UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Cricket Valley Energy Center LLC and Empire Generating Center, LLC,	)	
	)	
v.	)	**Docket No. EL21-7-000**
	)	
New York Independent System Operator, Inc.	)	

COMMENTS OF THE INSTITUTE FOR POLICY INTEGRITY AT NEW YORK UNIVERSITY SCHOOL OF LAW

Pursuant to the Federal Energy Regulatory Commission (Commission)'s October 15, 2020 Notice of Complaint and October 23, 2020 Notice of Extension of Time, the Institute for Policy Integrity at NYU School of Law (Policy Integrity) respectfully submits these Comments urging the Commission to reject key arguments in the Complaint filed in the above-captioned proceeding and not to grant the relief requested. Policy Integrity is a non-partisan think tank dedicated to improving the quality of government decisionmaking through advocacy and scholarship in the fields of administrative law, economics, and public policy.[1]

Complainants ask that the Commission, pursuant to section 206 of the Federal Power Act (FPA), extend the scope of the New York Independent System Operator (NYISO)'s Buyer Side Mitigation (BSM) requirements from Zones G-J to all zones in the ISO, cast aside the tests and exceptions NYISO currently employs to implement BSM, and formally transform the policy basis for BSM from mitigating buyer side market power to shoring up the payments that flow

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[1] Policy Integrity's timely motion to intervene in this proceeding, filed by doc-less intervention, was accepted on October 20, 2020. These comments do not reflect the views of NYU School of Law.

through the capacity market to resources that receive no support under state policy.[2] They argue that these changes are needed because state policy "represent[s] a material and immediate threat to the NYISO-administered capacity market."[3] The nature of this threat, according to the Complaint, is capacity market "price suppression," meaning the decrease in the clearing price for capacity owing to some non-market factor or intervention.[4]

For the Commission to act under section 206 of the FPA,[5] the Complainants must persuade the Commission to take two steps: first, to find that NYISO's existing Tariff is unjust, unreasonable, or unduly discriminatory, and, second, to agree with Complainants that the modification or replacement they have put forward is just and reasonable and not unduly discriminatory and preferential.[6] Further, its findings must be supported by substantial evidence.[7] These Comments address both of the steps asked of the Commission, but emphasizes the first—the need to show that existing rates are not just and reasonable or are unduly discriminatory or preferential. Of course, because Complainants fail to demonstrate that NYISO's current rates are unjust, unreasonable or unduly discriminatory, even if the Complainants' proposed replacement

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[2] In some instances, the Complaint refers specifically to policies targeting nuclear generation, in others, to New York's clean energy policies more generally.

[3] Compl. at 15.

[4] *Id*. at 18.

[5] 16 U.S.C. § 824e.

[6] *Emera Maine v. FERC*, 854 F.3d 9, 24-25 (D.C. Cir. 2017).

[7] *Ameren Servs. Co. v. Midwest Indep. Transmission Sys. Operator, Inc.*, 121 FERC ¶ 61,205 at P 32 (2007) ("In a section 206 matter, the party seeking to change the rate, charge or classification has a dual burden—it must first provide substantial evidence that the existing rate is unjust, unreasonable or unduly discriminatory, and then demonstrate through substantial evidence that the new rate is just, reasonable and not unduly discriminatory.").

rate were not itself fatally flawed, the Commission would still be precluded from taking the second step and accepting that proposal.[8]

Our Comments present three main points that show why the Complaint's arguments and evidence fall short of the legal standards required for the Commission to make the findings and grant the relief requested. First, the Complaint misreads the state programs at issue as a source of capacity market distortion rather than as one part of a larger effort to correct the more fundamental distortion in wholesale electricity markets arising from failure to value the climate change externality of emissions from electricity generation. Second, the analysis presented by the Complaint mischaracterizes how externality payments provided by those state programs actually affect capacity market prices, and so grounds its requested remedy on a false premise. More specifically, the Complaint does not demonstrate that state policies cause the alleged market "price suppression." Third, the remedy sought by the Complainants would itself distort the current capacity market price signal, inappropriately boosting it and thereby encouraging the entry of unneeded and thus cost-ineffective capacity. These points leave the Commission no basis to conclude that substantial evidence supports the Complainants' arguments. These points also prevent the Commission from concluding that the Complaint meets the two-part legal standard imposed by FPA section 206, because the Complaint does not identify reasons for finding that the operation of NYISO's capacity market yields unjust or unreasonable rates, nor does it demonstrate why its remedy would result in rates that are just and reasonable.

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[8] *Emera Maine*, 854 F.3d at 24 (observing that "section 206 mandates a two-step procedure that requires FERC to make an explicit finding that the existing rate is unlawful before setting a new rate," and, further, that "[t]he proponent of a rate change under section 206[] bears the burden of proving that the existing rate is unlawful." (internal quotations omitted)); *see also Florida Gas Transmission Co. v. FERC*, 604 F.3d 636, 641 (D.C. Cir. 2010) (prohibiting Commission action based solely on "speculation, conjecture, divination, or anything short of factual findings based on substantial evidence").

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I. NYISO'S CAPACITY MARKET IS NOT RENDERED UNJUST AND UNREASONABLE BY NEW YORK'S CLEAN ENERGY POLICIES

The Complaint misunderstands the role that New York's clean energy policies play in NYISO's markets. As explained below, the state seeks with its programs that provide additional revenue for non-polluting energy generation ("externality payments") to correct significant market failures that FERC and NYISO have not addressed, not to distort the wholesale markets' operation. Chief among those market failures is the climate change externality of greenhouse gas emissions from electricity generation.

A. NYISO's Wholesale Energy and Capacity Markets Are Not Economically Efficient Because They Ignore a Significant Market Failure

Economic theory holds that, under certain well-defined conditions, perfectly competitive markets are economically efficient because they maximize the total net benefits to society.[9] In those markets, prices reflect social marginal costs perfectly and, therefore, provide clear and reliable signals as to the efficient allocation of society's resources. If the Commission's rules could ensure that wholesale markets' design satisfies these conditions, the resulting prices would be economically efficient and would steer the portion of society's resources that flows through the electricity sector to maximize net social welfare.[10] However, when one of those conditions is not met, a market fails to achieve economically efficient outcomes.[11] For instance, if market transactions inflict damage on non-parties to a transaction and the transacting parties do not account for those "external" damages, then markets are not efficient. As the noted economist

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[9] ROBERT S. PINDYCK & DANIEL L. RUBINFELD, MICROECONOMICS 611–13 (7th ed. 2009) (explaining that competitive markets will achieve an efficient allocation of resources).

[10] *Id.* (explaining the conditions necessary for competitive markets to achieve efficiency and the conditions under which competitive markets "fail"); *see also* ANTONIO VILLAR, GENERAL EQUILIBRIUM WITH INCREASING RETURNS 6 (1996) (explaining that price-taking behavior, perfect information, complete markets and quasi-concave payoff functions defined over convex choice sets are required for competitive equilibria to exist and be efficient. Thereby, completeness implies that there are no uninternalized externalities).

[11] *See* SYLWIA BIAŁEK & BURCIN UNEL, CAPACITY MARKETS AND EXTERNALITIES 6 (2018), http://policyintegrity.org/files/publications/Capacity_Markets_and_Externalities_Report.pdf [hereinafter BIAŁEK & UNEL (2018)].

Arthur Pigou recognized in 1920 and many economic textbooks have since explained, in that case, intervention is needed to restore efficiency and increase social welfare.[12]

NYISO's energy markets, as currently designed, give rise to large externalities. The external climate damages caused by CO_2 emissions from just one 650MW combined cycle natural gas-fired facility, like the one operated by Empire Generating, amount to about $51.47 million annually, based on the U.S. Interagency Working Group's (IWG) Social Cost Carbon.[13] Yet such a facility must pay only $5.3 million, or 10% of the damages it causes, for CO_2 emission allowances,[14] leaving most of the CO_2 costs it imposes on the society uninternalized.[15] Emissions of SO_x and NO_x, which wholesale electricity also do not value commensurate with their social costs, add further $1.75 million in social damages.[16] Additional damages from other emissions, such as methane and particulate matter, which are also not fully accounted for in

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[12] *See* A.C. PIGOU, THE ECONOMICS OF WELFARE (1920); *see also* PAUL KRUGMAN & ROBIN WELLS, MICROECONOMICS 437–38 (2d ed. 2009); JONATHAN GRUBER, PUBLIC FINANCE AND PUBLIC POLICY 136 (5th ed. 2016).

[13] Empire generated 2,463,914MWh in 2019 according to EIA-923 data and emitted 976780.1 tons of CO2 emissions according to the Air Markets Program Data (https://ampd.epa.gov/ampd/).The monetary damages of these emissions equal to $51,476,310 in 2020 dollars using the Interagency Working Group's Social Cost of Carbon value of about $52.7 per ton in 2020 dollars. *See* Interagency Working Group on Social Cost of Greenhouse Gases, Technical Support Document: *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*, at 16 (2016).

[14] The average price for a RGGI CO_2 permit in 2019 was $5.425 (https://www.rggi.org/auctions/auction-results/prices-volumes).

[15] Emissions control regulations that result in compliance costs dependent on the generation amount other per-MWh costs also count towards internalization of emissions.

[16] According to the Air Markets Program Data (available at https://ampd.epa.gov/ampd/), Empire emitted 5.44 tons of SO_x and 79 tons of NO_x in 2019. We assume that those emissions were spread evenly across the year and multiply them by the average marginal social costs of those two pollutants when emitted from at Empire's location—$43969.05/ton and $19187.58/ton respectively. We use the marginal social costs from the Estimating Air pollution Social Impact Using Regression model (available at https://barney.ce.cmu.edu/~jinhyok/easiur/) and take the conservative value for emissions occurring 150 meters above the ground (according to EIA 860 data, Empire's stack is only 81 meters high). The reported estimates are in USD 2020.

electricity market transactions, make the true cost of externalities associated with operations of New York's fossil fuel-fired power plants higher still.[17]

When external damages are not fully internalized, polluting resources receive an implicit subsidy,[18] allowing them to make higher profits than they would in an efficient market and causing them to enter and operate above the economically efficient level. This in turn displaces or prevents the entry of clean resources that would—on a level playing field—be cost-effective.

The typically prescribed, "first-best" solution when there are externalities is a corrective tax (also called a "Pigouvian tax") on emitting resources. But when taxation is not feasible, policymakers can address negative externalities by compensating resources that do not produce the externality.[19] More specifically, by compensating resources in an amount that is closely related to the value of avoided emissions, policymakers can ensure that the difference in revenues between clean and polluting resources accounts for external costs to a degree similar to what would result under taxation.[20] As a result, even if the market cannot fully reach the first-best outcome, well-designed externality payments change the generation mix in a way similar to

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[17] *See* JEFFREY SHRADER, BURCIN UNEL & AVI ZEVIN, INST. FOR POL'Y INTEGRITY, VALUING POLLUTION REDUCTIONS: HOW TO MONETIZE GREENHOUSE GAS AND LOCAL AIR POLLUTANT REDUCTIONS FROM DISTRIBUTED ENERGY RESOURCES 19–21 (2018) (describing features of and damage done by local pollutants). Notably, three-quarters of gas-fired facilities are "dual fuel," meaning that they can and sometimes do burn more emissions-intensive petroleum-based fuels instead of natural gas. U.S. Energy Info. Admin., *New York: State Profile and Energy Estimates*, https://www.eia.gov/state/analysis.php?sid=NY#25 (accessed Oct. 28, 2020).

