Out* period when the tax equity investor is not present in the partnership point to the necessary presence of the tax equity investor itself. Moreover, the effect is only present for wind plants, where tax equity investors directly benefit from increased production at the expense of the equity sponsor, who may incur additional maintenance expenses to achieve peak performance. The presence of the effect only for private equity-sponsored deals and the most sophisticated tax equity providers suggests that tax equity brings expertise to the way in which the plants are constructed and/or run. The next section investigates these effects in more detail.

7 The mechanism behind tax equity's role in increasing plant capacity factors

This section explores the mechanism behind the outperformance of tax-equity-funded plants. We examine which, if any, of the factors that we found were associated with performance in Table 3 are favored by tax equity investors and whether this selection process drives the

[14] Matching on exact age is important because age and seasonality are primary determinants of production, as visible in Figure 6. There are not enough plants to additionally match on other characteristics while maintaining the potential for statistical power.

entirety of the effect.

Table 7, Panel B investigates whether tax equity is associated with the determinants of plant capacity factors from Panel A. We use plant-level regressions with balancing authority × state and COD year fixed effects and with the standard errors clustered by COD year.

Since Panel A shows that plant capacity factors are strongly associated with weather, we include measures of historical weather at the plant site leading up to the financing date. For solar plants, *DNI_10* measures the average hourly-sampled direct normal irradiation (DNI) for the ten years before the year that the financing deal occurs in IJ Global, and *Wind_10* measures the average hourly-sampled wind speed in the last ten years. These should be highly relevant measures to developers and investors, given the strength of weather effects on performance in Table 4. In untabulated regressions, both annual average DNI and wind speed are strongly predicted by their past 10-year averages, with coefficients close to 1.

Columns 1-3 of Table 7, Panel B investigates solar plants, and we find that none of the factors associated with plant performance are also associated with tax equity. This is reasonable because the returns of tax equity investors in solar plants depend minimally on production. When we investigate wind plants in columns 4-6, we find that *SupplierIsOM* is associated with tax equity. Thus, it appears that tax equity investors associate themselves with wind plants that are spending the most on maintenance and maximizing utilzation. We also find that the tax equity plants have lower, not higher, monthly average windspeed for the past 10 years, . As we saw in column 9 of Table 7, Panel A, though, the effect of *TaxEquityXIn* on capacity factors for wind plants is still present even when controlling for *SupplierIsOM* and *Windspeed*.

7.1 Tax equity and likely maintenance or downtime events

Routine maintenance of wind and solar plants should not result in downtime that is noticeable at the monthly level, as one module or turbine is generally taken out of service at a time. However, unplanned maintenance can result in lost production. In an extreme case, the

Neosho Ridge Wind Farm in Erie, Kansas, was shut down from April to June 2022 due to a transformer malfunction and oil leaking from the windmills.[15] In 2023, Midway Wind filed a civil action against Siemens Gamesa Renewable energy, its turbine supplier and O&M provider, for malfunctioning turbines and lax maintenance causing low production at its plant.[16] If tax equity's effect is through increased monitoring or up-front contracting for high-quality maintenance, we would expect the distributions of performance to differ, particularly in the lower tail. Figure 6, Panel C shows that for wind but not for solar, the production distribution of tax-equity funded plants has a smaller left tail.

Table 8 examines two measures of low plant production. The first, *Below P10*, is an indicator for whether production during the month was below the 10th percentile for that type (solar or wind) of plant in our sample in that month. The second, *Below 0.10*, is an indicator for whether the plant's capacity factor was below 0.10 during the month. This occurs in 1.7% of months for wind plants and 2.5% of months for solar plants.

Columns 1 and 4 of Table 8 show that there is no association between tax equity and *Below P10* or *Below 0.10* for solar plants during the tax equity holding period. For wind plants, however, the association is negative. Columns 2 and 3 show that a tax-equity funded plant is 3.46-3.90 percentage points less likely to be in the bottom decile of performance for a given month, which is a large effect. Columns 5 and 6 show that a tax-equity-funded wind plant is 0.921-1.21 percentage points less likely to have a month in which production is below 0.10, an effect that is more than half of the mean. This significantly smaller left tail for wind production in the presence of tax equity conditional on plant characteristics is consistent with the right-shifted density for tax equity financed wind plants shown in Panel C of Figure 6. These results show that the increased production associated with tax equity is especially pronounced in the lower tail: tax equity-funded plants avoid very low production outcomes.

[15]Source: National Wind Watch, 3/31/2022.

[16]Midway Wind, LLC vs. Siemens Gamesa Renewable Energy, filed on March 8, 2023 in the District Court of New York County.

8 Is the higher production associated with private equity distortionary?

8.1 Tax equity investors and plant revenues

Does the presence of tax equity investors and the associated increased efficiency of plants affect the plants' financial performance? Whether the increased production associated with tax equity results in an increased total revenue depends on the revenue per megawatt hour produced. Plants often bid into competitive auctions to supply electricity, and may have to bid lower to secure a buyer for increased production. An article in *Utility Dive*[17] describes how power prices are frequently negative in California due to the existence of tax credits and the priority given to renewables in auctions.

Table 9 presents OLS models of R_S on *TaxEquity* and other explanatory variables. Table 2, Panel B shows that the mean and standard deviation of R_S are 50.37 and 36.03, reflecting substantial variation. For solar, the mean is 61.10, and for wind, the mean is 40.81. We include balancing authority × state × year and plant age in years fixed effects. Columns 1-4 of Table 9 show that the presence of tax equity is statistically insignificant for solar plants. For wind plants, the picture is different. Column 5 shows that *TaxEquity* is associated with a negative effect on revenue per megawatt hour sold of 4.908. This is 12% of the mean and 17% of the standard deviation for wind plants. Column 6 shows that the coefficient on *TaxEquity* becomes statistically insignificant when including the average capacity factor of the plant over the year, *AnnualCapFac*, suggesting that the decline in average price received is a function of the increase in electricity produced.

In columns 7 and 8 of Table 9, we replace the variable *TaxEquity* with *TaxEquityXIn* and *TaxEquityXOut*. *TaxEquityXIn* is significant with a coefficient of -5.454 in column 7 but not when *AnnualCapFac* is included in the regression in column 8.

These results show that the effect of tax equity on revenue is through its effect on the ca-

[17] "Prognosis negative: How California is dealing with below-zero power market prices," May 11, 2017

pacity factor, with higher capacity factor plants selling electricity at lower cost per megawatt-hour. This is consistent with wind tax equity investors' incentives to influence the plant to produce beyond where the marginal benefit equals the marginal cost.

8.2 Do back-leverage debt holders attenuate the distortions associated with tax equity investors?

As Figure 2 illustrates, when tax equity is present, a project sponsor with insufficient cash equity can also take on debt using back-leverage. Tax equity investors generally do not permit the tax equity partnership to have secured debt. With back-leverage, the sponsor borrows against their equity contribution to a project company. Thus, the collateral is the sponsor's equity interest and right to payments from the project company. Back leverage investors, like tax equity investors, tend to be large banks with similar project selection and management criteria.

Back leverage in the presence of tax equity is riskier than a traditional term loan because the tax equity investor has a direct claim on the project's assets, while the debt claim is indirect. Thus, the lender must perform careful due diligence and protect their claim. Moreover, the lender's claim is safer when the sponsor's equity claim is more valuable. If the increased production associated with the presence of tax equity is value-increasing or value-neutral, one would expect to see no effect from the presence of back leverage. On the contrary, if the increased production associated with tax equity is value-destroying to the cash sponsor's claim, one would expect the presence of back leverage to attenuate the effect to the extent that the lender has some bargaining power when the project is financed.

Table 10 presents two measures of the presence of back leverage that are robust to missing data on loan size and maturity. The first, *HasTermLoan*, is an indicator variable for whether there are one or more loans described as a term loan in the project. Table 2 shows that 46.8% of solar and 49.5% of wind projects have a term loan. Some term loans in IJ Global have short maturities, and some have no maturities given. A second variable, *HasLTDebt*,

is an indicator variable for the presence of a loan that has a non-missing maturity in IJ Global of 2 years or more. We choose 2 years because a project typically takes 18 months to complete and shorter maturity loans are generally construction loans. Table 2 shows that 35.8% of solar and 24.0% of wind projects have such a loan. We interact these terms with the presence of tax equity to measure any effects.

Columns 1 and 5 of Table 10 show that there is no effect of *HasTermLoan* and *HasLTDebt* on *CapacityFactor*. Columns 2, 3, 6, and 7 show that there is an effect when *TaxEquityXIn* is interacted with *HasTermLoan* and *HasLTDebt*. The size of the effect of back leverage almost reverses the effect of tax equity. Thus, the presence of back leverage has a mitigating effect on tax equity's effect on production. This suggests that tax equity's effect on production may be suboptimal for the project sponsor's stake. In columns 4 and 8, there is no significant counteracting effect of *HasTermLoan* and *HasLTDebt* on revenue per megawatt sold.

