Incumbent's Bane or Gain? Renewable Support and Strategic Behavior in Electricity Markets

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ABSTRACT

Incumbent firms play a decisive role in the success of renewable support policies. Their investments in renewables as well as their operational strategies for their conventional CO_2 emitting technologies affect the transition to a sustainable energy system. We use a game theoretical framework to analyze incumbents' reactions to different renewable support policies, namely feed-in tariff (FIT), feed-in premium (FIP), and auction-based policies. We show that a regulator should choose a support scheme based on concerns about either market power or emission abatement: in FIP-based policies, the incumbent's strategic behavior leads to lower CO_2 emissions, but a higher market price compared to FIT-based policies. Furthermore, for FIP-based policies, the regulator might want to incentivize incumbents directly (to further reduce CO_2 emissions) or newcomers (to further reduce market power). Particularly in FIP-based auctions, incumbents have the incentive to obtain all auctioned capacity, which could lead to an unchanged market price despite the entrance of new capacity into the market.

Keywords: Electricity market, Renewable energy, Support policies, Game theory, Incumbent

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1. INTRODUCTION

To achieve the transition from Europe's formerly regulated, fossil fuel- and nuclear-dominated electricity system towards the envisioned liberalized, carbon-free, and renewable-energy-dominated structure, most countries have implemented different support policies for renewable energy sources such as wind and solar photovoltaic (PV) panels. These policies not only impact the composition of the deployed technologies but can also lead to fundamental shifts in the energy investor landscape. While investments in conventional power generation were largely made by utility incumbents, the picture is less clear when it comes to investment in renewables (Clifton, Díaz-Fuentes, and Revuelta, 2010). While incumbents are among the leading investors in renewables in some markets, such as Spain (Ratinen and Lund, 2014), in other markets, particularly the ones that relied on a feed-in tariff policy like Germany, incumbents have actively attempted to block the introduction of new renewables and newcomer firms have invested in renewables (Helms, Salm, and Wüstenhagen, 2015).

Incumbent firms play a decisive role in the transition towards a sustainable energy system (e.g., see Heiskanen et al., 2018; Geels, 2014). Incumbents and energy policies are interlinked in

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two ways: Firstly, incumbents' approach in adapting their conventional generation to renewable support policies is crucial for the success of decarbonization as the incumbents own the majority of CO_2 intensive electricity generation. Consequently, focusing on renewable investment developments and overlooking incumbents' reactions would lead to an incomplete picture of the decarbonization process.

Secondly, incumbents' potential to exercise market power is impacted by renewable support policies, and at the same time, affects the efficiency of those policies. In 2015 the top 5% of incumbent utilities in the OECD owned more than 50% of the electricity generation capacity (Frei et al., 2018), which suggests that incumbents are, to some extent, able to exercise market power. Furthermore, German market development in the last two decades showcases how incumbents' market power is impacted by, among other things, the increasing role of renewable generation: the electricity share of the big four incumbents[1] and their sister companies has decreased from about 75% in 2007 to about 50% in 2017.[2] On the other hand, incumbents may use their market power to strategically manipulate market prices, which might affect the efficiency of renewable support policies (von der Fehr and Ropenus, 2017). The interplay of incumbents' behavior, competitiveness, and renewable policies will likely gain more importance considering that the EU guidelines on "Environmental and Energy State Aid" (European Commission, 2014) are believed to favor big companies due to the EU's preference for market-based support policies (Verbruggen et al., 2015).

Given this background, it is crucial to analyze incumbents' reactions to renewable support policies, accounting for the possibility of strategic behavior. The interactions between environmental objectives, market structure, and competitiveness level can have important implications for policy design. Therefore, within this paper, we develop a two-stage investment/operation model to analyze the interactions between incumbent and newcomer firms as well as between conventional and renewable technologies under different policy designs (i.e., feed-in tariff (FIT), feed-in premium (FIP), and auction-based policies). Particularly, we analyze the effects of renewable support policies on market price (as a measure of market power) and CO_2 emitting conventional production (as a measure of success of climate policies).

We show that under a FIP scheme the regulator might want to target either the incumbent or the newcomer specifically, as the ownership of the renewables affects the market outcomes: while market price (as a measure of market power) decreases as a function of only newcomer's investment, CO_2 emitting conventional production decreases more if incumbent owns more renewables. In contrast, in a FIT scheme, only the total installed renewable capacity affects market prices and CO_2 emissions, whereas the ownership structure is irrelevant. We show that depending on whether the regulator is more concerned about market power (price) or emission abatement, it should choose a different support scheme: in a FIP policy (and FIP-based auctions), the strategic behavior of the incumbent leads to lower CO_2 emissions, but higher market prices compared to a FIT policy (and FIT-based auctions). We also show that in comparable conditions, incumbents invest more in renewables under FIP than FIT. Moreover, while strategic behavior may justify why incumbents have been relatively less responsive to FIT and FIP, under auctions, the incumbents strategically decide to invest in renewables as much (in FIT-based auctions) or even more than the newcomer (in FIP-based auctions). Consequently, we can show that comparing different support policies at the same total renewable target, FIP-based auctions lead to more CO_2 reduction but allow for more exercise of market power (higher market prices).

1. RWE, E.ON, Vattenfall and EnBW.
2. Own calculations based on BNetzA (2008) and BNetzA (2018).

The remainder of the paper is organized as follows. Section 2 reviews the related literature. In section 3, the general structure of the model is explained and formulated for the benchmark case of no support policy. Section 4 analyzes and compares strategic behavior under FIT and FIP. In section 5, we analyze auction-based policies. Section 6 discusses the results and provides policy recommendations. Section 7 concludes the paper. Finally, the proofs of the propositions as well as an illustrative numerical example are presented in the Appendix.

2. LITERATURE

Our research question bridges the gap between three strands of literature on the analysis of electricity markets: investment incentives, strategic behavior under decarbonization policies, and incumbents' behavior. There is a large body of literature addressing different aspects of investment decisions such as risk (e.g., Deilen, Felling, Leisen, and Weber, 2018), market design (e.g., the capacity payment debate in Ritz, Teirilä, and Ritz, 2018; Llobet and Padilla, 2018), and joint R&D and generation capacity investments (e.g., Santen, Webster, Popp, and Pérez-arriaga, 2017). Regarding strategic company behavior, there are plenty of empirical market power assessments for different markets (e.g., Mountain, 2013; Woerman, 2018) as well as theoretical assessments of the effects of oligopolistic or monopolistic markets on outcomes of energy policies (e.g., Ambec and Crampes, 2015).

Our paper contributes to the literature on the diffusion pattern of renewables under decarbonization policy instruments by allowing strategic behavior for incumbents. Li, Liu, and Zhu (2020) investigate the effects of a policy mix of emission trading schemes and feed-in premium on investment and operation decisions of renewable and conventional technologies under carbon price uncertainty. They show that the renewables follow an S-shaped diffusion pattern. Drake et al. (2016) compare the capacity and generation decisions of a firm under emission cap-and-trade, emission tax as well as investment and generation subsidies. Helm and Mier (2019) show that, under the assumption of perfect competition, efficient investments in intermittent renewable and fossil capacities can be obtained if a Pigouvian tax internalizes the external costs of fossil fuels. While the papers above focus on a central planner's perspective or a perfectly competitive market setting, we concentrate on a liberalized market with imperfect competition.

Aflaki and Netessine (2017) analyze investments in intermittent energy sources in the presence of inelastic demand and a heavily dirty backup source. They show that charging more for emissions could unexpectedly discourage investment in renewables since the effectiveness of carbon pricing mechanisms depends on the intermittency of renewable technologies. Pineda, Boomsma, and Wogrin (2018) compare social welfare under feed-in tariff, feed-in premium, and tradable green certificate policies under different levels of risk aversion and market competitiveness. They show that the level of risk aversion of investors is the primary driver of the optimal choice of renewable support scheme. Even though the two papers above include numerical simulations of imperfectly competitive spot markets, unlike our study, they do not provide analytical solutions. Moreover, given that they allow firms to specialize in either conventional or renewable technology, they do not analyze the incentives of conventional incumbents to invest in renewables, which is the focus of our paper.