[18] For an explanation of how a lack of pollution pricing constitutes de facto subsidies for polluting units, see Matthew Kotchen, The Producer Incidence of Fossil Fuel Subsidies in the United States, CESifo Area Conference on Energy and Climate Economics (2020), https://www.cesifo.org/de/node/58932.

[19] *Id*. at 7.

[20] *Id.* at 7–8. For example, under the Illinois ZEC program, nuclear resources receive payments based directly on the emission rate of displaced generation and the best estimate of the monetary value of the climate damages avoided by displacing that generation, which is the Social Cost of Carbon. *See* 20 ILL. COMP. STAT. 3855 § 1-75(d-5)(1)(B) (2020).

changes induced by emissions taxes: clean resources clear the auctions more often and receive higher net revenue compared to a no-regulation alternative.[21] Put another way, well-designed externality payments to non-emitting generators cause the market to recognize which generators are more economic from society's perspective. Units that appear uneconomic if externalities are ignored get an incentive to stay in the market, and units that appear economic if externalities are ignored get efficient signals to exit. State policies that pay for avoided emissions thus help to fix a market failure and "level the playing field."

B. New York State's Clean Energy Standard Improves Efficiency of NYISO's Wholesale Energy Market by Helping to Correct a Market Failure

New York's Public Service Commission took the approach described above when designing Tier 3 of its Clean Energy Standard, which assigns Zero Emission Credits (ZECs) to nuclear resources.[22] In New York, a ZEC value reflects in part the cost of carbon, specified as the difference between the IWG SCC value and the coincident Regional Greenhouse Gas Initiative (RGGI) allowance price.[23] New York's examination of the program's benefits and costs, including its avoidance of greenhouse gas emissions and local pollutants, concluded that the net benefits of ZEC payments from 2017 to 2023 would fall between $928 million and $1.08 billion.[24] Importantly, even if they were not explicitly tied to the value of the uninternalized climate externality, these payments would still be welfare-improving so long as they result in outcomes closer to those that

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[21] BIAŁEK & UNEL (2018), *supra* note 11, at 11

[22] Order Adopting a Clean Energy Standard, N.Y. Pub. Serv. Comm'n Case 15-E-0302, at 130 (Aug. 1, 2016).

[23] *See* Amicus Brief of Policy Integrity, In the Matter of Hudson River Sloop Clearwater, Inc., v. N.Y. State Pub. Serv. Comm'n, 119 N.Y.S.3d 390 (N.Y. Sup. Ct. Mar. 28, 2019).

[24] N.Y. DEP'T PUB. SERV., CLEAN ENERGY STANDARD WHITE PAPER – COST STUDY 84 (2016), https://perma.cc/JJM6-9SWQ.

would occur in an efficient market.[25] When the Complaint characterizes resources compensated by New York State policies as "uneconomic,"[26] it relies on a blinkered view of what "economic" means. That view ignores the relevance of the climate change externality to economic efficiency from society's perspective, and, by also ignoring that competitive markets are efficient only in absence of market failures, mischaracterizes the impacts of New York's externality payments on the operation of NYISO's wholesale electricity market.

C. Corrective Externality Payments Do Not Impede Economic Efficiency and Are Compatible with Just and Reasonable Rates

When evaluating whether New York's policies lead to unjust and unreasonable rates, or whether a countermeasure is necessary to establish a just and reasonable replacement rate, the Commission should recognize that the fundamental purpose of organized energy and capacity markets is to provide efficient signals for the entry, operation, and exit of resources—as doing so is understood to give rise to just and reasonable rates.[27] And it should further recognize that externality payments that correct for a market failure are consistent with that purpose, in contrast to subsidies that are granted as a result of manipulation of the social or political environment based on the personal preferences of decisionmakers for certain products, services, or

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[25] Sylwia Białek & Burcin Unel, *Efficiency in Wholesale Electricity Markets: On the Role of Externalities and Subsidies* 15 (Working Paper, 2020), https://policyintegrity.org/documents/Bialek_Unel_11.15.2020.pdf. [hereinafter Białek & Unel (2020)]. This working paper is attached to these comments as Exhibit 1.

[26] Compl. at, *e.g.*, 20–21, 24, 27.

[27] Order 2222, 172 FERC ¶ 61,247, P 18 (2020) (". . . effective wholesale competition encourages entry and exit and promotes innovation, incents the efficient operation of resources, and allocates risk appropriately between consumers and producers."); Calpine Corp. v. PJM Interconnection, LLC, 169 FERC ¶ 61,239, P 22 (Dec. 19, 2019) (noting capacity market prices are meant "to serve as signals for the efficient entry and exit of resources"); *see also* FPA § 202(a) (charging the Commission to establish regional districts for the purpose of "assuring an abundant supply of electricity with the greatest possible economy and with regard to the proper utilization and conservation of natural resources").

technologies.[28] As such, NYISO's wholesale market rates are not made unjust and unreasonable by New York's clean energy policies, and mitigating payments made pursuant to those policies—payments that correct for externalities—would risk undoing the efficiency-enhancing signals that those payments send.

II. THE COMPLAINT DOES NOT SHOW THAT STATE POLICIES "THREATEN" NYISO'S CAPACITY MARKET

The Complaint argues that NYISO's BSM rules are unjust and unreasonable because they allow payments to clean energy resources to "suppress" capacity prices, but it does not demonstrate how, and ultimately asks the Commission to base a sweeping and disruptive order on loose inference instead of hard evidence. Close examination of the Complaint's argument reveals that the Commission cannot lawfully order NYISO to amend its tariff because the Complaint does not present substantial evidence that price suppression is actually occurring. Not only is evidence of capacity market price suppression absent from the Complaint, our own analysis of mechanisms underlying electricity markets identifies affirmative evidence that the effects of state policies play out in *energy* markets rather than putting downward pressure on capacity prices. This new analysis provides the Commission with a compelling basis to take another, more critical look at the arguments that Dr. Shanker first presented in relation to PJM's capacity market and now presents here.[29]

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[28] BIAŁEK & UNEL (2018), *supra* note 11, at 7.

[29] *See* Compl., Exh. JRS-2 (Affidavit of Dr. Shanker in Calpine Corp. v. PJM Interconnection, Inc., Docket No. EL16-49-000 et al.).

A. The Complaint Does Not Show that State Policies Cause "Price Suppression"

The Complaint relies on a series of assumptions and implications to arrive at its conclusions. The most basic of these is the assumption that NYISO wholesale markets would, in the absence of state policy, be efficient. As explained above, NYISO's current treatment of greenhouse gas emissions ensures that NYISO's markets are *not* efficient when considered from a social welfare perspective. Assuming otherwise leads the Complainants to make a further unsubstantiated and incorrect assumption, namely that where state policy causes a material change in capacity market prices, the capacity market is not operating efficiently and is imposing rates that are unjust, unreasonable, or unduly discriminatory or preferential.

The Complaint and its supporting affidavit also rely on assumptions and implications, and not substantial evidence, in their characterization of a causal relationship between state policy support payments and a decrease in capacity market prices. More specifically, the Shanker Affidavit relies on two lines of argument, one irrelevant, the other dependent on inappropriate analytical and logical leaps. The irrelevant argument refers to the reasoning in the Commission's "clean MOPR" order for PJM Interconnection (PJM) and compares the proportion of peak load supplied by state-supported nuclear resources in PJM to the proportion in NYISO. The affidavit calls this proportion the "'intensity' of the ZEC program" and invites the reader to infer that, if the lower level of "intensity" in PJM warranted Commission intervention, it stands to reason that the higher level in NYISO does as well.[30] But this "intensity" signifies nothing concrete about how ZEC programs actually bear upon capacity market prices in NYISO. In this way, the affidavit *implies* a causal relationship, but it does not actually describe one, leaving it to the

[30] Shanker Affidavit at PP 40–43.

reader to infer the mechanism or mechanisms through which causation might occur. The Shanker Affidavit makes the same point again, but differently (it calls it a "final check on materiality") by enumerating the Going Forward Costs of state-supported nuclear units in PJM and stating that "subsidies are retaining units that otherwise would incur significant losses . . . ."[31] Here again, the affidavit tells us nothing about whether and how ZEC program payments cause price suppression in NYISO, only that externality payments are being paid to units that might not meet their costs with wholesale market revenues alone. The Commission has rejected such arguments elsewhere.[32]

The Shanker Affidavit's other line of argument expressly construes a causal relationship between ZEC program payments and capacity market prices, but in a way that depends on what the affidavit calls "a major assumption."[33] This line of argument begins by comparing the volume of ZEC program payments to NYISO capacity market payments made to upstate resources.[34] Having estimated these amounts, Shanker then suggests that they can be used to identify how far along the demand curve the capacity market would shift if no ZEC program payments were made. Crucially, however, this step assumes "all other things held equal," which is to say it assumes that eliminating ZEC program payments would not result in changes to capacity market offers for the units that do not receive the payments from the state. It also

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[31] *Id.* at P 45.

[32] *See CXA La Paloma v. Cal. Indep. Sys. Operator Corp.*, 169 FERC ¶ 61,045 at PP 12–13 (2019) ("Even when considered together, these exhibits show, at most, market trends such as the increased penetration of renewable resources and low prices in the energy market, all of which create new economic pressure for conventional resources, but do not necessarily demonstrate an unjust and unreasonable resource adequacy paradigm.").

[33] Shanker Affidavit at P 44.

[34] *Id.* at P 42.

assumes that the nuclear offers with and without ZEC payments would differ exactly by the amount of the externality payments. These assumptions are an extension of the affidavit's mistaken treatment of state programs as compensating capacity (rather than energy) and are incorrect. In particular, Shanker transforms the yearly ZEC payments into per-kW payments and discusses them as if ZECs were payments for capacity,[35] even though New York's programs operate as payments for *energy*, which have different economic consequences (described more fully in Part II.B, below), as well as different welfare properties, compared to payments for capacity, even if their total amount is the same.[36] These assumptions and analytical transformations do not establish reasoned links—they represent inappropriate logical leaps that cannot serve as the basis for characterizing how externality payments for energy affect capacity prices.

To be fair, the Shanker Affidavit acknowledges that eliminating ZEC program payments would have "price impacts" that "spur increased exports and cause otherwise uneconomic units to re-enter the market, which would moderate the price increases."[37] But vague caveats are all the affidavit offers before concluding—in reliance on its "major assumption"—that "it is clear that the net impact would be material."[38] In short, the affidavit's assertions and assumptions do not show that state-directed externality payments for energy from clean resources are actually suppressing capacity market prices.

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[35] *Id.* at PP 41–45.

[36] *See, e.g.*, Özge Özdemir, et al., *Capacity vs Energy Subsidies for Promoting Renewable Investment: Benefits and Costs for the EU Power Market*. 137 ENERGY POL'Y 111166 (2020) (discussing differences in impacts between capacity and energy market subsidies).

[37] Shanker Affidavit at P 44.