9 Discussion

9.1 Are tax equity investors worth their cost?

In this subsection, we ask whether tax equity investors are worth their cost in an example calibrated for a typical 100MW wind plant in 2023. We note that the changes in operations are associated with increases in energy generation but changes in operational costs and revenues per unit of generation. We begin by assuming that the plants without tax equity are able to choose their own optimal level of scale and capital utilization while taking into account that additional utilization may mean less ability to target production into higher price seasons or times of day.[18] Assuming that these wind plants are acting optimally, the optimal capacity factor is simply the observed average in the data conditional on not

[18] A descriptive regression of R_S on $CapacityFactor$ restricted to 2023 wind plants yields the following result: R_S = 64.4-70.2×$CapacityFactor$, which implies average price declines by \$5.2 per MWh for a one standard deviation (0.0739) increase in capacity factor. Both coefficients are significant, with p-values less than 0.001. This estimate of the relationship between the quantity a wind plant produces and the average price at which they sell electricity, while extremely simple, is consistent with our R/S results in column (7) of Table 9, that the tax equity financed wind plants receive \$5.5 per MWh less than comparable plants with 0.0324 percentage points higher capacity factor according to column(7) of Table 4.

having tax equity, which is 0.323—slightly less than the combined sample average reported in Table 2.

The average revenue per MWh of electricity sold is \$40.81, which means this hypothetical plant with no tax equity considerations generates average annual revenue of $0.323 \times 100 \times 8,766 \times \$40.81 = \$11,555,017$ before accounting for tax incentives. Total operating and maintenance expenses are estimated at 0.01 per KWh produced, which means net revenues are $\$11,555,017 - (0.323 \times 100 \times 8,766 \times 10) = \$8,723,599$. This calculation does not consider revenue from the sale of renewable energy certificates (RECs), the price of which can vary by state, as well as it does not include other potential tax incentives or subsidies.

If the sponsor cannot monetize tax credits and obtains tax equity, with 50% financing provided by the tax equity investor who has bargaining power, the plant instead maximizes value conditional on the constraint that they change behavior in a way that satisfies the tax equity investor. Empirically, we measure the change in capacity factor that manifests from this new optimization problem as the difference between tax equity and non-tax equity financed projects, which is 0.032 higher (Table 4, Panel A, column 7) and would yield a new capacity factor of 0.355.

We make further assumptions that rising to this higher capacity factor both is costly from an O&M perspective and lowers the average price at which plants sell electricity, which we find evidence of in Tables 7 and 9. If we assume that producing at a high capacity factor of 0.355 involves using an OEM O&M provider at (conservatively, given Briggs (2017)) a 15% premium, O&M expenses increase to \$0.0115 per KWh. Selling more electricity at non-peak times and seasons leads to an average revenue that declines by \$5.5 per MWh according to column (7) of Table 9. The net revenue taking both of these margins of adjustment into account is $((0.323+0.032) \times 100 \times 8,766 \times (40.81-5.5-11.5)) = 7,409,505$, or 15.1% lower than without these operational adjustments for this typical 100MW plant.

Combining the revenue and cost impacts for this typical 100MW wind plant leads to \$1.314M lower pretax income per year. If we assume these net costs are deductible from income that is taxable at a 21% rate, then this is a decline in free cash flow of \$1.04M per

year. With a 7% discount rate[19] and a 10-year holding period for the tax equity investor, a loss of $1.04M per year is a present value loss of approximately $7.3M. While we don't have complete cost data on all of the plants in our sample, on-shore wind plants cost up to $1,800,000 per MW,[20] so 100MW plants will cost in the realm of $180M, with half paid for by tax equity. Thus, the $7.3M lower present value of returns in our calibrated hypothetical from operational changes due to tax equity can be thought of as decreasing the return of the investment by $7.3/180 = 4.1\%$ for the entire project. By comparison, Morellec, Nikolov, and Schürhoff (2018) find that agency agency conflicts reduce firm value by 5.4% on average, suggesting that this agency conflict is as important as other conflicts in finance.

9.2 Tax credit transferability from the Inflation Reduction Act

The Inflation Reduction Act of 2022 (IRA) allows renewable energy tax credits to be transferred to a third-party buyer in exchange for cash. Transferability has allowed tax equity investors to attract buyers through syndication, which allows less experienced buyers to benefit from due diligence and structuring provided by these experienced tax equity investors.

It is reasonable to ask whether tax credit transferability, which has the potential to bring an influx of capital provided by potentially less sophisticated investors, may blunt this effect. On one hand, tax equity contracts may still be arranged by traditional tax equity investors and may change little, regardless of who the end-user is. On the other hand, these sophisticated investors may no longer have the incentive to exert effort to ensure high plant production.

The tax credit transfer market is nascent. A detailed set of regulations was released by the Internal Revenue Service (IRS) in June 2023, and there was not much activity in 2023, according to the trade journal Power Finance & Risk.[21] Announced in February 2024, a tax credit transfer agreement between Schneider Electric and ENGIE covering four projects was

[19] The National Renewable Energy Laboratory (NREL), in its 2024 Cost of Wind Energy Review, employs an after-tax weighted average cost of capital (WACC) discount rate of 6.61% for utility-scale wind projects, and we have not assumed any debt here.

[20] See the Office of Energy Efficiency & Renewable Energy Economics and Incentives for Wind.

[21] January 5, 2025, Page 8.

among the "first of its scale."[22] In 2024, about $15B of the $33B in tax equity financing was transferred, according to Rubiao Song, managing director and head of tax equity investments at JP Morgan.[23] Given the lead times for the EIA to publish plant production data, it is early to investigate the effects of transferability empirically.

10 Conclusion

This paper examines whether tax equity investors are associated with higher-quality renewable projects and if they are, whether they select better projects, alleviate financial constraints, or if their presence changes the plant's operation. This is an important question as the Inflation Reduction Act of 2022 makes credits more easily transferable and could lead to an influx of capital provided by potentially less sophisticated investors. Examining tax wind equity investors' incentives suggests that they have the incentive to maximize production without internalizing the potential increased maintenance costs associated with it.

We find that tax equity investors are associated with 6-9% more efficient projects and that at least part of the effect is related to their presence in the capital structure during their investment period, if only through governance practices established by initial contracting. The effect is only obvserved in wind plants where the tax equity investor prefers more production over profitability and thus has a potential agency conflict with the sponsor, and does not appear in solar plants where there is no such conflict.

Tax-equity-funded wind projects also produce less revenue per unit of electricity and dollar of development cost. Moreover, the presence of back-levered debt, which is issued by equally sophisticated investors and has claims on the sponsor's equity, blunts the effect of tax equity on production. For reasonable assumptions about maintenance costs that are needed to support higher production, the presence of tax equity results in lower profits to the sponsor during the tax equity investors' tenure. These findings indicate that tax

[22] According to the press release on February 20, 2024.

[23] Norton Rose Fullbright Currents podcast episode 279: "Cost of Capital: 2025 Outlook," January 9, 2025. The $15B transferred is made up of $5B direct transfers and $10B from hybrid tax equity structures.

equity investors contribute to renewable energy efficiency primarily through monitoring and contracting to induce the plant to operate in a way that is more consistent with their own goals. However, their benefits appear to favor consumers via lower electricity prices rather than increasing the returns to equity sponsors.

Our study has implications not only in the U.S. and for the renewable power industry but in other countries and settings that use similar structures, such as flow-through shares in Canada, or where cash subsidies for desired project development are more common, for example, contracts for difference (CfD) in the U.K.

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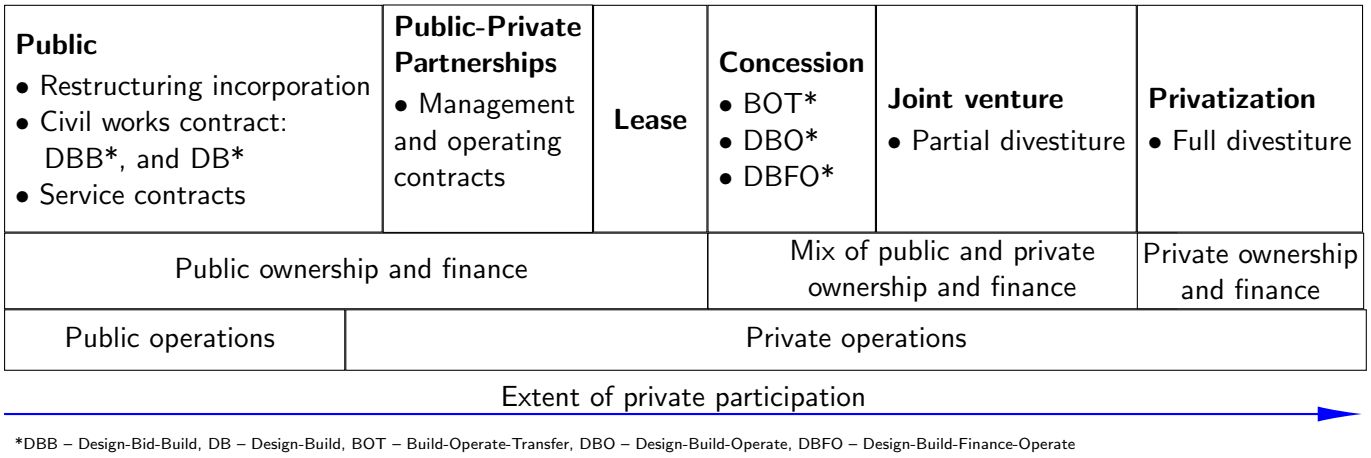
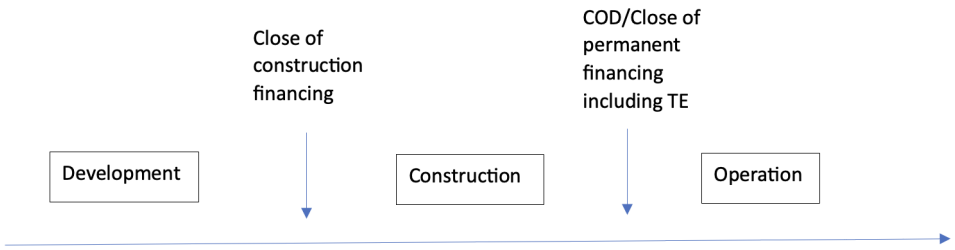
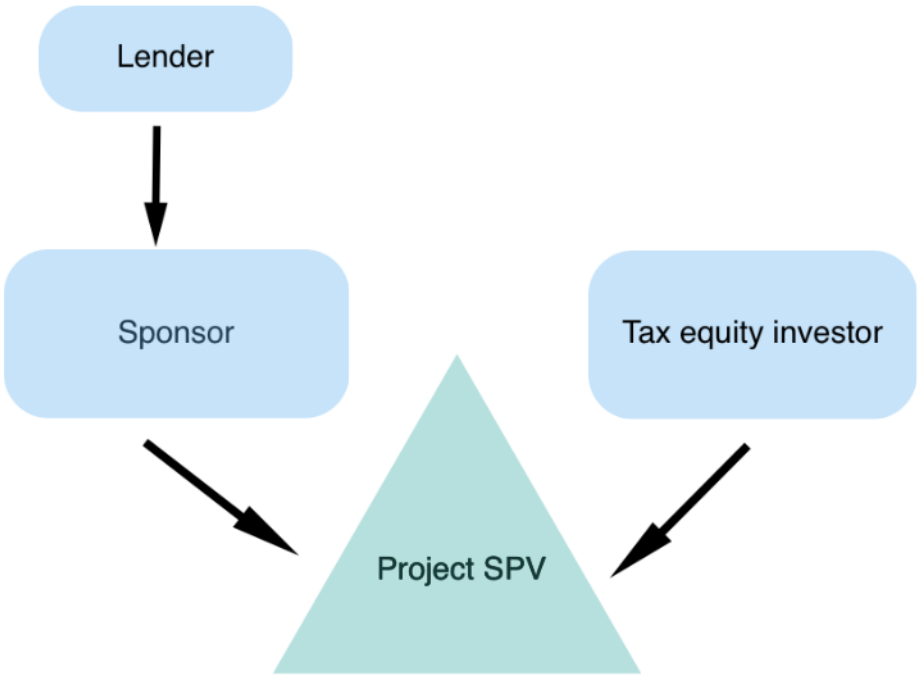