So far, only limited research has analyzed renewable investment incentives of strategically behaving incumbents under renewable support policies. Dressler (2016) examines the strategic behavior of a conventional firm and a renewable firm in both spot and forward electricity markets. She shows that FIP, compared to FIT, may increase market power and favor conventional production.

Von der Fehr and Ropenus (2017) demonstrate that under a green certificate policy, a dominant firm may squeeze the margin of a fringe by driving down the price of certificates. However, under FIP, such margin squeezes are not possible. Oliveira (2015) demonstrates that while FIP incentivizes firms to invest in a diverse set of renewable capacities, it leads to higher market prices. Even though there are similarities between our framework and these papers, our approach is designed specifically to analyze and compare incumbent and newcomer firms under different support policies. We show that modeling incumbents' behavior needs specific attention as renewable investment incentives of incumbents significantly differ from those of newcomers.

The existing literature on the analysis of incumbents behavior in renewable investments lacks a stylized game-theoretical analysis like the framework presented in our study. As of 2013, incumbent utilities in the European Union own 82% of utility-scale (over 1 MW) non-renewable capacities, while their share in utility-scale renewable generation is only 16% (Kelsey and Meckling, 2018). Several studies have associated incumbents' reluctance towards renewable investments to firm-level path dependencies (Stenzel and Frenzel 2008), limited abilities to identify and exploit new markets and their tendency to rely more on beliefs than on facts (Ratinen and Lund, 2014), as well as the high cost of capital for incumbents (Helms, Salm, and Wüstenhagen, 2015). Moreover, merit order effects also lead to profit losses for the incumbent's conventional technology (Kungl, 2015). Therefore, incumbents may either leave renewable investments to the newcomers or reduce their conventional profits by investing in renewables. In many cases, such as in Germany, incumbents chose the first strategy for a long time and refused to invest in renewables (Brunekreeft, Buchmann, and Meyer, 2016).

Our main contributions to the above-described literature are twofold: first, while the literature on the incumbents' renewable investments mainly uses empirical or descriptive approaches to justify investment reluctance of incumbents in the past under FIT and FIP, we develop a stylized framework to show that market power also leads to underinvestment of the incumbents under FIT and to a lesser extent under FIP. We also extend this literature by showing that in auctions (as the recently more favored support scheme) incumbents are expected to become significantly more involved in renewable investments. Second, by providing an assessment of strategic behavior in the operation stage of different renewable policies, we also provide insights into whether policies can be tailored to improve the competitiveness of the market or, alternatively, further decrease CO_2 emissions from conventional technologies.

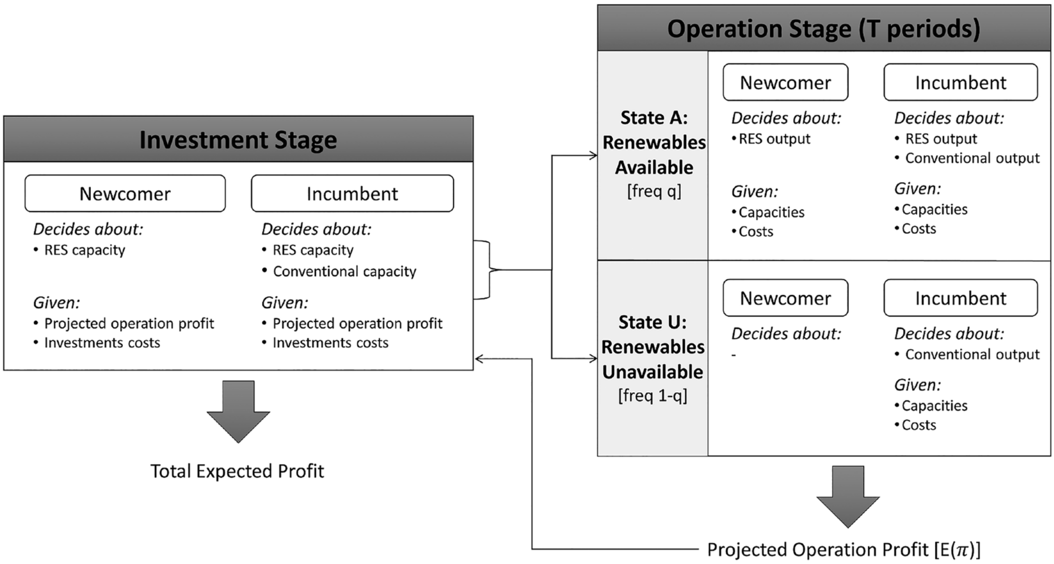
3. MODEL DESCRIPTION

This section introduces the general model design, which is an extension to Darudi and Weigt (2019). In the following, we first present the two-stage layout of the model, the renewable intermittency representation, and the relevant players. Afterward, we explain the mathematical representation of the model and derive the generic incentive structures.

3.1 General Model Design

In order to capture the links between investment incentives and operational decisions, we use a two-stage setup, as indicated in Figure 1. We differentiate between two actors: the incumbent owns an existing conventional technology capacity while the newcomer owns no preexisting capacity. Both actors decide on their renewable investments in the investment stage. The firms are not investing in conventional technologies, mirroring the developments observed in many electricity

Figure 1: Schematic presentation of the two-stage model structure.



markets in which new investments in conventional technologies are very limited, and many systems are characterized by overcapacity (de Groot, Crijns-Graus, and Harmsen, 2017).

During the operational stage, the firms choose their power plants' outputs subject to availability of capacity. We model intermittency of the renewable source in the operation stage by using a binary approach, similar to Aflaki and Netessine (2017). We assume two states of availability for renewables: the fully available state, A, and the unavailable state, U, which are realized in q and q' periods, respectively. At the investment stage, the values for q and q' are known to investors.[3] At each of the $q+q'$ period of the operation stage, firms know the state they are participating in (A or U), which is a justifiable assumption given the massive progress in renewable forecast methods as well as findings that suggest overall RES intermittency is economically much more relevant than the unforecastable short-term intermittency of RES (Gowrisankaran, Reynolds, and Samano 2016). We assume a uniform market-clearing approach that reflects the hourly spot market structure observed in most European markets (Brijs et al. 2017).

The investment and operation stages influence one another: installed capacity in the investment stage sets the upper bound for renewable production in the operation stage. On the other hand, the expected profitability of the operation stage influences investment decisions in the investment stage. Using the backward induction method, we solve the model for different levels of competition, namely a perfectly competitive and an imperfectly competitive setting using Cournot competition.

3.2 Mathematical Model Formulation

Both the incumbent (I) and the newcomer (N) aim to maximize their profit from selling energy in the operational stage (π in states A and U) while accounting for the investment costs $C_{inv}(.)$ for renewable capacities (K^{res}) in the investment stage:

3. Our approach is equivalent to having risk neutral players facing a known two-point distribution probability with probabilities $q/(q+q')$ and $q'/(q+q')$ for the available and unavailable states, respectively.

$$\max_{K^{res}} \; q\pi^{A} + q'\pi^{U} - C_{inv}\left(K^{res}\right) \tag{1}$$

Investment costs are assumed to be convex to reflect the fact that potential sites for renewable generators (i.e., wind turbines or PV panels) vary in quality; therefore, later investments in renewables are costlier, given that more favorable sites are already occupied. For the sake of mathematical tractability, we assume a quadratic investment cost function with investment costs for incumbents and newcomers being independent of each other:[4]

$$C_{inv}\left(K^{res}\right) = \frac{1}{2} c^{res} K^{res\,2} \tag{2}$$

While conventional technology has an operation cost c^{mrg} per unit of generation, renewable technology has no operation cost. Moreover, the inverse demand function is linear, denoted by:

$$\begin{aligned} P^{U} &= a - b Q_{I}^{cnv,U} && \text{if state U} \\ P^{A} &= a - b\,(Q_{I}^{cnv,A} + K_{I}^{res} + K_{N}^{res}) && \text{if state A} \end{aligned} \tag{3}$$

where P^U and P^A are market prices in states U and A, respectively. $a,b > 0$ are scalers. $Q_I^{cnv,U}$ and $Q_I^{cnv,A}$ are the conventional production of the incumbent in states U and A, respectively. Note that in state A, the renewable production of the firms is equal to their renewable installed capacity (K_I^{res} and K_N^{res} for incumbent and newcomer, respectively) because it is in contradiction to the profit maximization logic of the firms to invest in a costly capacity that is not fully used. This full capacity dispatch of RES is in line with clearing procedures in actual markets in which zero marginal cost RES are brought online first since they stand on the cheapest end of the merit order.