[38] *Id.*

B. State Policies' Effects Are Generally Unlikely to Result in the "Suppression" of Capacity Prices

Policy Integrity's analysis of interactions between state policy interventions, wholesale energy markets, and capacity markets, attached as Exhibit 1, finds that, in the long-term, capacity prices will tend to be unaffected by state policy support for non-emitting resources.[39] It finds also that, in the short- to medium-term, state policies may even increase capacity prices. In contrast to Complainants' reliance on assumptions and implication, this analysis constitutes clear, affirmative evidence *against* the claim New York's clean energy policies suppress capacity market prices. As explained below, the crucial insight Policy Integrity brings to this issue is that energy markets play a mediating role that equilibrates between state policy and capacity prices. Dr. Shanker's affidavit offers no countervailing evidence to this point. Given that the Complaint does not provide hard evidence of price suppression, the Commission may not accept this premise without first finding such evidence elsewhere; and, as explained below, should the Commission look to economic theory,[40] it will not find support for the Complaint's arguments.

Notably, Dr. Shanker's affidavit observes that he made a similar argument in relation to PJM's capacity market;[41] others did the same in ISO-New England.[42] But those arguments, like the one presented in the Complaint, also did not present substantial evidence of their assertions

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[39] *See* Białek & Unel (2020, *supra* note 25.

[40] *See* S.C. Pub. Serv. Auth. v. FERC, 762 F.3d 41, 65 (D.C. Cir. 2014) (holding that substantial evidence can include "reasonable economic propositions").

[41] Compl., Exh. JRS-2.

[42] *See* ISO New England, Inc., 162 FERC ¶ 61,205, P 109 (Mar. 9, 2018) ("Among the principles CPV Towantic offers is that energy markets must also be protected from price suppression arising from the entry of state-supported resources.").

that state policy causes capacity market price suppression.[43] Moreover, those arguments did not have the benefit of access to the analysis presented in Exhibit 1, which the Commission has not yet considered and which represents grounds for rejecting the argument in the Complaint—even if it is similar to arguments that the Commission previously found persuasive.

As mentioned in Part II.A, above, the Complaint presents an intuitively appealing but simplistic rationale—and one that is incorrect because it ignores the significant role the energy market plays. Externality payments for non-polluting resources, according to the Complaint, increase the revenue those resources receive, allowing them to offer their capacity at a lower price into the capacity market. This, in turn, shifts the capacity supply curve down, lowering or "suppressing" the market clearing price.[44] But this logic completely ignores the effects of externality payments on prices in energy markets as well as on the behavior of generators that do not receive them, and, as a consequence, leads to false conclusions.

To predict how per-MWh clean energy externality payments affect wholesale capacity markets, one must first analyze the effects of payments on energy markets and understand how energy and capacity markets interact. To begin, note that while equilibrium energy market revenue could cover capital, operations, and maintenance costs in theory, design features of actual electricity markets, such as caps on energy prices or pure short-run marginal cost pricing, cause a "missing money" problem.[45] Capacity markets are meant to enable generators to recover

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[43] *See* Comments of Policy Integrity, Calpine Corp. v. PJM Interconnection, LLC, 169 FERC ¶ 61,239 (Oct. 27, 2019).

[44] To be clear, that prices are lower in this or other cases does not necessarily signify that they have been suppressed or that they are less efficient.

[45] NYISO maintains an offer cap of $2,000 and the maximum energy price that can be reached given that offer cap follows from of NYISO's shortage pricing rules. For a detailed explanation of the relationship between missing money and capacity markets, see Paul L. Joskow *Challenges for Wholesale Electricity Markets with Intermittent*

that missing money, and, as economists have shown repeatedly, a generator's price offer in a capacity market is related to that generator's revenue shortfall during periods of peak demand in energy markets.[46] In other words, what determines a generator's capacity market offer is the difference, during a peak demand period, between the energy price in an idealized energy market and the actual realization of the energy price.[47]

The externality payments targeted by the Complaint supplement payments for energy generation: pollution-free generators receive them for each MWh of energy they produce. As such, those payments lower the generator's perceived marginal cost of generation and incentivize a lower offer price in the *energy* market. This lower offer is the first-order effect of a payment for clean energy generation.

These lower, policy-driven offers cause energy prices to decrease in the short-term whenever resources receiving externality payments are on the margin. In the medium-term, new entry in the class of technology eligible for externality payments will affect energy prices. [48] When the resources receiving externality payments have low marginal costs, as is the case in New York, most energy prices will be affected because new entrants shift the whole energy

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Renewable Generation at Scale: the US Experience, 35 OXFORD REV. ECON. POL'Y 303 (2019). This description ignores other types of revenues, such as ancillary services revenues and uplift payments, because they tend to be very small in relation to energy/capacity revenue.

[46] Paul Joskow & Jean Tirole, *Reliability and Competitive Electricity Markets,* 38 RAND J. ECON. 60 (2007); *see also* Peter Cramton, Axel Ockenfels & Steven Stoft, *Capacity Markets Fundamentals*, 2 ECON. ENERGY & ENV'T POL'Y 27, 30, 35 (2013), Paul L. Joskow*, Capacity Payments in Imperfect Electricity Markets: Need and Design*, 16 UTILITIES POL'Y 159 (2008).

[47] "Idealized market" refers here to an energy-only market with scarcity pricing. For an explanation of equilibrium capacity prices see generally Joskow & Tirole, *supra* note 46.

[48] The externality payments will tend to attract new entrants in the class of technology eligible to receive them because in the near-term after the introduction of the payments, the resources receiving them make higher profits in the periods when they are inframarginal.

supply curve to the right, decreasing energy prices during low and high demand periods alike. That decrease in energy prices will, in turn, lower energy market revenue for all other units. Given that competitive capacity market offers reflect the capital and O&M costs not recovered through energy market revenue, in the medium-term, resources not receiving externality payments submit *higher* offers into capacity markets.[49] For resources receiving externality payments, this eventual decrease in energy prices reduces whatever extra profits they were making due to those payments.

When many units, especially units that are on the margin in the capacity market, increase their capacity price offers, capacity prices rise, even if some (non-marginal) resources submit lower offers.[50] The Affidavit completely ignores the changes in offers made by resources not receiving externality payments that are induced by externality payments and suggests only that resources receiving externality payments will change their offers as a result of those payments. Unsurprisingly, it then reaches the conclusion that such payments will cause capacity prices to fall, even though it is the units that do not receive such payments that will tend to be marginal and so price-setting in the capacity market.

The Shanker Affidavit also ignores long-term effects, which, as shown in Exhibit 1, will tend to leave capacity prices unaffected by externality payments if they go to non-peaking resources.[51] This effect is a result of the equilibrating entry and exit of resources as a response to market prices. New resources that are eligible for externality payments, for instance those receiving RECs, will continue to be built as long as investments in those resources are expected

[49] For a more formalized description of this logical chain, see Białek & Unel (2020), *supra* note 25, at 17–18, 21–22.
[50] For a description of the mid-term capacity price effects, see Białek & Unel (2020), *supra* note 25, at 22.
[51] Białek & Unel (2020), *supra*, note 25, at 20.

to be profitable. And that ongoing development will continue to affect energy market prices. At the same time, some resources that do not receive such payments will fail to clear capacity markets (with new entry, more capacity is available but demand for capacity is unchanged), which, combined with lower energy revenues, will push those resources towards retirement. Such entry and retirement will continue until the electricity markets return to equilibrium, such that no generation types experience excess returns or losses.

As explained above, equilibrium capacity prices are a function of energy prices during peak demand periods. More specifically, they depend on the difference between realized prices in price-capped energy markets and the prices that would be reached in an idealized energy market without price caps. (The latter prices reflect the amount of energy market revenue necessary for peak generators to break even without supplemental revenue from a capacity market.) Consequently, externality payments can cause long-term capacity prices to fall only when given to peaking units, and thereby reducing the peak energy price.[52] This does not tend to occur in New York State, where such payments flow to low-merit resources, like wind, solar, and nuclear generators. In other words, economic reasoning that takes the interaction between energy and capacity markets into account does not support the premise that changes to generation prices from per-MWh payments cause price declines (let alone "suppression") in the *capacity* markets. Contrary to the argument presented in the Complaint,[53] merely showing that externality payments somehow affect the resource mix is not enough to demonstrate that a wholesale market tariff is unjust and unreasonable. The total revenue of a given resource may

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[52] *Id*.

[53] Compl. at 22–23.

decrease due to changes in energy markets and the potential ability of a resource to clear the capacity market may change as well, but just and reasonable market design does not require that all resources get to recover their costs.[54] Therefore, the record cannot justify a finding that NYISO's existing rules are unjust and unreasonable.

III. COMPLAINANTS' REMEDY WOULD *DISTORT* CAPACITY MARKET PRICES AND THUS WOULD NOT BE JUST AND REASONABLE

If the Commission fails to show that the existing rates are unjust and unreasonable, it may not adopt a replacement rate. By acting to "correct" a problem that has not been shown to exist, the Commission would make itself the cause—rather than the remedy—of distortion of capacity market price signals. Furthermore, even if the Complainants were correct about clean energy program payments' effects on capacity market prices, the approach they propose for setting a remedial price floor is flawed. Thus, even if the second step of section 206 were relevant in this case, Complainants "Clean MOPR" proposal would still be unacceptable because it would not result in a just and reasonable replacement rate.

A. Complainants' "Clean MOPR" Would Lead to an Inefficient Generation Mix and Be Costly to Ratepayers

Contrary to the claims in the complaint, implementing a Clean MOPR would distort the capacity market's investment signal by decoupling the prices paid in the market from the amount of capacity available and thus suggesting a greater need for capacity than actually exists.

[54] *See CXA La Paloma, LLC v. Cal. Indep. Sys. Operator Corp.*, 165 FERC ¶ 61,148 at P 71 (2018) ("The Commission has been clear that suppliers in competitive wholesale electricity markets are not guaranteed full cost recovery, but only the opportunity to recover their costs. Thus, even if CXA La Paloma is experiencing financial hardship, it has not demonstrated that the existing resource adequacy construct in California systematically denies it or other resources a meaningful opportunity to recover their costs.")

Normally, the role of a capacity market price is to provide signals for efficient investment. If the market functions well, a high capacity price would signal a need for capacity and drive entry, and a low price would signal excess capacity and drive exit. Thus, low prices are as crucial to efficient investment decisions as high prices. Even if one accepts the Complainants' rationale for imposing a Clean MOPR as correct—and we show above that it is not—imposing an offer floor would push capacity market prices artificially high, as if additional capacity were needed, even though the total available capacity, including clean energy resources, were actually sufficient. At the same time, from the social perspective, the cost of maintaining or building the units that are unnecessary for providing electricity or reliability represents a pure welfare loss. Consistent with this point, the Commission has recognized that excess capacity is undesirable and to be avoided.[55]

The degree to which capacity market prices are decoupled from available capacity quantities will depend on the share of resources receiving externality payments that are subject to mitigation (i.e. not exempted) and on the level of the offer floors imposed: a larger share of mitigated resources and higher offer floors would exacerbate the problem. Considering several stylized scenarios helps to clarify this point.