Figure 1: Public vs. private ownership and control of infrastructure
Inspired by Walter (2016) and World Bank PPP in Infrastructure Resources Centre. "PPP arrangements/types of public-private partnership agreements"



Panel A



Panel B

Figure 2: Typical structure of tax equity investment

This figure describes the timing and structure through which tax equity investors are added to a utility scale generation project. Panel A presents a timeline of the development, construction, and operation of a power plant, along with when the tax equity (TE) closes. This is an example of a partnership flip structure which is the most common structure of tax equity investment. In this structure, the tax equity investor has the right to the tax benefits of the deal until they are used up, after which the developer claims the majority of earnings. The lender lends to the sponsor and not directly to the project SPV.

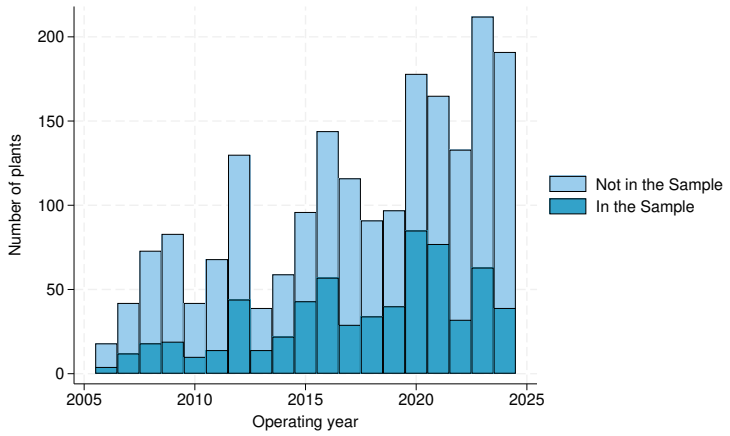


Figure 3: All wind and solar plants built in the US vs. plants in this sample

This figure shows the count of all wind and solar plants with commercial operation date (COD) in Form EIA 860 between 2006 and 2023 and with a capacity of at least 20 MW. Plants that are included in the sample for this paper are financed through project (not corporate) finance and can be identified in the description given by IJ Global.

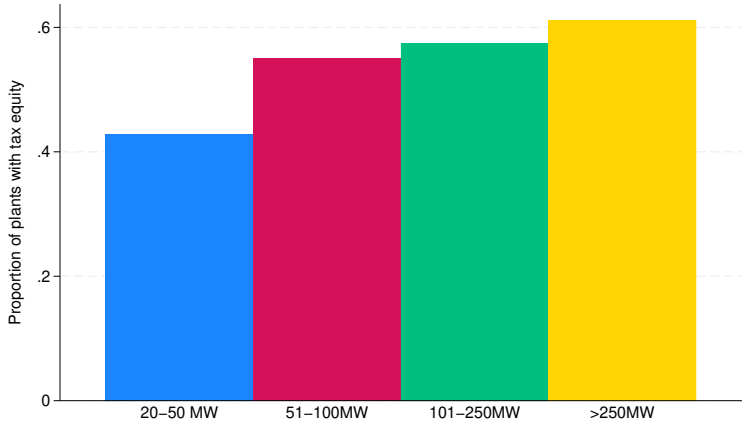
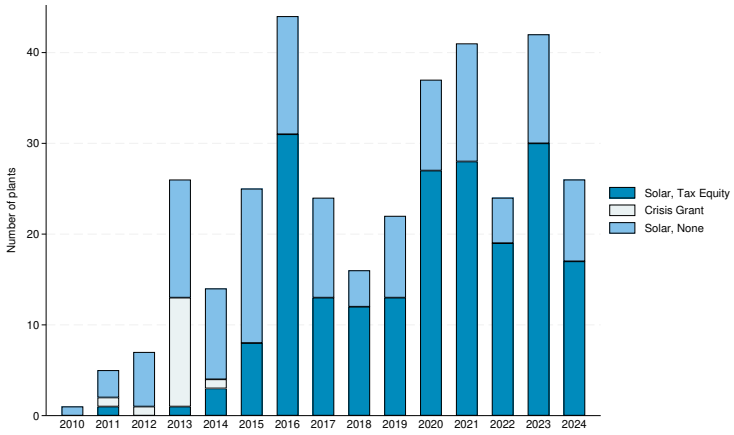
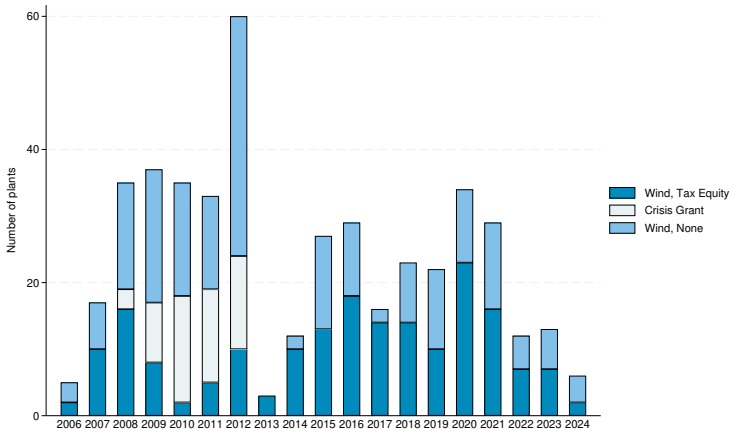


Figure 4: Incidence of tax equity financing by plant size in megawatts (MW)

This figure shows the proportion of wind and solar plants that fall into each capacity category in our sample that are financed with tax equity. The remainder are plants that are financed with project finance but do not include a tax equity investor.