The newcomer and the incumbent face the following profit maximization problems in the investment stage, respectively:

$$\text{N}: \max_{K_N^{res}} \; q\pi_N^{A} - C_{inv}\left(K_N^{res}\right) \tag{4}$$

$$\text{I}: \max_{K_I^{res}} \; q\pi_I^{A} + q'\pi_I^{U} - C_{inv}\left(K_I^{res}\right) \tag{5}$$

in which π_N^A, π_I^U and π_I^A are the profit of newcomer in state A and profits of incumbent in state U and A, respectively. π_N^A is simply:

$$\pi_N^{A} = P^{A} K_N^{res} \tag{6}$$

The incumbent, on the other hand, obtains revenue in both states of the operation stage:

$$\max_{0<Q_I^{cnv,U}<K_I^{cnv}} \pi_I^{U} = P^{U} Q_I^{cnv,U} - c^{mrg} Q_I^{cnv,U} \tag{7}$$

$$\max_{0<Q_I^{cnv,A}<K_I^{cnv}} \pi_I^{A} = P^{A} (Q_I^{cnv,A} + K_I^{res}) - c^{mrg} Q_I^{cnv,A} \tag{8}$$

where K_I^{cnv} indicates the preexisting conventional capacity of the incumbent. Following the assumption that the market is characterized by overcapacity, the conventional capacity constraint is

4. We assume that the firms have identical renewable investment cost so that the differences between the firms' renewable investments are due to their incentive structure rather than technological advantages of firms over each other. However, the timing of investments can have important implications for investment incentives in the long run if one actor is able to secure the best locations early and thereby limit the other players in their cost structure.

not binding in either of the states.[5] We also limit our analysis to the cases in which the regulator has not set its renewable target so high that conventional technology is fully crowded out of the market.

Given this setting and formulation, we may already draw some general conclusions regarding the actors' behavior. The periods in which the unavailable state realizes do not affect renewable investment decisions as, by definition, renewables cannot participate in the market. As a result, the characteristics of only the available state, e.g., occurrence frequency and market price of state A, will be relevant for the renewable investment decisions. The price of the available state depends on the competitiveness assumption. Under perfect competition, the price of the available state will reflect the marginal generation costs of the conventional technology. Consequently, renewable capacities will only be added up to the point that their (normalized) marginal investment costs equal this marginal benefit. Allowing for the possibility of strategic behavior does not alter the logic that market conditions matter for renewable investments only in the available state; however, strategic behavior leads to changes in the market price, which will affect investments in renewables. Moreover, one should consider that the incumbent has a second decision layer as it can also alter its conventional generation output. We leave the unavailable state out of our renewable investment analysis since conventional technology's profits in the unavailable state neither affect nor is affected by the entrance of renewables.

4. FEED-IN-TARIFFS AND FEED-IN PREMIUMS

In this section, we compare firms' behavior under feed-in tariff (FIT) and feed-in premium (FIP) policies, which have been widely applied in European countries in the last two decades to support renewable investments (Dressler, 2016). We first present the adjusted model formulation for the two support schemes, followed by a comparison of perfect and oligopolistic competition. Then, we compare the effectiveness of the two schemes in achieving specific policy targets under imperfect competition.

4.1 Model Adjustment

Under a FIP regime, renewable production is paid a constant feed-in rate of p on top of the market price. Therefore, π_N^A (see equation (6)) is adjusted to:

$$\pi_{N}^{A} = (P^{A,FIP} + p)K_{N}^{res,FIP} \tag{9}$$

where superscript *FIP* indicates that variables are defined for FIP. Similarly, the incumbent's spot market profit is altered as follows:

$$\max_{0<Q_I^{cnv,A,FIP}} \pi_{I}^{A} = P^{A,FIP}(Q_{I}^{cnv,A,FIP} + K_{I}^{res,FIP}) + pK_{I}^{res,FIP} - c^{mrg}Q_{I}^{cnv,A,FIP} \tag{10}$$

All other aspects remain equivalent to the formulation presented in Section 3.2.

Contrary to the FIP, FIT entitles renewable energies to receive a fixed payment f without directly participating in the market. However, renewable production is still accounted for in the spot market as it reduces the residual demand that conventional units face (i.e., the merit order effect). Consequently, π_N^A changes to:

5. A binding conventional capacity constraint in state U could provide further investment incentives for new conventional capacity. A detailed assessment of a greenfield setting with investment in conventional and renewable capacity is provided in Darudi and Weigt (2019).

$$\pi_N^A = fK_N^{res,\ FIT} \tag{11}$$

where superscript *FIT* indicates that variables are defined for FIT. Incumbent's profit in state A is split into the market revenue for the conventional technology and the feed-in tariff for the renewable technology:

$$\max_{0<Q_I^{cnv,A,FIT}\le K_I^{cnv}} \pi_I^A = P^{A,FIT}Q_I^{cnv,A,FIT} - c^{mrg}Q_I^{cnv,A,FIT} + fK_I^{res,FIT} \tag{12}$$

All other aspects of the model remain the same as section 3.2.

4.2 Perfect Competition vs. Strategic Behavior

We now investigate the behavior of the two actors under different levels of market competitiveness. As mentioned earlier, we model firms' behavior using a Cournot competition approach, i.e., the firms compete based on quantities (investment and production). In a perfectly competitive market, the firms behave as price takers, i.e., their investment or generation do not affect market prices (e.g., $\partial P^A / \partial Q_I^{cnv,A} = 0$). In contrast, in an imperfectly competitive market, the firms behave as price makers and consider the negative effects of their investment or generation on the market price (e.g., $\partial P^A / \partial Q_I^{cnv,A} = -b$) while making investment and generation decisions. As a result, firms may strategically decide to partially withhold investment or generation to (further) increase the market price above marginal costs of the marginal technology. Comparing firms' behavior under perfectly and imperfectly competitive markets, we make the following claim:

Proposition 1: Under perfect competition, the newcomer and incumbent firms' renewable investments are identical regardless of the type of support policy, whereas in imperfectly competitive markets, the incumbent's renewable investment is less than that of the newcomer.

Proof is provided in the Appendix.

Although this finding is a direct result of the underlying model assumptions and the basic premise of perfect and imperfect competition, the resulting incentive structures provide interesting insights. In a sufficiently competitive market setting, the incumbent's renewable investments remain independent of the incumbent's previously installed conventional capacity. Therefore, any differences observed between the investments of incumbent and newcomer need to be justified by other aspects such as considerable differences in investment costs.

In imperfectly competitive markets, the main driver for the incumbent to invest less in renewables is that additional renewable investment leads to price decrease, which causes a marginal loss on conventional production (see Proof of Proposition 1 for details). As a result, a lower conventional generation would increase investment incentives for the incumbent. In the extreme case that the conventional technology is fully crowded out in the available state, even in imperfectly competitive markets, the incumbent will have investment incentives identical to the newcomer. This translates into a specific investment behavior by the incumbents over time. At the beginning of the implementation of support policies (in which markets are mostly dominated by conventional generation), incumbents have lower investment incentives as the losses due to the merit order effect are high. However, as more and more renewable capacities enter the market (probably mostly by newcomers), the share of conventional production diminishes, which increases investment incentives for incumbent firms. This matches the observations in many markets, such as Germany, in which incumbents are characterized by a delayed entrance to renewable capacity investments (Kungl, 2015). Our finding complements the literature that justifies this delay by a misperception of the incumbents regarding market conditions and over-relying on outdated beliefs and data rather than having a forward-looking strategy (Ratinen and Lund, 2014).