First, assume that, in an extreme scenario, the offer floors are set so high for both new and existing resources that those floors exceed the annualized cost of building and maintaining

[55] *PJM Interconnection, L.L.C.*, 147 FERC ¶ 61,108, at P 68 (2014) ("PJM's proposed OATT and RAA revisions have *significant undesirable effects* such as increasing the risk for capacity market sellers, creating undue barriers to entry, limiting opportunity for beneficial trade, and unnecessarily raising the cost of capacity through the *acquisition of excess capacity*.") (emphasis added).

capacity of peak generators. In that case, the existing 26GW fleet of fossil-fueled resources[56] would either never retire or be replaced by new emitting generation capacity despite the fact that in the future, for instance in 2030, when New York requires 70% of generation to come from renewable resources,[57] most fossil-fueled generators would never clear the energy market.[58] What is more, the total amount of emitting generation capacity would increase in this "Clean MOPR" scenario, because the nuclear and renewable capacity that have been clearing the capacity market in the past would no longer clear the auctions. As a result, new gas capacity would be overbuilt; specifically, total capacity would come to equal the amount of capacity clearing the capacity market plus the clean capacity needed to meet the state's goals. The excess capacity would also put additional downward pressure on energy prices.

If calculated offer floors turn out to be below the annualized cost of building and maintaining capacity for peak generators but above the cost of maintaining resources ineligible for externality payments, the aggregate capacity would still be inefficiently high because the Clean MOPR would prevent some of those resources from retiring. However, the inefficient entry from new, resources ineligible for externality payments would be lower than in the extreme scenario described above.

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[56] *See* NYISO 2020 LOAD AND CAPACITY DATA: GOLD BOOK, at 92 tbl. III-3a (2020) ("Existing Summer Capability by Zone and Type").

[57] N.Y. Climate Leadership & Community Protection Act § 4, *codified in relevant part at* N.Y. Pub. Serv. L. § 66-p(2). State law further requires that 100% of electricity be clean by 2040. *Id.*

[58] Given that wholesale capacity markets are only FERC-jurisdictional insofar as they constitute a "rule or practice affecting" rates, should a capacity market only administer resources that are unable to participate in the energy market, that capacity market would not "affect" rates and so would no longer be FERC-jurisdictional.

A scenario involving even lower offer bids would mitigate the inefficiencies related to overcapacity. If all offer floors were set below future capacity clearing prices,[59] the overbuilding of capacity would be avoided. However, such a situation would also imply that the Complainants are misguided in their claim that the resources receiving externality payments are not competitive without those payments, even according to their flawed definition of competitiveness.[60]

The above discussion of different scenarios suggests that the measure proposed in the Complaint will tend to either lead to a socially inefficient excess capacity or be unnecessary by the Complaint's own logic. And to the extent that state-determined externality payments are corrective—meaning that they correct inefficiencies related to externalities and do not merely confer rents—the inefficiencies associated with capacity overbuilding will be in addition to welfare losses that would result from undoing the corrective effects of externality payments.

B. Complainants' Proposed Remedy Is Logically Inconsistent with Their Other Arguments and Is Not Just and Reasonable

The Commission should not accept the Complainants' proposed solution because it is inconsistent even with the reasoning the Complainants themselves put forward. They suggest that the Commission set the minimum offer floors for resources receiving externality payments

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[59] Such an outcome is purported to occur in PJM, at least in the short term, as the statements by the market operator and the Market Monitor indicate. For instance, Joseph Bowring, PJM's Market Monitor, stated that there has been no demonstration that the expanded MOPR will raise capacity prices, and that he disagrees with the assumption that renewable resources aren't competitive in the market. *See* Michael Yoder, *NJ BPU Conference Addresses FRR, Alternatives*, RTO INSIDER, Sept. 22, 2020, https://rtoinsider.com/njbpu-conference-addresses-frr-alternatives-173928/.

[60] As we explain above, the logic of the complaint fails to account for the avoided pollution value of resources and thus mischaracterizes the effects of externality payments on wholesale electricity markets.

by using calculations that, in essence, estimate what capacity price those resources would require in order to break even given only the expected energy and ancillary services revenue (and not the externality payments).[61] But the minimum offers Complainants propose would not represent what would actually occur in the absence of externality payments, i.e. they would not equal the "unit specific costs without subsidization" that the Complainants claim should always be a "reasonable mitigation level".[62] This discrepancy is again due to the Complainants disregarding the equilibrating effects that happen in energy markets in response to the externality payments.

A critical feature of this reasoning is the fact that state-directed externality payments decrease energy prices,[63] resulting in a decrease of energy market revenues for the resources receiving payments. If the goal of a Clean MOPR is to emulate the same outcomes that would happen without those payments, then replacement offer floors would need to account for the *counterfactual* energy prices that would result in the absence of those payments, and not *observed* energy prices. In other words, given that the energy market prices adjust to externality payments immediately, checking whether a resource is economic or not—according to the Complainants' definition of competitiveness—cannot rely on observed energy prices. Those prices are already affected by externality payments. If one calculates profits of a unit receiving such payments using the observed energy market revenue but excluding the payments, it will generally appear as if the unit receiving payments is making losses.

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[61] The Complainants suggest using exact same calculations as prescribed in PJM's MOPR process. For details of calculations of the bids in PJM, see Compliance Filing Concerning the Minimum Offer Price Rule, Request for Waiver of RPM Auction Deadlines, and Request for an Extended Comment Period of at Least 35 Days, Docket No. EL16-49, at 51–72 (Mar. 18, 2020).

[62] Shanker Affidavit at P 32.

[63] For an explanation of that effect, see Part II.B.

If the Commission somehow finds that the existing rates are unjust and unreasonable—and, to be clear, it should not—and decides to implement the Complainants' proposal—which, again, it should not do—then it should direct NYISO to construe counterfactual energy prices that would have prevailed absent externality payments, and use those counterfactual prices in computing the replacement offer floors.

CONCLUSION

For the reasons explained above, the Commission should deny the Complaint.

Respectfully submitted,

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Dated: November 18, 2020

CERTIFICATE OF SERVICE

In accordance with Rule 2010 of the Commission's Rules of Practice and Procedure, I hereby certify that I have this day served by electronic mail a copy of the foregoing document upon each person designated on the official service list compiled by the Secretary in this proceeding.

Dated at New York, New York this 18th day of November 2020.

Respectfully Submitted,

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Exhibit 1

Comments of the Institute for Policy Integrity
at New York University School of Law

Docket No. EL21-7-000

Efficiency in Wholesale Electricity Markets: On the Role of Externalities and Subsidies

Sylwia Bialek, Burcin Unel*
November 2020

Abstract

We evaluate the effects of homogeneous subsidies granted for emission-free electricity generation on market outcomes and social welfare. We use an analytical model to assess the conditions under which such subsidies increase efficiency of wholesale energy and capacity markets. While the subsidies, even when combined with energy consumption taxes, cannot achieve first-best outcomes when there are resources with heterogeneous emission intensities, there exists a range of subsidy rates that are welfare-enhancing when greenhouse gas externalities are taken into account. We also derive the conditions under which generation subsidies do not affect the equilibrium price in capacity markets. Finally, we evaluate the capacity market reforms that are being undertaken in the U.S. in response to these kinds of subsidies.

Keywords: capacity markets; renewables; subsidies; electricity markets; welfare.
JEL classification: H21; H23; Q28; Q41; Q58.
Competing interests: none.

1 Introduction

As the electricity sector is one of the leading sources of greenhouse gases, numerous national and sub-national governments are setting ambitious goals for reducing the sector's emissions. To achieve these goals, policymakers often rely on per-MWh subsidies for pollution-free electricity generation, such as: clean energy mandates, technology-specific

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payments, and production tax credits. International Energy Agency identified 441 active national and sub-national policies offering feed-in-tariffs, subsidies, tax relief or green certificates for renewable sources (IEA, 2019). The lack of social and political acceptance for the first-best approach of Pigouvian taxes[1] suggests that these subsidies will only increase in magnitude and scope unless the technological progress behind low-carbon resources accelerates significantly.

In the U.S., the increasing prevalence and magnitude of generation subsidies[2] raised worries about their effect on capacity markets, which complement wholesale energy markets in some regions to ensure adequate energy supply. In particular, a concern arose that subsidies could harm market efficiency by suppressing capacity prices below their competitive levels. The concern triggered controversial capacity market reforms that intended to mitigate the impacts of subsidies within three U.S. electricity trading regions: PJM, New York-ISO (NYISO) and ISO-New England (ISO-NE).[3] As the regions that experienced reforms constitute a significant part of the U.S. electricity system,[4] grid decarbonization efforts could be largely obstructed if the reforms reach their stated goal of "mitigating" the effects of subsidies for clean generation.

Given the prevalence of generation subsidies and the policy concerns around them, it is crucial to understand the consequences of subsidizing pollution-free electricity generation. Such consequences will generally depend not only on the design of the subsidy scheme [Fell and Linn (2013), Abrell et al. (2019)] but also on the organization of the electricity systems. The mechanisms through which subsidies affect final outcomes are different in settings with vertically integrated utilities than in systems with wholesale electricity markets. And within the electricity markets, it is conceivable that the impact channels depend on the market design, for instance on whether the market is operated as energy-

[1] In France, in December 2018, "yellow vests" protests were sparked by a planned fuel tax. In the U.S., many failed attempts were undertaken to introduce carbon tax, among others in Washington state, Washington, D.C., and in Congress with The Energy Innovation and Carbon Dividend Act of 2019. Furthermore, even in existing cap-and-trade systems – like the EU Emission Trading Scheme, RGGI, and the California cap-and-trade scheme – CO_2 permit prices are far below the marginal cost of social damages implying a limited internalization of pollution externalities. The global average carbon price is shown to be only $2 a ton (IMF, 2019).

[2] As of 2020, twenty-nine states have a Renewable Portfolio Standard. New York and Illinois pay some of their nuclear generators Zero-Emission Credits, while five further states are considering similar payments. Moreover, the federal Renewable Electricity Production Tax Credit provides another per-MWh subsidy to renewable generators.

[3] For the reform descriptions, see the discussion in Section 5 as well as the Orders 162 FERC ¶ 61,205 (2018), 169 FERC ¶ 61,239 (2019) and 172 FERC ¶ 61,058 (2020) issued by Federal Energy Regulatory Commission.

[4] In total, the three trading regions serve a third of all American electricity customers and host one fourth of the total 1,100 GW of generation capacity installed.

only or energy-plus-capacity market. And while cost-effectiveness of subsidies has been studied intensively in the context of production of goods [Jung et al. (1996), Acemoglu et al. (2012)], the interaction of generation subsidies with the design of wholesale electricity markets is still little understood.

Our main goal in this paper is to assess whether, and under what conditions, generation subsidies can lead to an increase in the economic efficiency of wholesale electricity markets. We consider only subsidies for generators that produce electricity pollution-free because of relevance of such subsidies for policy discussions and the problem of uninternalized externalities in electricity markets.[5] Given the recent reforms, we are particularly interested in settings with capacity markets. To answer these questions, we derive an analytical, partial-equilibrium model of wholesale energy and capacity markets building on the seminal study by Joskow and Tirole (2007). We determine the effect that generation subsidies have on the equilibrium prices and generation mix. We then compare the welfare outcomes under generation subsidies to two benchmarks: the status quo, where there is no tax on greenhouse gas emissions; and the "first-best" case, where there is a Pigouvian tax on externalities.