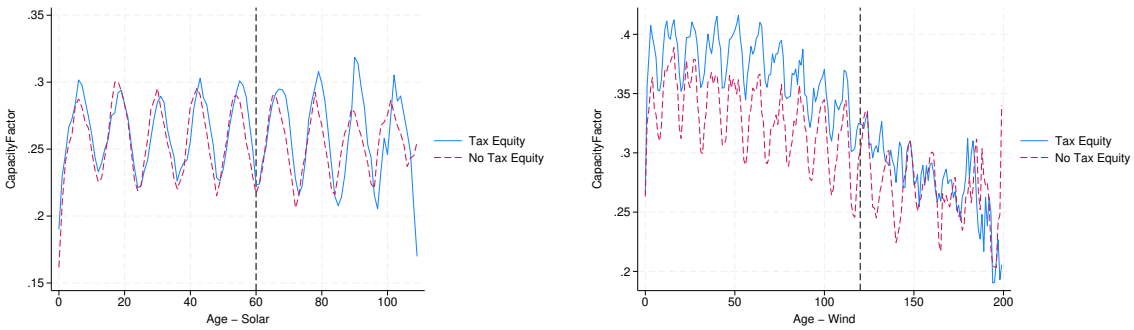


Panel A: Solar plants

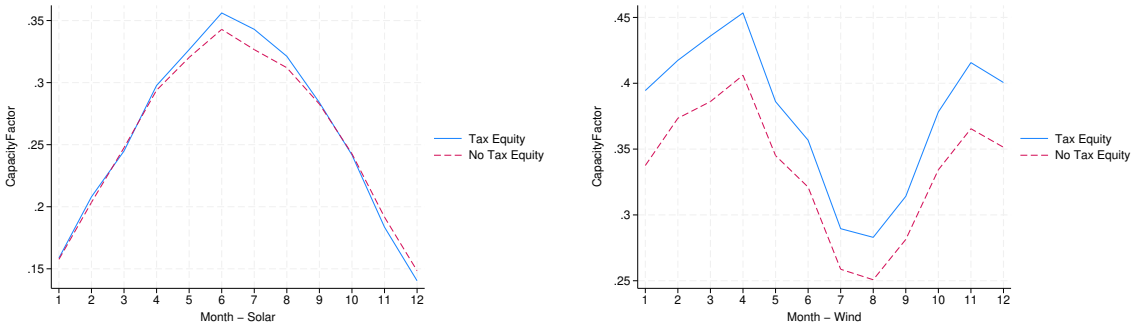


Panel B: Wind plants

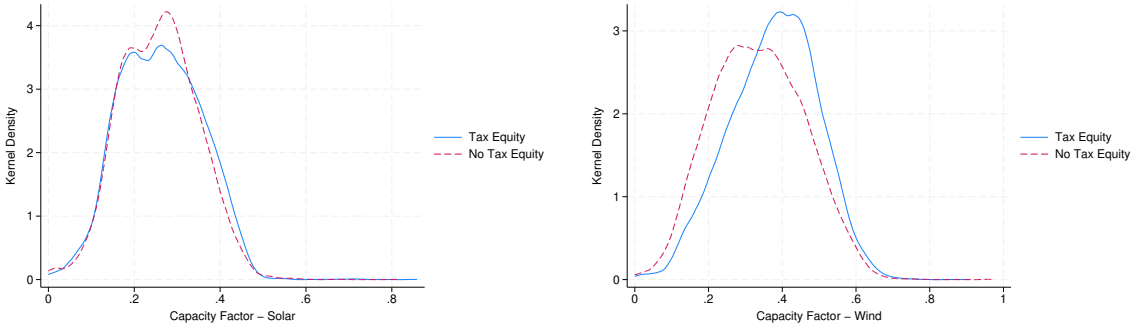
Figure 5: This figure displays the number of solar and wind plants by operation year and by whether they received tax equity or a Section 1603 grant for our sample of plants from IJGlobal. Panel A shows the counts for solar plants and Panel B shows the counts for wind plants.



Panel A. Performance of solar and wind plants by age in months.



Panel B. Performance of solar and wind plants by by month of the year.



Panel C. Kernel densities of the performance of solar and wind plants.

Figure 6: This figure displays the performance of solar (left) and wind (right) plants with and without tax equity. Panel A presents capacity factor as a function of age in months, with vertical lines representing the months at which tax equity investors typically exit their investments: 5 years for solar plants and 10 years for wind plants. Panel B presents months of the year, and Panel C presents kernel density estimates of plant performance.

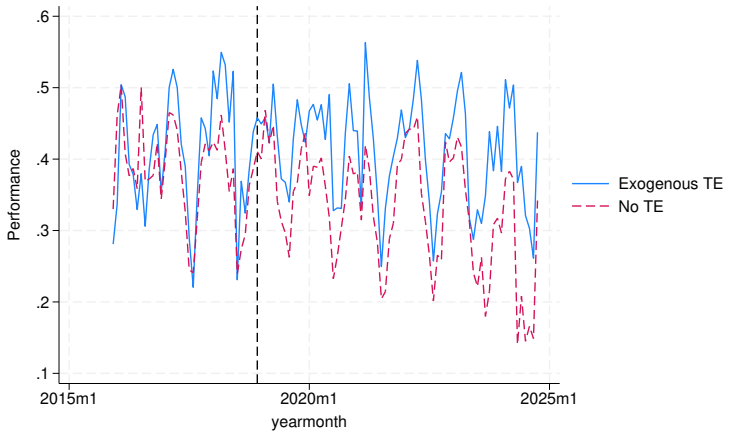


Figure 7: Study of 11 plants owned by Southern Company receiving previously unintended tax equity financing in December of 2018 from Bank of America, JP Morgan and Wells Fargo, due to the losses that the company incurred in its nuclear division and its inability to use the tax credits. The vertical line marks December 2018. Means and t-tests are included in Table 6

Table 1: Variable and industry jargon definitions

Variable	Description	Source
Bank5TaxEquity	Tax equity from one of the top providers of tax equity during the sample period, all of which are large banks: JP Morgan, Bank of America, Wells Fargo, Credit Suisse and US Bank.	IJ Global
CapacityFactor	The performance ratio, computed as monthly production scaled by total capacity. This variable is winsorized a the 1% level.	EIA Form 923
Below P10	An indicator variable for plant-months below the 10^{th} percentile in capacity factor.	EIA Form 923
Below 0.10	An indicator variable for plant-months that produce less than 10% of their name-plate capacity.	EIA Form 923
CapacityMW	The capacity of the plant in MW in a given year.	EIA form 923
COD	Commercial Operations Date	Jargon
CorpTaxEquity	Tax equity from a corporation that is not in the energy business, such as Amazon, Apple or Google.	IJ Global
CrisisBridge	An indicator for whether the project received a bridge loan in the construction financing to more quickly monetize the grant from section 1603 of the American Recovery and Reinvestment Tax Act (ARRTA) program.	IJ Global
CrisisGrant	An indicator for whether the project received a grant from section 1603 of the American Recovery and Reinvestment Tax Act (ARRTA) program.	Treasury.gov
CrystallineSilicon	An indicator for whether a solar plant has crystalline silicon modules. These modules are more expensive and typically perform better than the alternative, thin film modules.	EIA 860
DualAxisTracking	An indicator for whether a solar plant has modules that can track the sun on two axes. According to Solarfeeds.com, single-axis trackers are more reliable, cheaper and have a longer lifespan than dual-axis trackers.	EIA 860
Dev_Ownership	An indicator variable for whether a cash equity investor in the plant has expertise developing power plants	Capital IQ profile of sponsor.
DevIsOM	An indicator variable for whether the developer is also the operations and maintenance provider to the plant.	Power-technology.com
DNI	Direct Normal Irradiation, sampled hourly. DNI is for the current month, DNI_c is for the current year, and DNI_10 is DNI for the last ten years from the weather station closest to the plant. There are 546,219 weather stations in the US in our sample period.	NSRDB: National Solar Radiation Database
EnergyTaxEquity	Tax equity from an entity in the energy business, such as GE, EDF, or Siemens.	IJ Global
FinTaxEquity	Tax equity from a financial institution, insurance company, or private equity fund that is not one of the top five tax equity providers, for example, PNC or Starwood Energy Infrastructure Fund.	IJ Global
In/Out	Indicator for the time period when the Tax Equity investor is/is not an investor in the project: generally five years for the investment tax credit for solar plants, and 10 years for the production tax credit for wind plants.	
InvSpecificPower	In m^2/W, it is the specific area of a turbine in square meters scaled by its capacity in Watts. Specific area, also called "swept area," is equal to $\pi(D/2)^2$ where D is the diameter of the turbine blades.	EIA 923 Wind, Power-technology.com
OwnerIsOM	An indicator variable for whether an owner of the plant is also the operations and maintenance provider to the plant.	Power-technology.com
PPA	An indicator variable for whether a power purchase agreement exists between a plant and an offtaker.	EIA Form 923, Power-technology.com
PE_Ownership	An indicator variable for whether a cash equity investor in the project is a private equity firm.	Capital IQ profile of sponsor.
R_S	Revenue in dollars scaled by the amount of electricity sold during the year. This variable is winsorized a the 1% level.	EIA Form 923

SingleAxisTracking	An indicator for whether a solar plant has modules that can track the sun on a single axis. According to Solarfeeds.com, single-axis trackers are more reliable, cheaper and have a longer lifespan than dual-axis trackers.	EIA 860
StorageRatio	The ratio of the capacity of any battery storage to the total output capacity of the plant. This variable is zero if there is no storage. No wind plants in our sample have storage.	EIA 860
SupplierIsOM	An indicator variable for whether the supplier of the turbines or solar modules is also the operations and maintenance provider to the plant.	Power-technology.com
TaxEquity	An indicator variable for whether a deal has an external tax equity investor.	IJGlobal
TEExperience	An indicator variable for whether a plant is at least partially owned by an investor with tax equity experience at some point in the sample period, but the current plant received a Crisis Grant.	
TCBridgeLoan	Indicator for whether the project received a bridge loan, backed by the investment tax credits to come when the plant is operating.	IJ Global
TopDev	An indicator for whether the developer of the plant is one of the top 3 developers in our sample of solar plants (for solar plants) or wind plants (for wind plants).	Power-technology.com
TopSupplier	An indicator for plants using First Solar modules or GE wind turbines. First Solar is the most frequent provider of solar panels in our sample, and GE is the most frequent provider of turbines and also ranks first in terms of turbine performance according to S&PGlobal.com.	Power-technology.com
TurbineHubHeight	The turbine hub height in feet for a wind plant. According to the U.S. Department of Energy, the bigger the better.	EIA 860
Utility_Ownership	An indicator variable for whether a cash equity investor in the plant sells electricity to retail customers.	Capital IQ profile of sponsor.
Windspeed	Average wind speed in miles per hour sampled hourly for the current month (Windspeed), current year (Windspeed_a), and last 10 years prior to the construction financing of the plant (Windspeed_10). Wind speed is measured at the weather station closest to the plant. There are 546,219 weather stations in the US in our sample period.	NSRDB

Table 2: Summary statistics

Panel A presents plant-level variables and panel B presents cross-sectional summary statistics on variables that are measured monthly or annually. Variable definitions appear in Table 1.