Incumbents' heterogeneous investments in different renewable technologies can also be justified by this relation between conventional production and incumbent's investment incentives. Incumbents have shown diverse investment patterns in different renewable technologies. For instance, while incumbents in Germany have installed wind turbines, they have been idle in PV investments (Richter, 2013). While PV generation mostly coincides with peak demand (Cludius et al., 2014), wind generation is less correlated with peak hours. As incumbents are typically at their highest conventional production rates during peak hours, they have lower incentives to invest in PVs. Our justification is complementary to the literature (e.g., Choi, 2019) arguing that the distributed nature of PV installation does not fit the business model of incumbents with large power plants. However, this justification does not rule out investments in big centralized PV power plants, whereas the relation between conventional share and investment incentives does.

To enable policymakers to target the incumbent firms more directly in imperfectly competitive markets,[6] it helps to compare renewable investment incentives with respect to characteristics of the conventional technology. Incumbent's marginal profits of the conventional and renewable technologies should be equal in equilibrium.[7] In a FIT regime, while the marginal profit of conventional generation is its market markup ($markup_I^{cnv,A,FIT}$), the marginal profit of renewable generation is the feed-in rate minus normalized marginal investment costs; their equality leads to:[8]

$$f - markup_I^{cnv,A,FIT} = \frac{c^{res}}{q} K_I^{res} \tag{13}$$

Similarly, for the newcomer we have:[9]

$$f = \frac{c^{res}}{q} K_N^{res,FIT} \tag{14}$$

As a result, in line with findings of Ropenus and Jensen (2009), the markup of the conventional technology in a FIT scheme plays a crucial (negative) role in the renewable investment decisions of the incumbent; while it does not affect the newcomer's decision in a FIT regime. Therefore, classical market power mitigation policies (e.g., price caps) will also increase incumbents' renewable investments.

Similarly, under FIP regime, we have:[10]

$$c^{mrg} + p = \frac{c^{res}}{q} K_I^{res,FIP} \tag{15}$$

$$P^{A,FIP} + p - bK_N^{res,FIP} = \frac{c^{res}}{q} K_N^{res,FIP} \tag{16}$$

Accordingly, in line with findings of von der Fehr and Ropenus (2017), in a FIP scheme, the marginal cost of the conventional technology is one of the main drivers of renewable investment decisions for the incumbent, and the market price has no direct effect; while this is the opposite for

6. See Proposition 2 on why policymakers might want to target incumbents specifically.

7. If this were not the case, the incumbent has the incentive to produce more from the technology with the higher marginal payoff; meaning this would not have been optimum in the first place.

8. Refer to (36) for a mathematically rigorous derivation of the term. Note that $markup_I^{cnv,A,FIT} = P^{A,FIT} - c^{mrg}$.

9. Refer to (37) for a mathematically rigorous derivation of the term.

10. Refer to (34) and (35) for a mathematically rigorous derivation of the terms.

the newcomer. Consequently, policies targeting conventional generation, like a CO_2 price/tax or removing fossil fuel subsidies (Gerasimchuk et al., 2017), will impact the incumbents' investments.

4.3 Effectiveness of Support Regimes under Strategic Behavior

While the previous section focused on a comparison of incumbents and newcomers under perfect and imperfect competition, in this section, we analyze the effects of the incumbent's strategic behavior in the operation stage (Proposition 2) and investment stage (Proposition 3). We are particularly interested in the relation between renewable support policies and environmental targets (i.e., carbon emissions by conventional generation) and market competitiveness (i.e., market price) to identify if and when the regulator needs to target a specific type of investor:

Proposition 2: Under imperfect competition: In a FIT regime, the renewable investments of the incumbent and newcomer firms result in similar decreases in conventional production and market price, regardless of the firms' respective shares in renewable investments. In a FIP regime, the incumbent's renewable investments have a higher impact on conventional production than the newcomer's investments but do not impact the market prices.

Proof is provided in the Appendix.

Proposition 2 highlights that the ownership composition of renewable capacities does matter under FIP and thereby could justify or speak against favoring investments by incumbents or newcomers. If the reduction of CO_2 emissions is of concern, targeting incumbents leads to a more significant reduction of conventional production and consequently CO_2 emissions. On the other hand, if market power concerns are more prevalent, a FIP would only help insofar as newcomers are attracted to the market because even if incumbents invest in renewables, they will adjust their overall output accordingly to maintain their markup.[11] Overall, the ownership of renewable assets in an imperfectly competitive market may be a valuable aspect to consider and can give justification for prioritizing specific investor types over others or for protecting actor diversity (see also Karneyeva and Wüstenhagen (2017) on the relevance of actor diversity).

In a FIT regime, on the other hand, incumbents treat their own and competitive renewable production similarly with respect to their operational decisions. Therefore, ownership of the renewable capacities has no differentiated effect on conventional production (and thereby CO_2 emissions) or market price (market power).

One can extend the insights from these findings to further market aspects not considered in the model. For example, Batlle, Pérez-Arriaga, and Zambrano-Barragán (2012) show that in markets with vertically integrated incumbents, a FIP scheme leads to more entry barriers for newcomers due to higher market risk. Given that our model shows investments by newcomers play a crucial role in reducing market prices in a FIP scheme, vertically integrated markets will be even more susceptible to market power abuses.

While Proposition 1 and 2 analyzed strategic behavior in investment and operation stages independently, the effects of feedbacks between the two stages are analyzed in Proposition 3. To obtain an indication of the potential effectiveness of FIT and FIP, we compare their effects under the restriction that they provide the same aggregated renewable investment. We answer the following question: what scheme should policymakers favor if they aim for the same installed renewable capacity?

11. This finding is in line with Acemoglu, Kakhbod, and Ozdaglar (2017) which shows if all firms in a market own both conventional and renewable capacity, market price becomes independent of total renewable investments.

Proposition 3: Under imperfect competition, at a similar total renewable investment target for FIT and FIP, the incumbent will invest more into renewables and produce less conventional generation in a FIP regime with respective emissions being lower and market prices being higher than in a FIT regime.

Proof is provided in the Appendix.

With a FIP, both technologies receive the market price, whereas with a FIT, only conventional technology is affected by market prices. As a result, the incumbent has higher incentives to withhold conventional production to increase market prices under a FIP regime. This incentive structure leads to higher market prices and lower conventional production in a FIP compared to a FIT. However, as this in turn translates into lower CO_2 emissions, choosing FIP over FIT should provide higher emission reduction benefits at the cost of higher market prices. If the regulator has a market share target for renewables (in percentage), the higher price (and accompanying lower demand) allows them to achieve the same renewable market share target with lower total renewable investments (in GW) under FIP compared to FIT. In Appendix B, we complement the analytical assessments of this section by using an illustrative numerical simulation to showcase the impacts of strategic behavior in a representative simplified electricity market.

5. AUCTIONS

While FIT and FIP schemes have been prominent renewable support mechanisms in the last two decades, recent years have seen a push toward auction-based schemes (Welisch 2018) to impose more control on the amount of investment in renewable generation capacities and to decrease renewable support costs due to the increased competition in the bidding stage (Voss and Madlener, 2017). Therefore, in this section, we build on the previous result to provide an assessment of incentive structures in auction regimes.