Despite the policy relevance, economic research on the impact of generation subsidies on the efficiency of wholesale electricity markets has been scarce. Most studies on the issue consider only private generation costs [Briggs and Kleit (2013), Brown (2018a), Brown (2018b), Blumsack et al. (2018), Llobet and Padilla (2018)], even though assuming away externalities leaves no room for the subsidies to be welfare enhancing. Other studies sidestep the question of efficiency, concentrating on the individual effects of the subsidies [Bento et al. (2018), Haan and Simmler (2018), Abrell, Kosch, and Rausch (2019)]. Yet others look at the costs and benefits of the subsidy policies by simulating their results in a complex electricity market model, often using energy-only models [Palmer et al. (2011), Fell and Linn (2013), Reguant (2019), Abrell, Rausch, and Streitberger (2019)]. While such studies give us a good grasp on the net effects of a particular policy, they typically cannot provide information about the underlying mechanisms and, therefore, do not easily lend themselves to generalization of the results.[6] Finally, some analyses are conducted from the perspective of a social planner, abstracting away from wholesale electricity markets [Antoniou and Strausz (2017), Eichner and Runkel (2014)] even though

[5]Subsidies that are not a response to a market failure will by definition be distortive.

[6]The exception is Fell and Linn (2013) who use a simple investment model that cleanly delineates the intuition behind intermittency and cost-effectiveness of different subsidy policies. However, the model does not account for many basic features of energy markets and abstracts from the existence of capacity markets.

the wholesale market design can render some allocations infeasible.

Abstracting away from the design of wholesale electricity markets, such as the existence of capacity markets, limits the researchers' ability to account for the interaction between the energy and capacity markets, and thus hinder their ability to evaluate long run equilibrium outcomes in these markets. In regions like PJM, capacity markets are an important source of revenue for generators with total annual capacity payments corresponding to around one third of energy payments.[7]

Our first contribution in this paper is to fill this gap in understanding the interaction between generation subsidies and wholesale energy and capacity markets. We derive changes in long-run equilibrium energy mix and energy and capacity prices spurred by subsidies. To the best of our knowledge, this paper is the first to show analytically the relationship between generation subsidies and equilibrium capacity market prices.

Our second contribution is providing an analytical framework for analyzing market effects of various reforms. The framework allows researchers to incorporate the desired heterogeneity of generation – including heterogeneity in emission intensities – and demand variability while allowing for transparent, closed-form solutions for energy and capacity prices, and capacity levels. The models also accounts for the inter-dependency between energy and capacity markets. This is especially important given that regulators are currently rethinking the design of electricity markets for a decarbonized future.

As a third contribution, we provide a welfare assessment of subsidies in settings with wholesale electricity markets. We outline the conditions under which subsidies can be welfare-improving. We demonstrate that while subsidies cannot produce the first-best outcomes, there always exists a range of welfare-enhancing subsidy rates when pollution damages are ignored by the market participants and subsidies are financed from a general budget. For subsidies financed through additional charges on electricity consumption, there exist demand and supply technology configurations where any subsidy rate reduces economic efficiency. We also show that, when there is heterogeneity in the emission intensity of generators, the optimal subsidies for cleaner resources should be technology-specific, based on the emissions a specific technology could avoid.

Finally, we analyze the welfare implications of the recent capacity market reforms in the U.S.. We show that, since the capacity market price suppression through generation subsidies can happen only under limited circumstances, policies that indiscriminately mitigate any subsidy, without taking its welfare effect into account, will harm the economic efficiency of wholesale electricity markets.

[7] In the 2018/2019 capacity year, the total capacity payments in PJM were $11.0 billion (IMM, 2019).

Our results are highly topical given the prevalence of generation subsidies and the increasingly ambitious clean energy targets that will lead to an even higher share of subsidized resources. We offer new insights about the optimal generation subsidies for policymakers pursuing increased generation from non-polluting resources. At the same time, we provide guidance for energy market regulators and operators on how these subsidies should be treated in the market.

The rest of the paper is divided as follows. Section 2 sets the modeling framework. In Sections 3 and 4, we compare welfare associated with market outcomes under three different regimes: no environmental policies ("status quo"), a Pigouvian tax, and generation subsidies. Section 3 focuses on energy-only markets, while Section 4 investigates energy-plus-capacity designs. Section 5 investigates the policy implications of our findings in the context of capacity market reforms in PJM, NYISO and ISO-New England triggered by generation subsidies for non-polluting resources. Section 6 concludes.

2 Electricity markets model - Preliminaries

To understand the effects of generation subsidies, we set up a model representing the long-term equilibrium in electricity markets under two market designs, an energy-only and an energy-plus-capacity market design. For the modeling, we use the framework of Joskow and Tirole (2007), but modify it in a number of dimensions.

First, we incorporate externalities and subsidies into the model. Second, to enhance tractability, we restrict ourselves to settings that allow closed-form solutions. Therefore, we assume the number of existing generation technologies and the number of possible demand states to be finite but arbitrary. Such a choice allows us to produce analytical insights on environmental policies under different resource configurations, and to capture the interactions between resource heterogeneity and environmental policies. Third, we explicitly model price formation in the wholesale energy and capacity markets to tease out the effect of generation subsidies on the markets, and thereby learn what price signals the different resources receive.

We assume there are M distinct, deterministic technologies available for electricity generation, indexed by j and contained in set $\mathcal{M}$.[8] The technology-specific useful life defines the maximum number of periods under which a given technology is physically

[8]The resources' temporal availability affects their environmental and market impacts [Fell and Linn (2013), Abrell et al. (2019)], therefore it also changes the optimal subsidies and welfare. However, it does not influence the logic behind the mechanisms that we uncover. Therefore, while generation intermittency can be incorporated in our model, we abstract from it for the sake of tractability.

able to operate. The technologies are also characterized by the investment cost of building 1MW of capacity, by pollution footprint expressed as damages from generation, e_j, and by a private marginal cost of generation, c_j^p.[9] We will refer to the marginal costs that a generator of type j faces as c_j. When there is no instrument that internalizes the externalities, c_j equals the private marginal cost, c_j^p, and when there is a Pigouvian tax it equals the social marginal cost of generation, $c_j = c_j^s = c_j^p + e_j$. We index the available technologies such that they are ordered according to their relevant marginal costs, i.e. $\forall j \in \mathcal{M},\ c_j \leq c_{j+1}$. There are no transmission constraints or line losses, so the location of generators is irrelevant.

There are N different states of demand for electricity, indexed by i and occurring with frequency $f_i \in (0,1)$, contained in set $\mathcal{N}$. The states of demand are indexed in accordance with increasing demand, such that

$$\forall i, k \in \mathcal{N}, \quad i > k \implies D_i(p) = D_k(p) + \epsilon_{ik}(p),$$

where $\epsilon_{ik}(p)$ is a positive function with sufficiently high values such that the problem of "shifting peak" as described by Steiner (1957) does not emerge.

There are two types of consumers — consumers with real-time meters who face state dependent prices, p_i, and consumers with traditional meters who always face a constant, pre-defined price p for a unit of electricity.[10] The state-specific demands are denoted respectively by $\hat{D}_i(p_i)$ and $D_i(p)$, and the load profiles of all consumers are identical up to a scale factor.

The market operator runs a separate standard uniform price auction for every time period to balance the electricity supply and demand. Utilities bid in the demand curve corresponding to the demand state prevailing in a given time on behalf of their consumers. We assume that utilities pass through the wholesale prices to consumers on real-time meters. For other consumers, utilities impose a constant, volumetric energy charge and a fixed charge. Generators bid into the auction their whole generation capability at the marginal cost of generation they face. As the supply curve is in general a step function,

[9] The private marginal cost should be understood as representing fuel costs, variable labor costs, etc. if the plant were to run on its full capacity for its full lifetime. The modeling framework abstracts from the start-up costs, minimum load considerations etc.

[10] An optimal contract with consumers on traditional meters includes probabilities of the consumers being rationed in individual states. However, when the marginal generation costs during peak demand are relatively low compared to the marginal surplus from peak electricity consumption for consumers on traditional meters, the optimal rationing probability is zero. To simplify the exposition, we thus assume that the above condition is met and abstract away from consumer rationing. For discussion of interruptibility, see Joskow and Tirole (2007).

the clearing price can be above the price bid by marginal generator – situation referred to as "scarcity pricing."

It is straightforward to see that a generator that clears the energy auction in demand state i also clears with higher demand levels, i.e. in states with indices higher than i. We refer to a generator as an "i^{th}-merit" generator if it clears the energy auction in state i but does not clear the market in state $i-1$. The capacity utilization rate of an i^{th}-merit resource is thus given by the sum of frequencies of the states when resource clears the market, $\sum_{k=i}^{N} f_k$. To ensure the uniqueness of equilibria, we assume that no two technologies have the same levelized costs of energy at the possible capacity utilization rates.[11]

In the set of technologies clearing the auction in a given state demand state, we call the technology with the highest marginal cost the marginal technology for that state. The merit order is defined as mapping h assigning a marginal technology to demand state, $h : \mathcal{N} \mapsto \mathcal{M}$.

The market operator may also want run a capacity market in addition to energy markets. The supply curve in capacity markets is formed through generator bids representing the minimum price they are willing to accept for keeping their capacity ready to produce electricity in a given time period. We model this market as a uniform price auction where the amount of capacity procured corresponds to the predicted maximum amount of demand.[12]

3 Energy-Only Markets

In this Section, we analyze the effects of subsidies on energy-only markets, like ERCOT in Texas. In the next Section, we extend the analysis to understand how capacity markets interact with generation subsidies.

[11] Levelized cost of energy represents the average revenue per unit of electricity generated that would be required to recover the costs investment and generation given the share of time that the generator clears the market. The assumption of unique levelized costs eliminates the possibility of two technologies looking the same from the market perspective.

[12] In the U.S., the Midcontinent Independent System Operator, among others, uses this type of capacity market. Other U.S. capacity auctions use capacity demand curves, which complicate the exposition but do not change the underlying mechanisms studied here.

3.1 General findings on energy supply and equilibrium energy prices

Below we present a two-step procedure for establishing market equilibrium with an energy-only market design. In the first step, we identify the set of technologies that are economic and therefore belong into the equilibrium generation mix. In the second step, we derive the equilibrium prices and energy consumption in individual states.

Let $\mathcal{P}_{\mathcal{N}}$ denote the m-element subset of generation technologies that, given the distribution of states, f_i, clear the energy auction in at least one demand state. In what follows, we will refer to those technologies as "economic."[13] We make the following observation about the relationship between the demand states and economic types of generators:

Lemma 1. *In a competitive electricity market with technologies that have constant returns to scale and unique levelized costs of entry, the mapping from the demand states to the set of economic technologies that defines the merit of the economic generators, $g : \mathcal{N} \mapsto \mathcal{P}_{\mathcal{N}}$, is surjective. Consequently, the set $\mathcal{P}_{\mathcal{N}}$ contains at most $m = N$ elements.*

Proof - see appendix A.1. □

Under these assumptions, the equilibrium resource mix and prices remain constant over time, despite the individual generators exiting the market as a result of their limited useful life. As generators retire at the end of their useful life, they get swiftly replaced by a generator of the same technology, leading to a constant equilibrium capacity mix and prices. As the useful life solely redefines the cost structure allowing the recovery of investment costs to be spread over multiple years, we can investigate optimality in an individual period and focus on annualized investment costs, I_j.