Panel A

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	— All Plants —			— Solar —			— Wind —		
VARIABLES	mean	sd	N	mean	sd	N	mean	sd	N
CapacityMW	139.4	101.4	656	105.9	82.99	327	172.7	106.9	329
PPA	0.547	0.498	656	0.529	0.500	327	0.565	0.496	329
TaxEquity	0.541	0.499	656	0.587	0.493	327	0.495	0.501	329
Bank5TaxEquity	0.165	0.371	656	0.174	0.380	327	0.155	0.362	329
FinTaxEquity	0.116	0.320	656	0.131	0.338	327	0.100	0.301	329
EnergyTaxEquity	0.0945	0.293	656	0.0520	0.222	327	0.137	0.344	329
CorpTaxEquity	0.0107	0.103	656	0.0153	0.123	327	0.00608	0.0778	329
UnknownTaxEquity	0.226	0.418	656	0.245	0.431	327	0.207	0.406	329
TCBridgeLoan	0.0396	0.195	656	0.0336	0.181	327	0.0456	0.209	329
HasLTDebt	0.299	0.458	656	0.358	0.480	327	0.240	0.428	329
HasTermLoan	0.482	0.500	656	0.468	0.500	327	0.495	0.501	329
CrisisBridge	0.00915	0.0953	656	0.0122	0.110	327	0.00608	0.0778	329
CrisisGrant	0.0716	0.258	656	0.0398	0.196	327	0.103	0.305	329
TopDev	0.194	0.396	571	0.198	0.399	243	0.192	0.395	328
TopSupplier	0.312	0.464	654	0.150	0.357	327	0.474	0.500	327
DevIsOM	0.280	0.450	254	0.356	0.482	87	0.240	0.428	167
SupplierIsOM	0.559	0.497	254	0.402	0.493	87	0.641	0.481	167
OwnerIsOM	0.0952	0.294	252	0.103	0.306	87	0.0909	0.288	165
TEExperience	0.261	0.441	119	0.368	0.496	19	0.240	0.429	100
CrystallineSilicon				0.724	0.448	283			
SingleAxisTracking				0.845	0.363	283			
DualAxisTracking				0.0141	0.118	283			
StorageRatio				0.00991	0.0599	327			
InvSpecificPower							3.912	0.784	315
TurbineHubHeight							299.4	42.87	210

Panel B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	— All Plants —			— Solar —			— Wind —		
VARIABLES	mean	sd	N	mean	sd	N	mean	sd	N
WCapacityFactor	0.305	0.0819	656	0.251	0.0457	327	0.359	0.0739	329
R_S	50.37	36.03	503	61.10	40.04	237	40.81	28.94	266
PE_Ownership	0.314	0.445	656	0.271	0.427	327	0.356	0.459	329
Dev_Ownership	0.425	0.495	656	0.361	0.481	327	0.489	0.501	329
Utility_Ownership	0.180	0.384	656	0.125	0.332	327	0.234	0.424	329
DNI				270.4	49.18	244			
Windspeed							3.036	0.949	305

Table 3: Plant- and deal-level determinants of plant capacity factors: production scaled by capacity, 1/2007-11/2024

OLS models of monthly plant capacity factor regressed on plant-level and deal-level determinants of capacity factors. Standard errors are clustered by plant and month and p-values are in parentheses. Monthly weather conditions (*DNI* and *Windspeed*) are available through 2022. Variable definitions appear in Table 1.

VARIABLES	(1) Capacity Factor Solar	(2) Capacity Factor Solar	(3) Capacity Factor Solar	(4) Capacity Factor Solar	(5) Capacity Factor Wind	(6) Capacity Factor Wind	(7) Capacity Factor Wind	(8) Capacity Factor Wind
DNI	0.000878***	0.000335***	0.000285***					
	(0.00)	(0.00)	(0.00)					
CrystallineSilicon		0.000464	0.00257	0.00404				
		(0.93)	(0.76)	(0.67)				
SingleAxisTracking		0.0377***	0.0483***	0.0491***				
		(0.00)	(0.00)	(0.00)				
DualAxisTracking		0.0594***	-0.0146	-0.0127				
		(0.00)	(0.53)	(0.58)				
StorageRatio		-0.0185	-0.0232	-0.0402**				
		(0.10)	(0.12)	(0.04)				
Windspeed					0.0497***	0.0235**	0.0287***	
					(0.00)	(0.02)	(0.00)	
InvSpecificPower						0.0198***	0.0219***	0.0249***
						(0.00)	(0.01)	(0.00)
TurbineHubHeight							-9.08e-05	-0.000155
							(0.54)	(0.29)
TopDev		-0.00147	-0.000861	-0.00353		0.00625	-0.0168	-0.0121
		(0.69)	(0.86)	(0.47)		(0.50)	(0.17)	(0.31)
TopSupplier		-0.000380	0.00770	0.0116		0.0105	0.0239**	0.0186*
		(0.94)	(0.24)	(0.14)		(0.13)	(0.03)	(0.06)
DevIsOM			-0.00172	-0.00328			0.0239	0.0276*
			(0.74)	(0.57)			(0.11)	(0.06)
SupplierIsOM			0.00613	0.00776			0.0334***	0.0343***
			(0.38)	(0.30)			(0.00)	(0.00)
OwnerIsOM			-0.00926	-0.00865			0.0200	0.0129
			(0.12)	(0.12)			(0.25)	(0.45)
PE_Ownership		-0.00178	-0.00300	-0.00568		0.00215	0.00275	0.000534
		(0.60)	(0.61)	(0.37)		(0.75)	(0.77)	(0.95)
Dev_Ownership		0.00349	0.00966*	0.00826		0.000479	0.00527	0.000464
		(0.26)	(0.09)	(0.19)		(0.94)	(0.55)	(0.96)
Utility_Ownership		-0.00323	-0.0122	-0.0127		-0.00595	0.00290	0.00116
		(0.44)	(0.16)	(0.16)		(0.38)	(0.79)	(0.92)
logCapacity		0.00219	0.00252	0.00577*		-0.0237***	-0.0301***	-0.0269***
		(0.24)	(0.37)	(0.09)		(0.00)	(0.00)	(0.00)
Observations	12,360	10,791	5,107	6,055	26,012	22,961	10,539	13,193
R-squared	0.622	0.861	0.884	0.866	0.240	0.758	0.766	0.736
State × Balancing × Month FE	NO	YES	YES	YES	NO	YES	YES	YES
Plant Age FE	NO	YES	YES	YES	NO	YES	YES	YES

Table 4: Capacity Factors and tax equity, 1/2007-11/2024

This table presents point estimates from OLS models of monthly *CapacityFactor*, which is electricity production scaled by theoretical maximum capacity. Panel A presents solar and wind plants. The Wald test for differences in the coefficients on TaxEquityXInXWind and TaxEquityXInXSolar in column 8 yields an F-statistic of 17.71 and a p-value less than 0.001. Panel B presents wind plants. Standard errors clustered at the plant and month levels and p-values are in parentheses. Fixed effects include State×Balancing Authority×Month, and Plant Age in months. Variable definitions appear in Table 1.

Panel A

	(1) Capacity Factor	(2) Capacity Factor	(3) Capacity Factor	(4) Capacity Factor	(5) Capacity Factor	(6) Capacity Factor	(7) Capacity Factor	(8) Capacity Factor
VARIABLES	Solar	Solar	Solar	Wind	Wind	Wind	Wind	All
TaxEquity	0.00181			0.0164**				
	(0.65)			(0.03)				
TaxEquityXIn		0.000215	-0.00128		0.0218***	0.0203***	0.0324***	
		(0.95)	(0.75)		(0.00)	(0.01)	(0.00)	
TaxEquityXOut		0.00624	0.00928		-0.00741	-0.00555	0.00995	
		(0.35)	(0.22)		(0.58)	(0.69)	(0.48)	
DNI			0.000323***					
			(0.00)					
Windspeed						0.0223**	0.0340***	
						(0.05)	(0.00)	
InvSpecificPower						0.0211***	0.0233***	
						(0.00)	(0.00)	
TopSupplier						0.00840	0.0143	
						(0.17)	(0.15)	
SupplierIsOM							0.0172*	
							(0.06)	
CrisisGrant	-0.00106	-0.000306	-0.00258	-0.00475	-0.00580	-0.0104	-0.0242	0.00376
	(0.91)	(0.97)	(0.77)	(0.67)	(0.60)	(0.39)	(0.20)	(0.68)
Utility_Ownership	0.000519	0.000443	0.00190	-0.00176	-0.000987	-0.00477	0.00821	0.00399
	(0.91)	(0.93)	(0.70)	(0.81)	(0.89)	(0.47)	(0.47)	(0.45)
Dev_Ownership	0.00963**	0.00976***	0.0102***	7.79e-05	0.000420	-0.000476	0.00713	0.00206
	(0.01)	(0.01)	(0.01)	(0.99)	(0.95)	(0.94)	(0.41)	(0.64)
PE_Ownership	0.000892	0.000853	0.00254	0.00497	0.00477	0.00107	0.00482	0.00237
	(0.84)	(0.84)	(0.56)	(0.41)	(0.43)	(0.86)	(0.59)	(0.61)
PPA	0.00569	0.00581	0.00446	-0.000607	-0.000425	-0.000945	-0.00936	0.00268
	(0.15)	(0.14)	(0.26)	(0.92)	(0.94)	(0.87)	(0.25)	(0.54)
logCapacity	0.00414	0.00413	0.000751	-0.0215***	-0.0206***	-0.0245***	-0.0305***	-0.00317
	(0.13)	(0.13)	(0.77)	(0.00)	(0.00)	(0.00)	(0.00)	(0.26)
TaxEquityXInXWind								0.0325***
								(0.00)
TaxEquityXOutXWind								-0.00786
								(0.53)
TaxEquityXInXSolar								-0.00744
								(0.15)
TaxEquityXOutXSolar								-0.00216
								(0.77)
Solar								-0.0699***
								(0.00)
Observations	18,014	18,014	12,360	32,134	32,134	25,853	14,210	50,148
R-squared	0.822	0.823	0.860	0.755	0.757	0.789	0.818	0.720
State× Bal.× Month FE	YES	YES	YES	YES	YES	YES	YES	YES
Plant Age FE	YES	YES	YES	YES	YES	YES	YES	YES