We focus on auctions in which the regulator sets a predefined target renewable capacity and defines the price level via the auction. While in FIT-based auctions, firms offer their required payment per unit of renewable energy production, in FIP-based auctions, firms offer their required premium on top of the market price. We assume that the firm with the lowest rate wins the full quantity of the auction. First, we focus on the firms' valuation of winning the auctions, which is defined as the difference between a firm's profit of winning and losing the auction. Analyzing values of winning the auction under FIT and FIP-based auction reveals that:

Proposition 4: Under imperfect competition, at a given capacity target, the value of winning the auction is the same for the incumbent and the newcomer in a FIT-based auction, but higher for the incumbent in a FIP-based auction.

Proof is provided in the Appendix

The intuition behind the incumbent incentives is based on the fact that the auction scheme predefines the resulting renewable capacity, i.e., the capacity will enter the market regardless of who owns them. Note that Proposition 2 remains valid for the operation stage of auctions because auctions do not change the market and support payments structure, and consequently, the firms' underlying strategic behavior remains the same. Therefore, in FIT-based auctions, market price, conventional production, and consequently, conventional technology's profits are independent of who wins the auction. Given that firms have identical costs for renewable investments and, by design, in FIT-based auctions both firms' renewable income depends only on the support rate, the firms have a similar valuation for winning the auction.

In contrast, in a FIP-based auction, market price and conventional production depend on who owns the renewable capacities (Proposition 2): If the incumbent wins the auction, it keeps the market price higher than if the newcomer wins the auction (by reducing its conventional production more) because if the incumbent wins, the incumbent's total conventional and renewable output benefit from the higher market price; however if the newcomer wins, only the conventional output of the incumbent benefits from the market price. Consequently, the incumbent has a higher incentive to win the auction because its gain from winning the auction (and keeping the market price higher) is larger than the newcomer's gain from winning (and inevitably facing the reduced price).

Given these insights on the different valuation of winning the auction, we can derive generic predictions regarding firms' bidding behavior. Bidding incentives depend on the clearing structure of the auctions: in a second-price sealed-bid auction, the lowest bidder wins the auction but earns the second-lowest bid. It is optimal for firms to bid truthfully based on their valuation so that their payoff becomes zero,[12] because bidding lower may result in losses and bidding higher may result in losing the auction without bringing in any additional profit in the case of winning the auction. In a first-price sealed-bid auction, on the other hand, the lowest bidder wins the auction and earns the bid it places. Therefore, the firm with the highest value bids so low that the firm with the second-highest value has a payoff of (slightly less than) zero and consequently becomes indifferent to winning or losing the auction.[13] In the case of FIT-based auctions, both first- and second-price regimes should lead to firms bidding similarly, as they have similar valuations. Therefore, assuming that in the case of similar bids the awarded capacity is distributed equally between the two firms, in a FIT-based auction, each firm wins half the auction. In a FIP-based auction, both first- and second-price regimes should lead to the incumbent winning the auction, as it has higher valuation for winning.[14] However, the payoff and bids in FIP-based cases will depend on the payoff scheme. In the second-price scheme, the incumbent will bid based on its own valuation but obtain the bid from the newcomer. In the first-price scheme, the incumbent will have to predict the newcomer's bid and bid slightly below it.

Auction-based policies are known to favor investments made by incumbents. For example, Leiren and Reimer (2018) explain that large companies can benefit from economies of scale due to having multiple projects compared to smaller companies. We complement this reasoning by showing that, even among firms with the same costs, FIP-based auction favors investments by incumbents.

When it comes to nullifying firms' strategic behavior, auctions have different effects on the investment and operation stages. While firms in simple FIT or FIP policies may withhold investments to increase profits, in auction policies, the incentives to strategically withhold investments are removed since the capacity entering the market is already set by the regulator. However, market power issues will be exacerbated in FIP-based auctions. Incumbents winning a FIP-based auction will keep market prices high despite the system having more overall capacity available (Proposition 2). Under some circumstances, direct support policy cost reductions, gained via competitive bidding in the investment stage, might even be offset by indirect cost burdens stemming from the higher exercise of market power in the spot market.

12. Translation of Proposition 2.1 in (Krishna, 2002) to our specific case.

13. Translation of Proposition 2.2 in (Krishna, 2002) to our specific case.

14. Changing the auction design might affect the share of awarded renewable support. For instance, if multiple rounds of auctions are implemented, in a FIP-based auction the incumbent might have less incentive to win the later auctions if winning the earlier rounds has led to having higher marginal investment costs compared to the newcomer. However, as the newcomer is also subject to increased investment costs after winning a round, one could expect that the incumbent's share will remain higher than the newcomer.

6. POLICY RECOMMENDATIONS AND DISCUSSIONS

Overall, our results provide important insights for policymakers in electricity markets. First, the basic result that the impact of renewable support policies strongly depends on the competitiveness of the market is not surprising, but nevertheless, an important aspect to consider while choosing and designing a support policy. Planning the premium or feed-in rates based on a perfectly competitive benchmark may result in unwanted levels of investment if real-world conditions are less competitive, which in turn, requires subsequent policy adjustment. Given the often complex and tedious decision processes in policymaking, a policy design based on a better ex-ante assessment of the market competitiveness may help to improve the policymaking process.

Second, the insights on the trade-offs between overall investment volume, investment shares, conventional generation, and market prices highlight the potential for tailoring renewable policies to support the overall energy policy setting. Among the trade-offs, the relevance of market power concerns versus environmental aspects is likely the most interesting for many systems. Given the high divergence in the number and type of incumbents in different restructured markets in the U.S. and Europe, as well as differences in conventional power plant fleets, regulators might favor FIP-based policies if they prefer lower conventional output at higher prices (e.g., in systems characterized by carbon-intensive coal generation with a rather modest market concentration) or FIT-based policies if lower market power and higher conventional production are desired (e.g., in markets with high shares of existing carbon-free generation and high market concentration). The stylized numerical example of the European power sector in the Appendix highlights that the identified relations may be of relevant size for policymakers given that, depending on the choice of support policy, incumbents' renewable investments, conventional productions, and the market price could differ significantly (by several GW, GWh, and percents, respectively).

Third, to have a comprehensive cost estimation of auction-based support policies, policymakers should take into account, not only the direct costs (e.g., awarded payments to the winners), but also the possible indirect costs for the consumers (e.g., stemming from higher market prices under FIP-based auction compared to FIT-based auction).

While our results are derived for a single market and only two investors, they can be extended to more markets and players. For example, incumbents may expand to markets outside their home country (Choi, 2019). Given that incumbents withhold renewable investment to avoid losses on their conventional technologies, we argue that they have higher incentives to invest in markets outside their home country in which they have less conventional production and, consequently, behave like newcomers. This is the case, for instance, in Germany where incumbents are rather inactive in renewable investments but own more renewable capacities elsewhere. Our reasoning approach complements the literature arguing that incumbents have internationalized because they find limited growth possibilities in their domestic market (Ratinen and Lund, 2014). In contrast, Choi (2019) argues that competitive pressure induced by support policies has motivated incumbents to develop resources related to renewables for their home country, which in turn, has allowed them to invest in renewables elsewhere. Ratinen and Lund (2014) also highlight that while incumbents in Germany under FIT have internationalized in renewable investments, Spanish incumbents under a FIP-based scheme have focused more strongly on their domestic market. This might be a consequence of incumbents having more incentives to invest under FIP than FIT (Proposition 3) and, therefore, feeling less pressure to seek markets outside of their home country.

Besides, having multiple incumbents and newcomers will still function under the basic logic and insights of our model, even though some adjustments are required as a result of the increased competitiveness.[15] For instance, under FIT, having higher competition in the spot market means that the markup of the conventional technology is lower, which in turn translates to higher investments by the incumbents. Furthermore, under FIP, the newcomers still play an important role in reducing market power, as the market price depends on their total renewable investments. On the other hand, if the newcomer is a price-taking fringe,[16] it does not withhold investment under FIP, which in turn increases newcomer's market share and decreases the market price. Whereas having a competitive fringe under FIT would not change the market outcome because the newcomer has no incentive to act strategically in the first place.