Lemma 2. *The marginal type of generator j in state i can be defined s.t.*

$$I_j + c_j \sum_{k=i}^{N} f_k \leq I_g + c_g \sum_{k=i}^{N} f_k \quad \forall g \in \mathcal{M}. \tag{1}$$

Proof - see appendix A.2. □

Condition (1) establishes which technologies are economic given the distribution of the demand states and the pollution internalization mechanism (or lack thereof), revealing the set of economic technologies, $\mathcal{P}_{\mathcal{N}}$, concluding the first step of the procedure.

[13] Note that with a Pigouvian tax in place, the definition a generator being economic also accounts for externalities.

The second step of our procedure establishes the equilibrium prices and consumption levels given the economic technology mix. We re-index all the economic technologies belonging to $\mathcal{P}_{\mathcal{N}}$ such that their indices correspond to the states in which they are marginal. Note that with re-indexing, it still true such that generators with lower marginal costs are lower in merit order, such that $\forall j \in \mathcal{P}_{\mathcal{N}},\ c_j \leq c_{j+1}$. However, this re-indexing allows us to skip technologies that are never economic given the demand states. Note also that technologies that are marginal in multiple subsequent states are indexed at least twice, i.e. i^{th}-merit and $i+1^{th}$-merit resources might represent the same technology.

Assume that markets and utilities account for externalities only to the extent that they are internalized through emission pricing, i.e. $c_j = c_j^p + tax$. Given this assumption and $\mathcal{P}_{\mathcal{N}}$, market prices and quantities, can be obtained using the following Lagrangian:

$$\begin{aligned} \max_{p,\,\{p_j\}_{j\in\mathcal{N}}} \quad & \sum_{i=1}^{N} f_i[S_i(p)) + \hat{S}_i(p_i) - \sum_{j=1}^{i} c_j K_j] - \sum_{i=1}^{N} I_i K_i \\ & - \sum_{i=1}^{N} \lambda_i (K_i - D_i(p) - \hat{D}_i(p_i) + D_{i-1}(p) + \hat{D}_{i-1}(p_{i-1})), \end{aligned} \tag{2}$$

with $\hat{D}_0 = 0$ and $D_0 = 0$, K_j denoting the capacity, i.e. number of MWs built of technology j, $S_i(p)$ and $\hat{S}_i(p_i)$ representing the gross surplus of consumers on traditional meters and real-time meters, respectively, and λ_i reflecting the shadow price of capital constraint in demand state i. This maximization leads to the following equilibrium prices, which are a generalization of Joskow and Tirole (2007) for a discrete number of states:

$$p_i^E = \frac{c_i \sum_{k=i}^{N} f_k - c_{i+1} \sum_{k=i+1}^{N} f_k + I_i - I_{i+1}}{f_i} \quad i = 1, 2 ... N-1 \tag{3}$$

$$p_N^E = c_N + \frac{I_N}{f_N}, \tag{4}$$

$$p^E = \frac{\sum_{i=1}^{N} f_i p_i^E D_i'}{\sum_{i=1}^{N} f_i D_i'}. \tag{5}$$

While competitive generators bid their marginal energy costs, equilibrium revenue they get should allow them to break even. Given that the generators of type N sell energy only in the peak period, the per MWh energy peak price, p_N^E, needs to cover their marginal costs of energy generation, c_N, and their annualized cost of investment adjusted by the frequency of peak demand occurrence, $\frac{I_N}{f_N}$. Prices above that level would induce new entry of generation, until, through increased supply of energy and downward-sloping demand, the price falls to p_N^E. The mid-merit generator makes energy sales in intermediate-peak and peak periods. Given p_N^E, the equilibrium p_{N-1}^E needs thus to meet the following condition: $I_{N-1} + (f_{N-1} + f_N)c_{N-1} = f_{N-1}p_{N-1}^E + f_N p_N^E$. Similar logic of "backward induction" can be used to obtain p_{N-2}^E, p_{N-3}^E, etc.

The deviations of the equilibrium prices from marginal costs represent scarcity pricing needed to equate demand and supply. The magnitude of the deviations decreases as the number of demand states. Note also that if a technology is marginal in more than one state, the prices in the states with lower indices equal its marginal generation cost.

The amount of capacity of each resource type is determined by the differences in demand levels between individual states, i.e. $K_i^E = D_i(p^E) + \hat{D}_i(p_i^E) - D_{i-1}(p^E) - \hat{D}_{i-1}(p_{i-1}^E)$. The results assume full divisibility of the generation units. Lumpiness of capacity investments complicates the formula, and detracts from efficiency as shown in Antoniou and Strausz (2017), but does not change the main insights from our model.[14]

The incentive-optimal price for consumers on traditional meters, p^E, does not guarantee cost recovery to the utility for providing electricity to those consumers. Therefore, the utility recovers (or returns) the missing (or excess) energy revenue from (to) consumers on traditional meters through the use of fixed charges.

If a utility is concerned about the external damages, it might want to deviate from pricing formula 5 even when the Pigouvian taxes are absent and implement its pricing for consumers on traditional meters using socially optimal price. Given that the utility can use a multiplicity of potential pricing designs for consumers on traditional meters, based on how it accounts for externalities in its objective function, we relegate the results relevant for those consumers to the appendix B and in the reminder of the paper we focus solely on consumers on real-time meters.

3.2 Comparing outcomes under the status quo and Pigouvian tax

Under current policies, there are no instruments that fully internalize external damages from emissions. Consequently, the wholesale prices obtained in formulas (3)-(4) (which

[14] If there is lumpiness in investment manifesting itself in minimal size of peaker capacity extension of y, the equilibrium capacity amount might be up to y units lower than than the equilibrium capacity with divisible investment. The deviation of the associated "lumpy" peak price from p_N^E is given by: $p_N^{cl} \leq p_N^E + y[\hat{D}'_N + D'_N f_3(D'_N - \sum_{i=1}^{N-1} D'_i)^{-1}]$. The smaller the minimum size of investment is in comparison to the demand, the lower will be the relative impact of lumpiness on the outcomes.

also correspond to retail prices for consumers on real-time meters) reflect private and not social generation costs, leading to distortions in market outcomes. We call those distortions "intensive" when the quantities produced by individual generator types are inefficient but the merit order, h, is the same as under the "first-best" Pigouvian tax,[15] such that the existence of externalities does not change the types of technologies that are "economic" and clear the market. A sufficient condition for the distortions having intensive character reads:

$$\forall i,j \in \mathcal{M}, t \in \mathcal{N}, \;\; I_i + c_i \sum_{k=t}^{N} f_k \leq I_j + c_j \sum_{k=t}^{N} f_k$$
$$\implies I_i + (c_i + e_i) \sum_{k=t}^{N} f_k \leq I_j + (c_j + e_j) \sum_{k=t}^{N} f_k \; .$$

When externalities change the merit order, we call the resulting distortions "extensive." If the distortions are extensive, resources that clear the market under the status quo are different than those that would clear under first-best outcomes. In the main body of the article, we focus on intensive distortions, which have closed form solutions, but we reproduce some of the results for extensive distortions in the appendix. We unify the analysis of the two types of distortions by extending a general model presented in Joskow and Tirole (2007) to account for emission damages and present it in Appendix C as a benchmark for our results.

We index the prices under the status quo approach with "SQ." Comparing the status quo prices obtained through formulas (3)-(4) with the socially optimal prices that account for social marginal costs (indexed with "$*$"), we arrive at Proposition 1.

Proposition 1. *When externalities do not change the merit order, the differences between the status quo and the socially optimal wholesale prices are as follows:*

$$p_i^{\Delta} = p_i^{SQ} - p_i^{*} = \frac{e_{i+1}\sum_{k=i+1}^{N} f_k - e_i \sum_{k=i}^{N} f_k}{f_i}, \;\; i = 1,2...N-1 \tag{6}$$

$$p_N^{\Delta} = p_N^{SQ} - p_N^{*} = -e_N \leq 0. \tag{7}$$

The status quo prices are (weakly) too high when pollution-free resources are marginal and suppressed when dirtiest resources are on the margin. For low polluting resources, the

[15] When some consumers are on traditional meters and thus do not respond to real time prices, first best cannot be reached. Therefore, even the Pigouvian tax represents a second-best world.

sign of price distortion depends on the pollution intensity of the technology that follows them in the merit order.

The distortions in prices translate into distortions in generation capacities, which for an i^{th}-merit resource can be written as:

$$K_i^{\Delta} = K_i^{SQ} - K_i^{*} = p_i^{\Delta}\hat{D}_i' - p_{i-1}^{\Delta}\hat{D}_{i-1}' \tag{8}$$

Inspecting Equations (6)-(8) it is easy to see that the distortions skew the generation mix towards polluting resources: the pollution-free resource is (weakly) underbuilt under the status quo[16] and the most polluting types of generation get overbuilt. Predicting the direction of capacity distortion for generators that have low but positive pollution requires knowledge of price sensitivity of demand and the relative magnitude of environmental externalities of the individual technologies. The realized capacity of those polluting resources that are sufficiently less polluting than the generators above or below them in the merit order is suboptimally low.

3.3 Equilibrium effects of subsidies

Policymakers attempt to correct distorted market outcomes. In recent years, their attempts have concentrated on generation subsidies for non-polluting resources. We incorporate such generation subsidies into the model by replacing generator j's marginal cost,c_j, with $c_j - s_j$ whenever it obtains a per MWh subsidy s_j. We will call a subsidy "non-disruptive" if it does not change the merit order.[17]

Theorem 1. *Assume that generation technologies exhibit constant returns to scale and that investments are perfectly divisible. Granting a non-disruptive generation subsidy, s, financed from the general budget to i^{th}-merit generators decreases p_i by $\Delta_i(s) = \frac{s}{f_i}\sum_{k=i}^{N} f_k$ and rises p_{i-1} by $\Delta_{i-1}(s) = \Delta_i(s)\frac{f_i}{f_{i-1}}$, while leaving the clearing prices in other states unaffected.*

Proof - see appendix A.3. □

Note that when the subsidy is granted to the 1^{st}-merit generators, the only price affected is p_1. If two or more pollution-free resource types follow each other in the merit order, i.e. if both i^{th} and $(i-1)^{th}$-merit resources are pollution-free, the price adjustment

[16] The amount of capacity for a pollution-free generation type will be correct if the adjacent merit order generators are also pollution free.

[17] "Disruptive" subsidies, which change the merit order, are discussed in the appendix D in the context of extensive externalities.

for the $i-1$ state is a compounded effect of the price effect in state i and the subsidy, leading to a decrease in p_{i-1} equal to s.