Panel B

VARIABLES	(1) Capacity Factor	(2) Capacity Factor	(3) Capacity Factor	(4) Capacity Factor	(5) Capacity Factor	(6) Capacity Factor	(7) Capacity Factor
TaxEquity	0.0279***	0.0208**	0.0164**	0.0204**	0.0167**		
	(0.01)	(0.02)	(0.03)	(0.02)	(0.03)		
TCBridgeLoan					-0.0417		
					(0.10)		
CrisisBridge					-0.0316		
					(0.14)		
TaxEquityXPE_Ownership						0.0197**	
						(0.05)	
TaxEquityXDev_Ownership						0.00497	
						(0.68)	
TaxEquityXUtility_Ownership						0.00280	
						(0.81)	
Bank5TaxEquity							0.0278***
							(0.00)
FinTaxEquity							-0.00690
							(0.54)
EnergyTaxEquity							0.0139
							(0.12)
CorpTaxEquity							-0.0162
							(0.14)
UnknownTaxEquity							0.00958
							(0.23)
PE_Ownership	-0.0250***	0.00106	0.00497	0.00556	0.00484	-0.00556	0.00913
	(0.00)	(0.88)	(0.41)	(0.48)	(0.42)	(0.54)	(0.15)
Dev_Ownership	0.00900	-0.000236	7.79e-05	0.0144*	0.000287	-0.00170	0.000761
	(0.31)	(0.97)	(0.99)	(0.05)	(0.96)	(0.87)	(0.90)
Utility_Ownership	0.00354	0.00587	-0.00176	0.00324	-0.00239	-0.00320	-0.00455
	(0.78)	(0.56)	(0.81)	(0.80)	(0.74)	(0.74)	(0.52)
CrisisGrant	-0.0428***	-0.0162	-0.00475	0.00220	0.00877	-0.00693	-0.00944
	(0.00)	(0.16)	(0.67)	(0.90)	(0.51)	(0.53)	(0.40)
PPA	0.00219	-0.00716	-0.000607	0.000465	-0.00171	-0.000434	0.00109
	(0.81)	(0.30)	(0.92)	(0.95)	(0.77)	(0.94)	(0.85)
logCapacity	-0.000763	-0.00747	-0.0215***	-0.0168**	-0.0207***	-0.0210***	-0.0243***
	(0.91)	(0.18)	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)
Observations	32,134	32,134	32,134	32,084	32,134	28,784	32,134
R-squared	0.056	0.705	0.755	0.818	0.757	0.726	0.758
State× Bal.× Month FE	NO	YES	YES	YES	YES	YES	YES
Plant Age FE	NO	NO	YES	YES	YES	YES	YES
Developer FE				YES			

Table 5: Section 1603 Grants to Probable Tax Equity Users

The propensity to use tax equity is estimated for plants that instead received a financial crisis grant during the period 2008-2013 by whether the sponsor uses tax equity at any other point in the sample outside of the crisis grant period. Only plants with those COD years are in the sample. Standard errors are clustered by plant and month and p-values are in parentheses. Variable definitions appear in Table 1.

VARIABLES	(1) Capacity Factor Wind	(2) Capacity Factor Wind
TEExperience	0.00628	
	(0.67)	
TEExperienceXIn		0.0111
		(0.49)
TEExperienceXOut		-0.00776
		(0.63)
PE_Ownership	0.000807	0.00114
	(0.94)	(0.92)
Dev_Ownership	0.00952	0.00920
	(0.45)	(0.47)
Utility_Ownership	-0.0111	-0.0117
	(0.22)	(0.20)
PPA	-0.0153	-0.0157
	(0.20)	(0.19)
logCapacity	-0.0247**	-0.0248**
	(0.04)	(0.04)
Observations	15,721	15,721
R-squared	0.808	0.809
State× Bal.× Month FE	YES	YES
Plant Age FE	YES	YES

Table 6: Exogenous tax equity financing

Means and t-tests for difference in mean performance between eight wind plants where a tax equity structure was implemented in December 2018 due to Southern Company's losses in the nuclear division, and a matched portfolio. The matched portfolio for each plant comprises all non-tax-equity wind plants that went into service in the same month. The sample starts when the first included plant starts service in December 2015, and ends at the end of the paper's sample period.

	(1) Pre 12/2018 (36 months)	(2) Post 12/2018 (71 months)
Included Plants	0.410	0.412
Matched Plants	0.381	0.330
Difference	0.028	0.0816***

Table 7: Do tax equity investors choose plant characteristics associated with performance?

OLS models of whether tax equity investors pick those plant characteristics associated with performance in Table 3. Variable definitions appear in Table 1.

VARIABLES	(1) Tax Equity Solar	(2) Tax Equity Solar	(3) Tax Equity Solar	(4) Tax Equity Wind	(5) Tax Equity Wind	(6) Tax Equity Wind
DNI_10	0.00401	0.00483	0.00401			
	(0.46)	(0.37)	(0.84)			
SingleAxisTracking		-0.374	-0.840			
		(0.12)	(0.67)			
Windspeed_10				-0.833	-0.902	-0.525**
				(0.29)	(0.27)	(0.04)
InvSpecificPower					-0.154	-0.0293
					(0.61)	(0.88)
TopSupplier		-0.207	-1.864		0.0507	-0.103
		(0.40)	(0.27)		(0.88)	(0.52)
SupplierIsOM			0.0782			0.363***
			(0.97)			(0.01)
Utility_Ownership	-0.0262	0.0527	0.178	0.0906	0.0832	0.518*
	(0.95)	(0.90)	(0.92)	(0.81)	(0.83)	(0.06)
Dev_Ownership	-0.173	-0.185	-0.941	-0.0764	-0.0281	-0.317
	(0.44)	(0.19)	(0.53)	(0.82)	(0.93)	(0.12)
PE_Ownership	-0.210	-0.147	-0.101	0.381	0.386	0.854***
	(0.61)	(0.72)	(0.94)	(0.45)	(0.46)	(0.00)
PPA	-0.387*	-0.444**	-1.098	0.0546	0.0404	0.179
	(0.07)	(0.04)	(0.59)	(0.89)	(0.91)	(0.26)
logCapacity	0.199	0.236	0.924	0.0169	-0.0127	-0.117
	(0.38)	(0.30)	(0.53)	(0.96)	(0.98)	(0.56)
Observations	327	283	81	329	315	161
R-squared	0.927	0.927	0.960	0.946	0.945	0.992
State× Balancing FE	YES	YES	YES	YES	YES	YES
COD Year FE	YES	YES	YES	YES	YES	YES

Table 8: Tax equity and states of very low plant production

OLS models of indicators for low plant production on the presence of tax equity. *Below P10* is an indicator variable for plant-months below the 10^{th} percentile in capacity factor and *Below 0.10* is an indicator variable for plant-months that produce less than 10% of their nameplate capacity. Variable definitions appear in Table 1.