7. CONCLUSION AND OUTLOOK

Many liberalized electricity markets are characterized by oligopolistic market structures inherited from the pre-liberalized era that are slowly changing as a result of the emergence of new power producers, many of which enter the markets due to renewable support policies. Within this paper, we develop a simple two-stage model to analyze the interaction occurring in such markets with a focus on strategic behavior and its impact on investment and operation behavior under FIP, FIT, and auction-based policies. We show that for FIT and FIP policies in an imperfectly competitive market, incumbents, compared to newcomers, have lower incentives to invest in renewables due to additional adverse feedback effects on their existing conventional generation. Auction-based policies, however, change the relative incentives of the firms: the incumbents have similar incentives (under FIT-based auction) or more incentives (under FIP-based auction) to invest in renewables than the newcomers.

We also show that in a level playing ground, FIP-policies lead to lower conventional generation at higher market prices compared to FIT-based counterparts. In FIP-based policies, the ownership distribution of renewables among incumbents and newcomers has a significant impact on conventional production and market prices. Therefore, depending on policy priorities, the regulator might want to specifically incentivize incumbents (leading to further reductions of CO_2 emissions) or newcomers (to reduce market power).

Finally, the resulting incentive structures and policy trade-offs should be seen as a complement to existing assessments on renewable investments and policy design. Other aspects addressing investment incentives—like asymmetric risk preferences, vertical integration of incumbents, or entry barriers—can have a decisive impact on whether incumbents or newcomers have higher incentives to invest in renewables. Our assessment of primary drivers helps to broaden this picture and can provide further explanations for observed real market developments. Similarly, the interplay of different energy and environmental policies—like the role of renewable support in emission trading systems or for energy efficiency measures—leads to complex settings with potential feedback ef-

15. As an example, we show Proposition 2 under FIP holds true assuming a symmetric set of incumbents *Is* and a symmetric set of newcomers *Ns*. We have $P^A = a - b\left(\sum_{I \in Is}(Q_I^{cnv,A} + K_I^{res}\right) + \sum_{I \in Ns} K_N^{res})$. FOC of (10) with respect to $Q_I^{cnv,A,FIP}$ yields for $\forall I \; in \; Is: \; Q_I^{cnv,A,FIP*} = \left(a - \mathrm{c}^{\mathrm{mrg}}\right)/2\mathrm{b} - 0.5\left(\sum_{i \in Is, i \neq I} K_i^{res,FIP} + \sum_{N \in Ns} K_N^{res,FIP}\right) - K_I^{res,FIP}$ which is in line with Proposition 2 because an incumbent's renewable investment ($K_I^{res,FIP}$) has a higher impact on conventional production of the incumbent ($Q_I^{cnv,A,FIP*}$) than renewable investments of a newcomer ($K_N^{res,FIP}$). The resulting market price is $P^{A,FIP*} = \frac{a + \sum_{I \in Is} c^{mrg}}{1 + \sum_{I \in Is} 1} - \frac{\mathrm{b}}{1 + \sum_{I \in Is} 1} \sum_{N \in Ns} K_N^{res,FIP}$, which is independent of incumbents' investments. Other propositions may similarly be proven for multiple firms.

16. Current conditions and trends suggest that renewable newcomers are gaining more market shares and, therefore, should not be treated as a fringe producer but rather full strategic players (Dressler, 2016).

fects. Our assessment of the trade-offs embedded in the strategic behavior of incumbents adds to this complexity. Consequently, the next research step should be to combine those different dimensions into a multifaceted model of firms' incentives and match it to specific real-world market settings.

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APPENDIX A: PROOF OF PROPOSITIONS

Proof of Proposition 1:

Perfect competition:

In FIP, replacing $P^{A,FIP} = c^{mrg}$ (because market price in state A under FIP, $P^{A,FIP}$, is the marginal cost of the marginal producer) in operational profits of the firms (equations (9) and (10)) yields:

$$\pi_N^A = (c^{mrg} + p)K_N^{res,FIP} \tag{17}$$

$$\pi_I^A = \left(c^{mrg} + p\right)K_I^{res,FIP} \tag{18}$$

which when substituted in investment optimizations ((4) and (5)) and taking first order conditions (FOC) with respect to the renewable investments yields:

$$q(c^{mrg} + p)K_N^{res,FIP*} - c^{res}K_N^{res,FIP*} = 0 \tag{19}$$

$$q(c^{mrg} + p)K_I^{res,FIP*} - c^{res}K_I^{res,FIP*} = 0 \tag{20}$$

which means at optimum (denoted by *) $K_I^{res,FIP*} = K_N^{res,FIP*}$.

In FIT, a similar procedure (replacing $P^{A,FIT} = c^{mrg}$ in equations (11) and (12), and substituting in (4) and (5), and taking FOC) yields:

$$\mathrm{qfK_N^{res,FIT*}} - \mathrm{c^{res}K_N^{res,FIT*}} = 0 \tag{21}$$

$$\mathrm{qfK_I^{res,FIT*}} - \mathrm{c^{res}K_I^{res,FIT*}} = 0 \tag{22}$$

which shows $K_I^{res,FIT*} = K_N^{res,FIT*}$, indicating that firms invest equally in renewables.

Imperfect competition:

In FIP, FOC of the incumbent's operation decision (equation (10)) with respect to $Q_I^{cnv,A,FIP}$ yields:

$$\mathrm{Q_I^{cnv,A,FIP*}} = \frac{a - \mathrm{c^{mrg}}}{2\mathrm{b}} - \frac{\mathrm{K_N^{res,FIP}}}{2} - \mathrm{K_I^{res,FIP}} \tag{23}$$

$$\mathrm{P^{A,FIP*}} = \frac{a + c^{mrg}}{2} - \frac{\mathrm{bK_N^{res,FIP}}}{2} \tag{24}$$

which means:

$$\mathrm{P^{A,FIP*}} - \mathrm{c^{mrg}} = \mathrm{b}\left(\mathrm{Q_I^{cnv,A,FIP*}} + \mathrm{K_I^{res,FIP}}\right) \tag{25}$$

Substitution of (23) and (24) in (5) and deriving FOC with respect to $K_I^{res,FIP}$ and substituting (25) yields:

$$\mathrm{q}\left(\mathrm{P^{A,FIP*}} + p - \mathrm{b}\left(\mathrm{Q_I^{cnv,A,FIP*}} + \mathrm{K_I^{res,FIP*}}\right)\right) - \mathrm{c^{res}K_I^{res,FIP*}} = 0 \tag{26}$$

Similar procedure for the newcomer (replacing in (4) and taking FOC) yields:

$$\mathrm{q}\left(\mathrm{P^{A,FIP*}} + p - \mathrm{bK_N^{res,FIP*}}\right) - \mathrm{c^{res}K_N^{res,FIP*}} = 0 \tag{27}$$

Comparing (26) and (27) shows that firms have similar marginal profits from market price ($P^{A,FIP*}$) and premium payments (p), and marginal investment costs. However, renewable investment reduces the market price ($\frac{\Delta P^A}{\Delta K_I^{res}} = -b$) which causes a marginal loss for firms amounting to $b(Q_I^{cnv,A,FIP*} + K_I^{res,FIP*})$ and $bK_N^{res,FIP*}$ for incumbent and newcomer, respectively. Therefore, to show ($K_I^{res,FIP*} < K_N^{res,FIP*}$), we need to show ($Q_I^{cnv,A,FIP*} + K_I^{res,FIP*} > K_N^{res,FIP*}$). Proof by contradiction: if $Q_I^{cnv,A,FIP*} + K_I^{res,FIP*} > K_N^{res,FIP*}$ does not hold true, one of the following cases occurs:

i) $Q_I^{cnv,A,FIP*} + K_I^{res,FIP} < K_N^{res,FIP}$, which when substituted in (26) and (27) yields $K_I^{res,FIP*} > K_N^{res,FIP*}$ which given $Q_I^{cnv,A,FIP*} > 0$ means $Q_I^{cnv,A,FIP*} + K_I^{res,FIP*} > K_N^{res,FIP*}$ which is a contradiction to the premise of this case.

ii) $Q_I^{cnv,A,FIP*} + K_I^{res,FIP*} = K_N^{res,FIP*}$, which when substituted in (26) and (27) yields $K_I^{res,FIP*} = K_N^{res,FIP*}$ meaning $Q_I^{cnv,A,FIP*} = 0$, which is in contradiction to the condition that conventional technologies are not crowded out in the available state.