Corollary 1. *Granting a non-disruptive generation subsidy financed from the general budget to i^{th}-merit generators increases equilibrium capacity of i^{th}-merit resource, scales down the capacity of $(i-1)^{th}$-merit and $(i+1)^{th}$-merit resources and has no impact on the capacity of other resources.*

The adjustments in capacity follow from the price adjustments described in Theorem 1. As p_{i-1} decreases while p_{i-2} remains constant, the equilibrium amount of $i-1^{th}$-merit generation drops. On the other hand, as both p_i and $\sum_{k=0}^{i-1} K_k$ decline, the equilibrium capacity of the subsidized resource rises. The contraction in capacity of $i+1^{th}$-merit resource derives from increased aggregate capacity in lower demand states, $\sum_{k=0}^{i} K_k$ combined with unchanged price p_{i+1}.[18] $\square$

3.3.1 Comparing effects of subsidies to first-best outcomes

To think through the effects of subsidies, assume that there are three types of resources: wind, coal and gas power plants – a resource mix that is relevant for ongoing policy discussions – and that the resources are characterized by a following cost ordering: $c_w < c_c < c_g$, $e_w = 0$, and $e_c > e_g$.[19] The price distortions under the status quo are:

$$p_1^\Delta = \tfrac{f_2+f_3}{f_1} e_c > 0,\ p_2^\Delta = \tfrac{f_3(e_g-e_c)-f_2 e_c}{f_2} < 0 \text{ and } p_3^\Delta = -e_g < 0,$$

leading to unerbuilding of wind and overbuilding of coal. There will be excess gas capacity if $e_c < e_g \frac{D_3'/D_2' f_2 + f_3}{f_2+f_3}$.

Giving a subsidy $s = e_c(f_2+f_3)$ to wind would implement the optimal level of $p_1^s = p_1^*$ but leave the prices p_2 and p_3 unaffected, preserving the distortions in capacity of the polluting resources. Alternatively, policymakers could implement a subsidy that brings the capacity of coal or gas capacity to an optimal level or use a subsidy that maximizes the welfare taking into account uniternalized pollution. Nevertheless, based on Theorem 1, it is clear that no subsidy rate can remove all the distortions.[20]

[18] Lumpiness of investment could lead to subsidies affecting resources that are further away in the merit order. However, as we argued previously, we expect the effects of lumpiness to be of third-order importance if the minimum investment size is relatively small compared to the demand. Therefore, we ignore it in our analysis.

[19] Note that for illustration purposes, we assumed that total social marginal costs of coal are lower than those of gas, $c_c + e_c < c_g + e_g$. However, this does not need to hold true and will mostly depend on the relative prices of coal and gas.

[20] For instance, in the example used, a subsidy is capable of changing solely the off-peak price, even though the prices in all three states are distorted.

Policymakers could refine the subsidy policy by combining it with an electricity consumption tax. With two instruments, it is possible to target two outcomes, e.g. induce optimal p_1 and p_3 using a combination of tax $t = e_g$ and subsidy $s = e_c(f_2 + f_3)$. Nevertheless, the combined instruments cannot restore the optimality since $p_2 \neq p_2^*$ (unless by coincidence).

Proposition 2. *If there are more than two demand states, and if there are two or more types of polluting generators that are economic, a homogeneous subsidy for pollution-free energy generation, even when combined with an electricity consumption charge, cannot produce first-best outcomes.*

With N demand states, up to N prices are distorted;[21] however, a subsidy affects only prices of pollution-free resources and prices of the resources directly below them in the merit order. Besides, a subsidy can not perfectly correct all the prices it affects, unless by accident – the distortions differ between the demand states and a homogeneous subsidy cannot target that distortion heterogeneity. Enhancing the subsidy with a consumption charge adds only one degree of freedom for the policymaker. □

3.3.2 Comparing effects of subsidies to the status quo

A subsidy for non-polluting generation, even when combined with a consumption tax, cannot implement first-best. However, it can still be a socially desirable tool.

Theorem 2. *When pollution is not internalized in the market but the merit order is correct, there exists a generation subsidy for non-polluting resources financed from the general budget that weakly increases efficiency of the market compared to the status quo.*

Proof - see appendix A.4. □

The intuition is that for a sufficiently small subsidy, all of the affected prices move closer to their optimal value. By the same token, there exists a threshold above which a subsidy brings all the affected prices further away from the social optimum. For subsidies falling in-between those extreme cases, social welfare increases in some of the states and decreases in other demand states. In such a case, establishing the net welfare effect of the subsidy will require knowledge of the demand functions.

Parallel results on subsidies for the case when pollution distortions have extensive character are derived in the appendix D.1. Together, those results demonstrate the potential

[21] As visible in formula 6, all prices are distorted unless two or more non-polluting resources follow one another in the merit order, in which case some of the prices will be correct.

of generation subsidies for non-polluting resources to increase the efficiency of electricity markets.

The derivations for the theorem above focus on the efficiency effects on energy markets and assume the subsidy is paid from the general budget. However, in most real-life applications the subsidy is financed through revenue-neutral charges on electricity [Abrell et al. (2019)]. Below, we show how such a financing structure modulates the effects of subsidies on the efficiency of energy markets.

Theorem 3. *When pollution is not internalized in the market, a sufficient condition for a subsidy recovered by a revenue-neutral consumption charge to increase welfare is that the status quo prices are distorted downwards in all demand states in which polluting resources are marginal.*

Proof - see appendix A.5. □

The intuition behind the theorem is that the consumption charge will work like a tax for polluting resources and like a subsidy for pollution-free resources. This is straightforward to see when prices are distorted in all states, for example, when there are no two consecutive demand states in which non-polluting resources are marginal. Here, any subsidy rate that leads to a sufficiently small price decrease in the states when pollution-free resources are marginal and a price increase lower than the smallest of price shortfalls in all the other states will increase welfare.

The sufficient condition from Theorem 3 is not met when a fossil-fueled generator type is much less polluting than the resource that follows it in the merit order. To see the effects of subsidies is such a setting, assume that there are three demand states and that the market is served by three types of resources: pollution-free baseload generators, low polluting mid-merit generators and highly polluting peakers. A subsidy combined with the consumption charge corrects p_1, increasing the capacity of the pollution-free resource at the expense of the low polluting generation, and corrects p_3 downwards. At the same time, however, it brings p_2 further away from optimal level. If, in such a setting, the peak demand and off-peak demand are highly inelastic while the intermediate demand state is very price elastic, a subsidy detracts from welfare – the additional volumetric charge causes a substantial shrinkage of the intermediate peak consumption but leaves the peak consumption almost unaffected. This causes the capacity of the most polluting resource, and thus pollution, to increase substantially.

Those findings contrast with the literature on two-part instruments which posits that it is always possible to reach an optimal solution in the presence of externalities through a combination of a subsidy for pollution-free energy producers and a consumption tax [Fullerton and Wolverton (2005)]. That difference in the results is due to heterogeneity in pollution intensity and the ensuing problem of having too many goals compared to available tools – an optimal pricing instrument would treat the different polluting resources differently, while a uniform subsidy for pollution-free generators cannot have a targeted, differentiated effect on the polluting generators.[22] Consequently, non-uniform generation subsidies that directly relate to the avoided pollution from the resource that the subsidized unit displaces are welfare dominant. In other words, the subsidized unit should not be rewarded for the absence of pollution, but rather for the avoidance of pollution.[23]

Proposition 3. *When there is heterogeneity in the pollution intensity of emitting generators, the optimal subsidy for a type of non-emitting generator should be specific to that resource and should account for the characteristics of the resources it displaces.*

A subsidy given to an i^{th}-merit resource affects only the i and $i-1$ prices. As a result, it changes the capacity of $i-1^{th}$-, i^{th}- and $i+1^{th}$-merit resources. Consequently, in accordance with Proposition 3, the optimal subsidy will depend on characteristics of those resource types only. □

These results have important insights for the design of clean energy policies, specifically renewable or clean energy standards. The conventional economic wisdom tells us that technology-neutral policy design would lead to the most cost-effective abatement solutions. Indeed, most jurisdictions use Renewable Energy Credits which provide uniform payments for all eligible technologies. Even when carve-outs for specific resources exist, those are usually motivated by usually supporting developing a nascent type of technology. However, our results show that this conventional wisdom might not apply when the payments cannot be designed perfectly, i.e. when they cannot be directly coupled to outcomes such as avoided pollution. When subsidies for non-polluting resources need to be set a fixed value and there is variation in the pollution intensity of fossil-fueled resources, differentiating subsidies by technology can lead to superior outcomes. Consequently, developing new policy instruments such as zero-emission credits or offshore wind renewable

[22] Some papers, for instance Goulder et al. (2016) and Eichner and Runkel (2014), show that subsidies for pollution-free resources can be more cost-effective than direct emission pricing or that feed-in-subsidies, in combination with other instruments, can help overcome the problem of lumpy entry costs [Antoniou and Strausz (2017)]. However, it is unclear to what extent those results hinge on the authors abstracting from different types of polluting generators and instead modeling only one type of emitting generator.

[23] Abrell et al. (2019) and Fell and Linn (2013) show how environmental values of pollution-free resources varies with the resources' intermittency profiles. Abrell et al. (2019) acknowledge that with such heterogeneity optimal subsidies should be differentiated by resource type.

energy credits might be justifiable on economic theory grounds if those resources avoid different amounts of pollution.

3.4 Transition effects of subsidies

The derivations in Section 3.3 focus on equilibrium outcomes, which is also the prevailing approach taken in the literature [Joskow and Tirole (2007), Palmer et al. (2011), Briggs and Kleit (2013), Brown (2018a), Llobet and Padilla (2018), Bento et al. (2018) Özdemir et al. (2020)]. However, policymakers are often concerned with transition effects caused by the introduction of a policy.

In the energy sector, transition to a new equilibrium will tend to be protracted compared to, for instance, adjustment to new monetary policies,[24] making the intermediate effects more relevant. Given the paramount importance of reliability, policymakers will also avoid any policy that produces an adjustment path with temporarily lower grid reliability, even if that policy results in superior equilibrium outcomes. For instance, a reform resulting in misaligned timing of entry and retirement decisions could harm the reliability of the grid, and would thus be rejected by regulators.

Below, we delineate some of the short-run changes induced by introduction of subsidies to a market operating under the status quo. While we cannot speak to the exact transition pathway, we provide general observations on the changes in profitability of the generators and capacity adjustments.

Introducing a non-disruptive subsidy to an i^{th}-merit resource is, from the perspective of the subsidized unit, tantamount to a decrease in its marginal cost. However, the subsidy will lead to an immediate drop in some prices only if i^{th}-merit resource is marginal in more than one state. Otherwise, all prices initially remain the same. The increased profitability of i^{th}-merit technology induces new entry, ΔK_i, shifting out the part of the supply curve above the subsidized resource, such that prices in all states $j \geq i$ decrease.

This price drop will reduce the per MW profits of all generators that do not receive a subsidy:

$$\Delta\Pi_j = \sum_{k=j}^{N} \Delta p_k f_k \ , \tag{9}$$

[24]For monetary policy, it is conceivable to have instantaneous adjustments [Auernheimer (1974)] while a transition under an energy sector regulation will unfold over multiple years at minimum. This happens as energy assets are very long-lived – some of the coal power plants that are still in operation are over 70 years old – and building generators require a substantial lead time. For instance, building a nuclear power plant takes at least 6 years, for natural gas the construction takes up to 24 months. Building transmission to interconnect a new generator to the grid can also take years.

whereby Π_j is the profit of non-subsidized j^{th}-merit technology and Δp_k denotes the short-time price change in state k in response to additional capacity of type i:

$$\Delta p_k = \begin{cases} \hat{D}_k^{-1}(\sum_{j=1}^{k}) - \hat{D}_k^{-1}(\Delta K_i + \sum_{j=1}^{k}) & \forall\, k \geq i \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

Given that with constant returns to scale technologies equilibrium profits are zero, the drop in profits causes losses. Therefore, in the short-term, all non-subsidized resources receive exit signals.