	(1)	(2)	(3)	(4)	(5)	(6)
	Below	Below	Below	Below	Below	Below
	P10	P10	P10	0.10	0.10	0.10
VARIABLES	Solar	Wind	Wind	Solar	Wind	Wind
TaxEquityXIn	0.0177	-0.0346**	-0.0390**	-0.00292	-0.00921**	-0.0121***
	(0.36)	(0.03)	(0.03)	(0.58)	(0.02)	(0.00)
TaxEquityXOut	-0.0345	0.0119	-0.0106	-0.0159**	-0.00734	-0.0183
	(0.22)	(0.78)	(0.83)	(0.02)	(0.60)	(0.27)
CrisisGrant	0.00822	0.0122	0.0220	0.00324	-0.000951	-0.000699
	(0.80)	(0.70)	(0.48)	(0.47)	(0.93)	(0.94)
InvSpecificPower			-0.0275**			-0.000295
			(0.02)			(0.94)
Windspeed			0.00260			0.00136
			(0.91)			(0.83)
Utility_Ownership	-0.0125	0.00500	0.00964	0.00111	-0.000173	-1.92e-05
	(0.60)	(0.78)	(0.59)	(0.82)	(0.97)	(1.00)
Dev_Ownership	-0.0375**	0.0181	0.0190	-0.00516	0.00549	0.00430
	(0.02)	(0.21)	(0.24)	(0.26)	(0.19)	(0.30)
PE_Ownership	-0.00734	-0.00261	0.00300	-0.00283	0.00365	0.00305
	(0.67)	(0.85)	(0.84)	(0.60)	(0.33)	(0.42)
PPA	-0.0323	0.0177	0.0237*	-0.00708	0.00365	0.00374
	(0.14)	(0.20)	(0.10)	(0.28)	(0.30)	(0.28)
logCapacity	-0.0208**	0.0484***	0.0533***	-0.00160	0.00675	0.0105**
	(0.03)	(0.00)	(0.00)	(0.46)	(0.12)	(0.04)
Observations	17,714	31,827	25,574	17,714	31,827	25,574
R-squared	0.448	0.541	0.575	0.535	0.406	0.449
State× Bal.× Month FE	YES	YES	YES	YES	YES	YES
Plant Age FE	YES	YES	YES	YES	YES	YES

Table 9: Annual wholesale revenue scaled by electricity sold, 1/2007-12/2023

OLS regressions of annual revenue scaled by electricity sold. Fixed effects include State×Balancing Authority×Month and Plant Age in months. Standard errors are clustered by plant and year and p-values are in parentheses. Variable definitions appear in Table 1.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S
VARIABLES	Solar	Solar	Solar	Solar	Wind	Wind	Wind	Wind
TaxEquity	-2.755	-2.664			-4.908*	-3.537		
	(0.47)	(0.48)			(0.07)	(0.17)		
TaxEquityXIn			-0.811	-1.316			-5.454*	-3.721
			(0.81)	(0.70)			(0.06)	(0.17)
TaxEquityXOut			-8.736	-6.817			-2.572	-2.794
			(0.26)	(0.36)			(0.48)	(0.47)
WAnnualCapFac		-197.7**		-195.0**		-61.36**		-60.99**
		(0.04)		(0.04)		(0.01)		(0.01)
CrisisGrant	18.61*	18.19**	17.79*	17.63**	21.14***	21.07***	21.21***	21.09***
	(0.06)	(0.04)	(0.07)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)
PE_Ownership	0.667	1.000	0.660	0.990	-2.532	-2.358	-2.487	-2.345
	(0.88)	(0.81)	(0.88)	(0.81)	(0.23)	(0.26)	(0.24)	(0.26)
Dev_Ownership	-4.783	-2.696	-4.986	-2.864	-1.047	-1.063	-1.101	-1.080
	(0.20)	(0.41)	(0.19)	(0.40)	(0.53)	(0.54)	(0.52)	(0.54)
Utility_Ownership	-4.902	-4.650	-4.841	-4.611	-2.361	-2.286	-2.430	-2.309
	(0.28)	(0.27)	(0.29)	(0.28)	(0.40)	(0.40)	(0.39)	(0.40)
PPA	-3.782	-2.683	-3.961	-2.822	2.916	2.620	2.891	2.614
	(0.40)	(0.53)	(0.38)	(0.51)	(0.16)	(0.22)	(0.16)	(0.22)
logCapacity	3.690	4.601*	3.674	4.577*	1.702	0.538	1.611	0.515
	(0.21)	(0.09)	(0.21)	(0.09)	(0.54)	(0.83)	(0.55)	(0.84)
Observations	1,339	1,339	1,339	1,339	2,184	2,184	2,184	2,184
R-squared	0.799	0.811	0.800	0.811	0.785	0.793	0.785	0.793
State× Balancing× Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Plant Age FE	YES	YES	YES	YES	YES	YES	YES	YES

Table 10: *CapacityFactors*, tax equity, and the the presence of back leverage

OLS models of monthly production scaled by capacity, with *TaxEquity* indicator interacted with measures of the presence of back leverage, which has claims on the project's cash equity as illustrated in Figure 2, Panel B. Standard errors are clustered by plant and by time period. Variable definitions appear in Table 1.

	e							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Capacity	Capacity	Capacity		Capacity	Capacity	Capacity	
	Factor	Factor	Factor	R/S	Factor	Factor	Factor	R/S
VARIABLES	Wind	Wind	Wind	Wind	Wind	Wind	Wind	Wind
HasTermLoanXTaxEquityXIn		-0.00991	-0.0200**	4.826				
		(0.32)	(0.05)	(0.26)				
HasTermLoan	-0.000924	0.00403	0.00840	-2.482				
	(0.87)	(0.57)	(0.27)	(0.46)				
HasLTDebtXTaxEquityXIn						-0.0197	-0.0265**	2.111
						(0.11)	(0.04)	(0.67)
HasLTDebt					0.00307	0.0113	0.0137	2.953
					(0.62)	(0.17)	(0.10)	(0.43)
TaxEquityXIn	0.0218***	0.0272***	0.0342***	-8.287*	0.0218***	0.0282***	0.0316***	-6.042*
	(0.00)	(0.00)	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.09)
TaxEquityXOut	-0.00752	-0.00726	-0.00459	-2.821	-0.00738	-0.00719	-0.00443	-2.591
	(0.57)	(0.58)	(0.74)	(0.43)	(0.58)	(0.58)	(0.74)	(0.48)
InvSpecificPower			0.0232***				0.0222***	
			(0.00)				(0.00)	
Windspeed			0.0214**				0.0219**	
			(0.04)				(0.04)	
CrisisGrant	-0.00583	-0.00617	-0.00923	21.21***	-0.00588	-0.00736	-0.0104	21.40***
	(0.60)	(0.57)	(0.42)	(0.00)	(0.59)	(0.51)	(0.37)	(0.00)
Utility_Ownership	-0.00100	-0.000670	-0.00535	-2.342	-0.00136	-0.00126	-0.00597	-2.723
	(0.89)	(0.92)	(0.42)	(0.41)	(0.85)	(0.86)	(0.37)	(0.33)
Dev_Ownership	0.000358	0.000425	-6.84e-05	-1.007	0.000501	0.000990	0.000855	-1.017
	(0.95)	(0.95)	(0.99)	(0.55)	(0.93)	(0.87)	(0.89)	(0.56)
PE_Ownership	0.00481	0.00547	0.00255	-2.670	0.00491	0.00532	0.00211	-2.274
	(0.43)	(0.36)	(0.68)	(0.20)	(0.42)	(0.39)	(0.74)	(0.28)
PPA	-0.000376	-0.000896	-0.00320	3.094	-0.000379	-0.00147	-0.00364	2.987
	(0.95)	(0.88)	(0.59)	(0.16)	(0.95)	(0.81)	(0.55)	(0.16)
logCapacity	-0.0207***	-0.0200***	-0.0219***	1.349	-0.0206***	-0.0211***	-0.0241***	1.733
	(0.00)	(0.00)	(0.00)	(0.61)	(0.00)	(0.00)	(0.00)	(0.52)
Observations	32,134	32,134	25,853	2,033	32,134	32,134	25,853	2,033
R-squared	0.757	0.757	0.790	0.770	0.757	0.758	0.790	0.771
State× Bal.× Month FE	YES	YES	YES	YES	YES	YES	YES	YES
Plant Age FE	YES	YES	YES	YES	YES	YES	YES	YES

Internet Appendix

A Background on tax equity structures

In the United States, tax equity financing is a specialized form of project finance driven by federal tax incentives, primarily the Investment Tax Credit (ITC) and the Production Tax Credit (PTC).

- **Investment Tax Credit (ITC):** Governed by Section 48 of the Internal Revenue Code, the ITC provides a tax credit based on a percentage of the project's eligible cost. For solar projects, the ITC has been a primary incentive and generally accrues in the year the plant is placed in service. The ITC also covers very small wind projects. Most of the benefit occurs in the first year, but the credit vests linearly over 5 years and investors selling early are subject to recapture of unvested tax credits.

- **Production Tax Credit (PTC):** Governed by Section 45 of the Internal Revenue Code, the PTC provides a tax credit based on the amount of electricity produced, typically for the first 10 years of operation. For wind projects, the PTC rate has historically been in the range of 1-3 cents per kilowatt-hour. Tax equity accounts for 65% of the capital for a typical wind plant, plus or minus 10%.[24]

- **Structure:** Project developers or sponsors, who often lack sufficient taxable income to fully utilize these credits, partner with tax equity investors (historically large banks and other financial institutions) who have significant tax liabilities. Investors typically provide a large portion of the project's upfront capital in exchange for the right to claim the tax credits and benefit from accelerated depreciation deductions. Tax equity financing allows developers to monetize tax credits and depreciation benefits that they cannot fully use themselves by selling non-controlling passive interests in the project to tax equity investors. Tax equity investors fund a large portion of the capital cost and receive a pre-negotiated return consisting primarily of tax credits and other tax benefits. Tax equity investors bear little risk. One possibility is that a construction delay might push the project into a year different from the one earmarked by the investor or into a year when tax credits are set to step down. Another remote risk is that the IRS will recapture the ITC credit if the plant is damaged or destroyed within five years. Given the relative seniority of tax equity, their presence in the capital structure may make other claims on the project riskier.

[24] Norton Rose Fulbright: Partnership Flips, structures and issues, February 18, 2021

- **Partnership Flip:** A common structure is the "partnership flip," where the tax equity investor receives a large initial allocation of tax benefits (often 99% of income, losses, and tax credits) and a smaller share of cash flows until they achieve a predetermined internal rate of return. After this target return is met, the allocation of benefits "flips," with the tax equity investor's share decreasing significantly (commonly to 5%).