Therefore, we must have $Q_I^{cnv,A,FIP*} + K_I^{res,FIP*} > K_N^{res,FIP*}$, which means $K_I^{res,FIP*} < K_N^{res,FIP*}$.

In FIT, FOC of the incumbent's operation decision (equation (12)) with respect to $Q_I^{cnv,A,FIT}$ yields:

$$\mathrm{Q_I^{cnv,A,FIT*}} = \frac{a - \mathrm{c^{mrg}}}{2\mathrm{b}} - \frac{1}{2}\left(\mathrm{K_N^{res,FIT}} + \mathrm{K_I^{res,FIT}}\right) \tag{28}$$

$$P^{A,FIT*} = \frac{a + c^{mrg}}{2} - \frac{b}{2}\left(K_N^{res,FIT} + K_I^{res,FIT}\right) \tag{29}$$

which means:

$$P^{A,FIT*} - c^{mrg} = bQ_I^{cnv,A,FIT*} \tag{30}$$

Substitution of (28) and (29) in (5) and deriving FOC with respect to $K_I^{res,FIT}$ and substituting (30) yields:

$$qf - qbQ_I^{cnv,A,FIT*} - c^{res}K_I^{res,\ FIT*} = 0 \tag{31}$$

Similar procedure for the newcomer (taking FOC of (4)) yields:

$$qf - c^{res}K_N^{res,FIT*} = 0 \tag{32}$$

Firms have similar marginal profits from feed-in payments (*f*) and marginal investment costs. However, renewable investment reduces the market price, which causes a marginal loss for the incumbent (amounting to $bQ_I^{cnv,A,FIT*}$). Given that $Q_I^{cnv,A,FIT*} > 0$, comparing (31) and (32) shows that $K_I^{res,FIT*} < K_N^{res,FIT*}$. ■

Proof of Proposition 2:

Under FIT, note $K_N^{res,FIT}$ and $K_I^{res,FIT}$ have the same coefficients in conventional generation and price (equations (28) and (29), respectively). Under FIP, note that $K_I^{res,FIP}$ factors stronger into the output decision for the conventional generation (equation (23)) than $K_N^{res,FIP}$ and does not affect the market price (equation (24)). ■

Proof of Proposition 3:

Renewable Investments: We need to show that $K_I^{res,FIP*} > K_I^{res,FIT*}$ if

$$K_N^{res,FIP*} + K_I^{res,FIP*} = K_N^{res,FIT*} + K_I^{res,FIT*} \tag{33}$$

First, we find the relation between *f* and *p* when (33) is true. Replacing (25) in (26) and solving for $K_I^{res,FIP}$ yields:

$$K_I^{res,FIP*} = \frac{c^{mrg} + p}{c^{res} / q} \tag{34}$$

Solving (27) for $K_N^{res,FIP*}$ also yields[17]:

$$K_N^{res,FIP*} = \frac{P^{A,FIP} + p - bK_N^{res,FIP}}{c^{res} / q} \tag{35}$$

Substituting (30) in (31) and solving for $K_I^{res,FIT*}$ yields:

$$K_I^{res,FIT*} = \frac{f - P^{A,FIT} + c^{mrg}}{c^{res} / q} \tag{36}$$

17. For the sake of mathematical traceability, we use this implicit form.

Finally, solving (32) for $K_N^{res,FIT}$ yields:

$$K_N^{res,FIT*} = \frac{f}{c^{res}/q} \tag{37}$$

Substituting (34)-(37) in (33) and rearranging yields:

$$f - p = \frac{1}{2}\left(P^{A,FIT*} - P^{A,FIP*} - bK_N^{res,FIP*}\right) \tag{38}$$

On the other hand, having $K_I^{res,FIP*} > K_I^{res,FIT*}$, based on (34) and (36), is equivalent to having:

$$\frac{c^{mrg} + p}{c^{res}/q} > \frac{f - P^{A,FIT*} + c^{mrg}}{c^{res}/q} \tag{39}$$

which by removing common c^{res}/q and c^{mrg} on both sides and replacing $f - p$ from (38) is equivalent to:

$$0 > \frac{P^{A,FIP*} - P^{A,FIT*}}{2} - \frac{b}{2}K_N^{res,FIP*} \tag{40}$$

Substituting $P^{A,FIP*}$ from (24) and $P^{A,FIT*}$ from (29) and substituting $K_N^{res,FIT*} + K_I^{res,FIT*}$ with $K_N^{res,FIP*} + K_I^{res,FIP*}$ (in line with (33)) simplifies the inequality to:

$$0 > \frac{b}{4}K_N^{res,FIP*} - \frac{b}{2}K_N^{res,FIP*} = -\frac{b}{4}K_N^{res,FIP*} \tag{41}$$

which holds true given that we know $K_I^{res,FIP*} > 0$. Therefore, we have proved that $K_I^{res,FIP*} > K_I^{res,FIT*}$.

Conventional production: We want to show $Q_I^{cnv,A,\,FIP*} < Q_I^{cnv,A,\,FIT*}$. Knowing $-\frac{K_I^{res,\,FIP*}}{2} < 0$ and (33), we have:

$$\frac{a - c^{mrg}}{2b} - \frac{1}{2}\left(K_N^{res,FIP*} + K_I^{res,FIP*}\right) - \frac{K_I^{res,\,FIP*}}{2} < \frac{a - c^{mrg}}{2b} - \frac{1}{2}\left(K_I^{res,FIT*} + K_N^{res,FIT*}\right) \tag{42}$$

which according to (23) and (28) gives:

$$Q_I^{cnv,A,\,FIP*} < Q_I^{cnv,A,\,FIT*} \tag{43}$$

Market price: given $P^{A*} = a - bQ_I^{cnv,A,FIT*} - b\left(K_I^{res,FIT*} + K_N^{res,FIT*}\right)$, (33) and (43), it is straightforward to show $P^{A,FIP*} > P^{A,FIT*}$. ■

Proof of proposition 4:

Increase in payoff from winning the auction for the firms (Δu_i) can be defined as:

$$\Delta u_i = v_i + b_i qR \qquad i \in \{I, N\} \tag{44}$$

in which qR is the total generation of R units of auctioned renewables, b_i is the value of the bid and v_i is the firm's valuation of winning the auction defined as:

$$v_i = \pi_i^{win} - \pi_i^{lose} \qquad i \in \{I, N\} \tag{45}$$

in which π_i^{win} (π_i^{lose}) is the profit of the firm excluding auction-based incomes if it wins (loses) the auction, that is $K_i^{res} = R$ and $K_j^{res} = 0\ \forall j \neq i$ ($\mathrm{K_i^{res}} = 0$ and $\mathrm{K_j^{res}} = R\ \forall j \neq i$)[18]. Therefore, under FIT-based auction, given that newcomer earns profit only from the auction's feed-in rate (equation (11)), profits of winning $\pi_N^{win,FIT}$, and losing, $\pi_N^{lose,FIT}$, are equal to:

$$\pi_{\mathrm{N}}^{\mathrm{win,FIT}} = -\ \mathrm{C_{inv}}\left(\mathrm{R}\right),\ \ \pi_{\mathrm{N}}^{\mathrm{lose,FIT}} = 0 \tag{46}$$

which substituted in (45) yields:

$$\mathrm{v_N^{win,FIT}} = -\ \mathrm{C_{inv}}\left(\mathrm{R}\right) \tag{47}$$

where superscript FIT denotes the FIT policy. On the other hand, for the incumbent, merging operation and investment stage problems (equations (5) and (12), respectively) yields:

$$\pi_{\mathrm{I}}^{\mathrm{win,FIT}} = \mathrm{q}'\pi_{\mathrm{I}}^{\mathrm{U*}} + \mathrm{q}(\mathrm{P^{A,FIT*}} - \mathrm{c^{mrg}})\mathrm{Q_I^{cnv,A,FIT*}} - \mathrm{C_{inv}}\left(R\right) \quad when\ \mathrm{K}_{\mathrm{I}}^{res,FIT} = \mathrm{R},\ \mathrm{K}_{\mathrm{N}}^{res,FIT} = 0$$

$$\pi_{\mathrm{I}}^{\mathrm{lose,FIT}} = \mathrm{q}'\pi_{\mathrm{I}}^{\mathrm{U*}} + \mathrm{q}(\mathrm{P^{A,FIT*}} - \mathrm{c^{mrg}})\mathrm{Q_I^{cnv,A,FIT*}} \quad when\ \mathrm{K}_{\mathrm{I}}^{res,FIT} = 0,\ \mathrm{K}_{\mathrm{N}}^{res,FIT} = \mathrm{R} \tag{48}$$

where $P^{A,FIT*}$ and $Q_I^{cnv,A,FIT*}$ should be substituted from (28) and (29), respectively, at the given $K_I^{res,FIT}$ and $K_N^{res,FIT}$ values. Therefore, given that π_I^{U*} is independent of renewables and $P^{A,FIT*}$ and $Q_I^{cnv,A,FIT*}$ are independent of the ownerships, substitution of (48) in (45) yields:

$$\mathrm{v_I^{win,FIT}} = -\ \mathrm{C_{inv}}\left(\mathrm{R}\right) \tag{49}$$

Comparing (47) and (49), we show that $v_N^{win,FIT} = v_I^{win,FIT}$, that is, the firms have similar valuation of winning the auction under FIT auction.

Similar procedures for FIP-based auction yields:

$$\pi_{\mathrm{N}}^{\mathrm{win,FIP}} = \mathrm{RP^{A,FIP*}} - \mathrm{C_{inv}}\left(\mathrm{R}\right) \quad when\ \mathrm{K_I^{res,FIP}} = 0,\ \mathrm{K_N^{res,FIP}} = \mathrm{R} \tag{50}$$

$$\pi_{\mathrm{N}}^{\mathrm{lose,FIP}} = 0 \tag{51}$$

$$\pi_{\mathrm{I}}^{\mathrm{win,FIP}} = \mathrm{q}'\pi_{\mathrm{I}}^{\mathrm{U*}} + \mathrm{q}\left(\left(\mathrm{R} + \mathrm{Q_I^{cnv,A,FIP*}}\right)\mathrm{P^{A,FIP*}} - \mathrm{c^{mrg}}\mathrm{Q_I^{cnv,A,FIP*}}\right) - \mathrm{C_{inv}}\left(\mathrm{R}\right) \quad when\ \mathrm{K_I^{res,FIP}} = \mathrm{R},\ \mathrm{K_N^{res,FIP}} = 0 \tag{52}$$

$$\pi_{\mathrm{I}}^{\mathrm{lose,FIP}} = \mathrm{q}'\pi_{\mathrm{I}}^{\mathrm{U*}} + \mathrm{q}\left(\mathrm{P^{A,FIP*}}\mathrm{Q_I^{cnv,A,FIP*}} - \mathrm{c^{mrg}}\mathrm{Q_I^{cnv,A,FIP*}}\right) \quad when\ \mathrm{K_I^{res,FIP}} = 0,\ \mathrm{K_N^{res,FIP}} = \mathrm{R} \tag{53}$$

Substituting $P^{A,FIP*}$ and $Q_I^{cnv,A,FIP*}$ from (23) and (24) in (45) gives:

$$\mathrm{v_N^{win,FIP}} = \mathrm{q}\left(\frac{\mathrm{R}}{2}\left(\mathrm{a} + \mathrm{c^{mrg}} - \mathrm{bR}\right)\right) - \mathrm{C_{inv}}\left(\mathrm{R}\right) \tag{54}$$

18. We define π_i^{win} and π_i^{lose} to include only the market-based income of the renewables, given that potential auction-based incomes of the firms (b_iR) are already considered in $\Delta \mathrm{u_i}$ (44).

$$v_I^{win,FIP} = q\left(\frac{R}{2}\left(a + c^{mrg} - \frac{bR}{2}\right)\right) - C_{inv}(R) \quad (55)$$

Comparing (54) and (55) shows that $v_I^{win,FIP} > v_N^{win,FIP}$, that is, the incumbent has higher valuation of winning the auction under FIP auction. ■

APPENDIX B: ILLUSTRATIVE NUMERICAL EXAMPLE

To showcase the impacts of strategic behavior on electricity markets, we provide an illustrative numerical simulation that is calibrated based on the characteristics of the European power sector. We construct the inverse demand function by assuming a long-term demand elasticity of -0.513 (Labandeira, Labeaga, and López-Otero, 2017), at the reference average hourly electricity consumption of 331 GWh (Eurostat, 2020b) and price (excluding taxes and levies) of 80 $€/MWh$ (Eurostat, 2020a) in 2018 for the EU28 countries. As a result, we obtain $a = 235.94$ and $b = 4.7*10^{-4}$ for the inverse demand function. We choose onshore wind as the RES technology present in the numerical simulation given that onshore wind is the largest source for RES generation in the EU. Based on a weighted average availability factor of 0.356 for onshore wind (IRENA, 2019), we obtain $q = 93557$ hours for the whole operational lifetime of 30 years. Using a similar approach to Coulomb et al. (2019), we calibrate the RES investment cost coefficient so that at the actual investment of 9 GW of onshore wind in 2018 in Europe (Wind Europe, 2019) the investment cost C_{inv} is equal to 1650 Euros/KW that is the weighted average investment cost for onshore wind projects in Europe (IRENA, 2018). Accordingly, we obtain $c^{res} = 184$. Finally, the marginal cost of the conventional technology is $c^{mrg} = 40$ $€/MWh$.

Part a) of Figure A.1 compares investments of the incumbent and newcomer under imperfect competition at various renewable targets under FIT and FIP policies. As discussed in Proposition 1, under imperfect competitive FIT and FIP, incumbent's investments (marked with squares) are less than those of the newcomer (marked with circles). For instance, at a target of around 140 GW under FIT, incumbent's investment is only a third of that of the newcomer. At the same target of 140 GW, in line with Proposition 3, the incumbent carries out more RES investments under FIP compared to FIT, i.e., around half as much as the newcomer's RES investment. Part a) of Figure A.1 also shows that as the share of the RES increases in the market, the gap between incumbent's and newcomer's investments decreases. This is, as discussed in section 4.2, a result of the higher investment incentive of the incumbent at lower conventional production observed at higher RES targets, which is also illustrated in part b) of Figure A.1. The gap between incumbent and newcomer's share decreases more rapidly in higher RES targets in a FIP regime, since, as discussed in Proposition 3, at similar RES targets, FIP leads to lower conventional generation compared to FIT regime. Parts b) and c) of Figure A.1 shows that FIP leads to lower emissions, but higher market prices compared to a FIT regime (Proposition 3). For instance, at the target goal of 200 GW RES capacities, if the regulator chooses FIP, the conventional generation in the available state will be only around 58 % of that of the equivalent FIT regime (i.e., 63 GWh conventional generation under FIP compared to 108 GWh under FIT) while the market price is 23 % higher (i.e., the market price of 112 $€/MWh$ in FIP regime compared to the price of 91 $€/MWh$ in FIT regime).

Figure A.1: Illustrative numerical comparison of FIT and FIP policies at various renewable capacity targets: a) installed RES capacity by firms, b) conventional generations at the available state, c) prices at the available state.