- **Investor Returns and Risks:** Tax equity investors' returns are primarily derived from the value of the tax credits and depreciation benefits. Typical yields on tax equity investments have been estimated to be between 6% and 7.5%. While considered relatively low-risk due to their senior position in the capital structure (often "back-levered" with priority over project debt), investors face risks such as the potential recapture of the ITC if the plant is significantly damaged or destroyed within five years of being placed in service.

- **Section 1603 Grant program:** Programs like the Section 1603 Grant Program (part of the American Recovery and Reinvestment Act of 2009), which offered a direct cash grant alternative to tax credits, and the more recent tax credit transferability provision under the Inflation Reduction Act of 2022, have provided alternative avenues for developers to monetize tax benefits without relying on traditional tax equity structures.

- **Back leverage** The developer often borrows to fund its share of the partnership contribution. This is called back leverage because the lender's claims are not directly on the project. In this case, the tax equity investor and the lender have to agree on the size and destination of any cash sweeps from the project.

B A stylized model of tax equity incentives

In this appendix, we introduce a stylized model of production with different ownership structures and tax treatment to highlight the frictions that tax equity can cause on the margin. This static model provides a framework for thinking about what responses are expected building on a simple Hall and Jorgenson (1967) framework with a capital ustilization margin and the separation of profits associated with tax equity structures. The goal is to highlight the nature of the agency conflict between the tax equity investor and the project sponsor of which we provide evidence. Further, we motivate hypotheses related to monitoring, contracting, and scale that arise from the model.

A project is financed with k capital and produces $f(k)$ electricity, where $f(0) = 0$ and $f'(k) > 0$. When q units of electricity are sold, they are sold at price p, which we assume is fixed for analytical simplicity although targeting peak hours and seasons can have a large impact on average price. Profits are taxed at rate τ. Capital is rented at rate r, and the rental cost is imperfectly deducted from taxable income at rate $z < 1$, to map into normal depreciation rules in the US.

The owner of the project wants to maximize after-tax profit, which we denote at π, and has a choice of how much capital to employ in production:

$$\max_k p(1-\tau)f(k) - r(1-z\tau)k$$

The solution, which is a version of the model presented in Hall and Jorgenson (1967), is to set the marginal user cost of capital to the marginal product of capital, $pf'(k) = \frac{r(1-z\tau)}{(1-\tau)}$

Profit maximization with production and investment tax credits

The government decides to subsidize the good through a production tax credit and an investment tax credit with the intention of increasing the amount of capital allocated to projects producing capital with production function $f()$. The investment tax credit, ITC, is paid as a share of total capital employed, and the production tax credit, PTC, is paid for each unit of electricity generated. The project has a slightly augmented optimization problem with the additional subsidies:

$$\max_k p(1-\tau)f(k) + \underbrace{PTCf(k)}_{\text{PTC received}} - r(1-z\tau)k + \underbrace{ITC \times k}_{\text{ITC received}}$$

The solution shows that both ITC and PTC represent reductions in the user cost of

capital. Insofar as the production function with respect to k is concave, either mechanism will push the profit-maximizing quantity up and encourage the use of more capital:

$$pf'(k) = \frac{r\left(1 - z\tau - \frac{ITC}{r}\right)}{\left(1 - \tau + \frac{PCT}{p}\right)}$$

Profit maximization including capital utilization

Now assume that the project can also choose a level of utilization $\theta \in [0, 1]$, which is associated with cost $c(\theta)$, which we assume is non-deductible from taxable income for analytical clarity. Effective capital in production is scaled by θ. The project owner still wants to maximize after-tax profit while choosing utilization level θ:

$$\max_{k,\theta} p(1-\tau)f(\theta k) + \underbrace{PTCf(\theta k)}_{\text{PTC received}} - r(1 - z\tau)k + \underbrace{ITC \times k}_{\text{ITC received}} - c(\theta)$$

Since the maximization problem has two arguments, we now have two first-order conditions. First, the marginal product of utilized capital still needs to equal the user cost of capital:

$$p\theta f'(\theta k) = \frac{r\left(1 - z\tau - \frac{ITC}{r}\right)}{\left(1 - \tau + \frac{\theta PCT}{p}\right)}$$

Second, the marginal cost of utilization is set equal to the marginal product of utilization at the profit maximizing solution:

$$p(1-\tau)kf'(\theta k) + kPTCf'(\theta k) = c'(\theta)$$

The first order condition with respect to capital shows that the decision of scale, while holding ex post utilization constant, is impacted by both the PTC and ITC. The first order condition with respect to utilization, holding the scale of the company fixed, sets the marginal product of additional utilization equal to it's marginal cost. Combining the FOCs yields the following

equation to characterize profit maximizing scale and utilization:

$$\begin{aligned} pf'(\theta k) &= \frac{c'(\theta)}{k\left(1-\tau+\frac{PTC}{p}\right)} \\ &\implies \frac{\theta c'(\theta)}{k\left(1-\tau+\frac{PTC}{p}\right)} = \frac{r\left(1-z\tau-\frac{ITC}{r}\right)}{\left(1-\tau+\frac{\theta PCT}{p}\right)} \\ &\implies \theta c'(\theta) = \frac{rk\left(1-z\tau-\frac{ITC}{r}\right)}{\omega} \\ &\implies k = \frac{\theta\omega c'(\theta)}{r\left(1-z\tau-\frac{ITC}{r}\right)} \end{aligned}$$

where ω is defined as $\frac{\left(1-\tau+\frac{\theta PCT}{p}\right)}{\left(1-\tau+\frac{PTC}{p}\right)}$. Here, optimal capital employed is strictly increasing in effort, the marginal cost of effort, and the investment tax credit, but decreasing in in the production tax credit if utilization is less than one.[25]

Profit maximization with the tax equity investor receiving PTC and ITC

Now we further assume that the project does not have sufficient taxable income in order to actually claim the PTC or ITC, so they bring in a tax equity investor who provides around half of the up-front capital and has claims over the tax credits. For analytical simplicity, we deviate slightly from the standard partnership flip in reality that also includes a very small amount of tax credits going to the other equity investors and a small amount of normal profits going to the tax equity investor. We assume that the tax equity investor provides exogenously defined $\alpha \in [0,1]$ share of the capital and receives all of the tax credits and other investors provide the rest, $(1-\alpha)$, of the capital and claim everything else, which avoids complications associated with endogenous prices of these contracts. This is a reasonable stylistic assumption because few firms provide tax equity and thus tax equity dollars are limited and tax equity investors have bargaining power from which to extract value.

The tax equity investor's profit maximizing problem is $\max_{k,\theta} PTCf(\theta k) + ITCk - \alpha rk$ such that $\theta \in [0,1]$, which yields the following solution for tax equity investor profit maximization:

$$\begin{aligned} (\theta PTCf'(\theta k) + ITC) &= \alpha r \\ kPTCf'(\theta k) &= 0 \\ &\implies PTCf'(k) + ITC = \alpha r \end{aligned}$$

The tax equity investor would like to maximize utilization, setting $\theta = 1$, because they do not

[25] Note that $\omega = 1$ if $PTC = 0$ and $\lim_{PTC \to \inf} \omega = \theta$.

personally bear the marginal cost of additional utilization. On the other hand, the sponsor's problem becomes $\max_{k,\theta} p(1-\tau)f(\theta k) - r(1-z\tau)(1-\alpha)k - c(\theta)$ such that $\theta \in [0,1]$. The solution to the sponsor's problem is characterized by the following equation:

$$\begin{aligned} p\theta f'(\theta k) &= \frac{r\,(1-z\tau)}{(1-\alpha)\,(1-\tau)} \\ p(1-\tau)kf'(\theta k) &= c'(\theta) \\ &\implies \theta\frac{c'(\theta)}{k(1-\tau)} = \frac{r\,(1-z\tau)}{(1-\alpha)\,(1-\tau)} \\ &\implies \theta = \frac{rk(1-z\tau)}{(1-\alpha)\,c'(\theta)} \end{aligned}$$

The first order conditions are similar to the standard project profit maximization problem, and they simplify to a statement that utilization increases in the cost of capital and the level of capital, while optimal utilization declines in the marginal cost of utilization, the tax rate, the sponsor's share of the original investment, and the deductibility of physical capital. The final solution would come from defining functional forms for production and utilization costs then comparing to the bounds on θ. Note that the solutions to the tax equity investor's problem and the solution to the sponsor's problem are not the same, which is the genesis of the agency conflict. While a disagreement in profit maximization could be solved in a frictionless equilibrium by changing the price of the contract, taking into account how the other side will respond, we note that tax equity does not appear to be provided in a perfectly competitive or frictionless environment because of the small number of firms participating.

This stylized model has two important implications for our empirical study of tax equity investors and the interpretation of the monitoring and contracting mechanism.

1. A simple monitoring story that sophisticated banks are able to monitor projects better than sponsors with the intention of maximizing project value, which could show up in our model as a rightward shift in the cost function $c(\theta)$, will increase utilization regardless of the subsidy structure. If tax equity monitoring technology is better, we expect to observe similar changes in project behavior among solar and wind plants.

2. The tax equity investor wants to have weakly more utilization than the sponsor who bears the marginal cost of effort, but only when the PTC subsidy is larger than zero, which is true only for wind plants in our sample. This suggests that the agency conflict exists for primarily for wind plants and not for solar plants. If the tax equity investor can push the firm to operate in such a manner to protect their interests and returns at the expense of other agents' claims, it will only show up for wind plants.