The retirement will decrease some of the losses described by the Equation (9), and it will continue as long as there are unprofitable technologies. While we cannot predict the exact path of adjustments, we know that the equilibrium capacities and prices will be as described in Theorem 1 and Corollary 1. The effects for disruptive subsidies follow a parallel logic.

Our findings suggest that if a policymaker decides to introduce a subsidy, the profitability of all non-subsidized units will drop. However, this effect will be only temporary. After the offsetting retirements, the profits of generators will rebound.

4 Energy-plus-capacity markets

4.1 General findings

The previous Section demonstrates that when prices are allowed to fluctuate to ensure revenue adequacy, energy-only markets are sufficient for providing electricity reliably. However, many real-life electricity markets have a cap on energy prices, which restricts the functioning of the markets and gives justification to creating capacity markets.[25] Below we show consequences of a price cap, p^{max}, such that $p^*_{N-1} < p^{max} < p^*_N$.[26]

After introduction of the price cap, with capacity levels defined by Equations (3)-(4), each MW of capacity of each generator type bears a loss of $(p^*_N - p^{max})f_N$. Retiring a fraction of their capacity would allow low- and mid-merit generators to recover some of the revenue lost: such retirement would increase p_1 and p_2 etc. and thus decrease the amount

[25] For the maximum prices that energy can reach in the U.S. wholesale markets, see Figure 1 in Chang et al. (2018).

[26] We concentrate on price caps above p^*_{N-1} as with lower caps, capacity markets cannot restore the optimum investment (see the problem of instruments vs goals as described in Joskow and Tirole (2007)). With the current price caps implemented across the U.S., the assumption might not be empirically true. Nevertheless, it helps us focus on the mechanisms investigated.

of "missing money" for remaining units of those types. For peakers, though, there is no similar mechanism that would allow the recovery of missing money. Consequently, a cap leads to under-investment in peak capacity, peak demand surpassing generation capacity, and, in turn, blackouts. To prevent such lack of resource adequacy following from energy price caps, market operators implement capacity markets.

Assume that the market operator is able to design and implement a capacity market in a way that ensures competitiveness of capacity bids. In such a setting, peakers will submit bids into capacity markets corresponding to the amount needed to break even, which is the revenue they lose because of the cap. Therefore, their capacity market bid per MW, b_N, is given by:

$$b_N = \pi^{loss} = (p_N^* - p^{max})f_N = (c_N - p^{max})f_N + I_N. \tag{11}$$

When capacity is procured in the amount corresponding to the expected peak demand, the technology that serves as a peaker plant becomes the marginal technology that also sets the capacity price.

An energy market with a price cap p^{max} and a technology-neutral capacity market lead to the same equilibrium investments as an energy-only market without a price cap if generators are price-takers and if, under the price-cap regime, consumers on real-time meters face an additional charge for every kWh they consume in the peak period, denoted by PC, for "peak charge", equal to the capacity price.[27] To see the equivalency, it suffices to note that consumers will face the same effective prices as before the introduction of the price cap as a result of the capacity price formation described above and the additional peak period charge. Identical prices will lead to identical consumption levels in all states.[28]

This equivalence implies that, in our modeling framework, finding the equilibrium allocations and prices in energy-plus-capacity markets is very straightforward: It solely requires solving for equilibrium prices and capacities in energy-only markets using the two-step procedure from Section 3.1, replacing p_N with price cap, and calculating the capacity price as defined in Equation 11.

[27] With stochastic outcomes, Mays et al. (2019) show that the existence of capacity markets tilts the resource mix towards the generator types with lower fixed costs and higher operating costs if risk trading is incomplete. Therefore, for the equivalence result, the extension of the framework to stochastic outcomes would require an assumption of complete risk trading.

[28] However, when capacity costs are recovered for all consumers through a charge on every kWh of electricity consumed (denoted by EC, for "energy charge") or by increasing the monthly fixed charge, the price cap will change the economic outcomes. Among other changes, such a capacity cost recovery method, will lead to altered consumer prices, $p_1^{cap,EC} > p_1^*$ and $p_N^{cap,EC} < p_N^*$. Given a downward-sloping demand, this will require overbuilding total capacity, in particular the peakers' capacity, while underbuilding some of the low-merit resources compared to the no-cap setting.

4.2 Comparing equilibrium outcomes under status quo and Pigouvian tax with energy-plus-capacity markets

As shown above, the existence of a capacity market does not necessarily change the resource mix and the energy prices other than peak price. Therefore, in the absence of a mechanism to internalize externalities, the market distortions with capacity markets will be the same as the distortions under energy-only markets described in Section 3.2.

However, the capacity prices will be weakly lower under the status quo than under the first-best setting. Recall that capacity prices are determined by the difference between the competitive energy price in the highest demand state, which is the break-even point for the marginal generator, and the price cap. A Pigouvian tax would increase the effective marginal cost of the marginal generator if it is an emitting one, and hence the amount of revenue that is needed to break even, increasing the capacity prices.[29]

4.3 Equilibrium effects of subsidies with energy-plus-capacity markets

When studying the effects of generation subsidies on the outcomes in energy-plus-capacity markets, we again note that the existence of a capacity market does not change the equilibrium resource mix and the energy prices other than peak price. Therefore, the welfare impacts of subsidies are the same as described in Section 3.3. In particular, the results on the existence of welfare-enhancing generation subsidies stand.

Comparing prices under the status quo to prices with subsidies leads to an important result relevant to current policy discussions in energy market discussions.

Corollary 2. *When giving a generation subsidy to a non-polluting resource does not change the identity of the generator type that is marginal in the peak period and this generator is a polluting one, the subsidy does not affect the long-term competitive equilibrium capacity price.*

As shown in Theorem 1, subsidies have an effect on energy prices only in the states in which the subsidized resources are marginal and in the lower, adjacent demand states. As the long-term capacity price is determined solely by the difference between the peak price and the price cap, a subsidy that does not change the identity of the peaker and which is not received by a peaker will leave the capacity price unaffected. □

[29] The peak price remains constant under the two regimes only if, under the status quo, a non-emitting generator as a peaker plant.

The energy market re-equilibrates in response to subsidies. Capacities and prices adjust to new levels where all generators break even. Therefore, a price cap has in the long-run the same effect on all the generators as described in Equation 11, and that effect is not changed by a subsidy unless the subsidy changes p_N. It is irrelevant here whether the subsidy is of disruptive or non-disruptive type.

Should the subsidies be paid to the peaker, the price p_N that the peaker needs to break even drops. This automatically reduces the "missing money" as described by Equation (11), thereby lowering the capacity prices at the equilibrium. From the perspective of the non-subsidized resources, the drop in capacity prices is equivalent to a decrease in peak price. It also has the same welfare effects.

Our results imply that the existence of capacity markets is irrelevant for the long-term welfare effects of subsidies if capacity markets are correctly designed. Consequently, in equilibrium, welfare implications of generation subsidies are like described in Sections 3.2 and D.1, implying existence of socially desirable subsidy designs. These results contradict the findings from previous studies on the impact of generation subsidies on the functioning of electricity markets, especially capacity markets. The main reason for the discrepancy is the fact that other studies ignored the existence of externalities, and therefore did not allow for the possibility that subsidies improve economic efficiency under certain circumstances.[30]

Further, our results contradict the conventional wisdom underlying the recently implemented policy reforms in wholesale capacity markets. Those reforms relied on the basic economic argument that subsidies would lead to price suppression in capacity markets, harming economic efficiency. While that argument would hold true in a simple market structure and when there are no externalities, the existence of capacity markets, the interdependent relation between energy and capacity markets, and externalities render the argument incorrect.

4.4 Transition effects of subsidies

Like in the case of energy-only markets, introduction of non-disruptive subsidy will at first have no effect on the energy market prices: While the subsidized technology will submit lower bids into the energy market, its existing capacity is limited, preventing lower energy prices. The subsequent rise in profit per MW of capacity for the subsidized

[30] Additionally, some papers include only one demand state, thereby not allowing the equilibrating processes like described in Theorem 1 to happen. Reliance on assumption of all generation types having the same marginal costs also precludes equilibrating mechanisms.

technology will allow it to bid lower in the capacity market. However, the subsidized technology will not be marginal in the capacity market and thus, in the short run, it will not affect the capacity price.

As the subsidy will eventually attract new entry from the subsidized technology, the energy prices and profits of other generators, Π_j, will respond following the logic similar to that given in Equations (10) and (10). The losses of the non-subsidized resources will be reflected in the next auctions in their raised capacity bids:

$$b_j = \pi^{loss} + \Delta\Pi_j. \tag{12}$$

Since $\Delta\Pi_j$ differs between technologies, a sloping capacity supply curve forms, with the subsidized technology submitting the lowest bids.

Because the new supply curve in the short-term will be almost everywhere above the old curve, the capacity market will clear with a higher price. However, this, combined with the fact that total capacity in the market is now higher than before the introduction of the subsidy, implies that some capacity will fail to clear the market. The units without capacity market obligation will experience a stronger loss and will receive a market signal to exit. While it is hard to predict how exactly the retirement and investment decisions will be timed, the new equilibrium that the market will reach will be like that described in Section 4.3.

5 Application of the results to capacity market reforms in PJM and ISO-New England

In recent years, wholesale market operators in various regions of the U.S. have reformed their capacity market design. The justification of the reforms has been the need to shield the capacity markets from the much-feared possibility of "price suppression," which is claimed to follow from generation subsidies for non-polluting resources, such as Zero-Emission Credits and Renewable Energy Credits.

In March 2018, the Federal Energy Regulation Commission (FERC), which regulates wholesale energy markets in the U.S., accepted a new capacity market construct proposed by ISO-New England. The construct, called "Competitive Auctions with Sponsored Policy Resources," imposes a floor on the bid that subsidized new-generation resources can submit into the capacity market (FERC, 2018). This minimum bid is calculated to reflect the generator's costs, should the generator receive no subsidies.[31] In December 2019, FERC directed another wholesale market operator, PJM, to mitigate the capacity market impacts of subsidies by implementing a Minimum Offer Price Rule (MOPR). The MOPR rule prevents all subsidized resources from submitting bids into capacity markets lower than their unsubsidized costs (FERC, 2019). In another trading region, New York-ISO, a similar rule (referred to as Buyer Side Mitigation) is currently being extended in the context of subsidies for non-polluting generation (FERC, 2020).

These reforms have been controversial. Proponents argue that the reforms correct the price suppressive effects of subsidies. Opponents argue that the changes harm pollution-free generators and hurt states' decarbonization efforts. The stakeholders used their own analyses to argue their point, and so far, no rigorous academic studies have emerged on the topic.

Capacity markets are a substantial source of revenue for generators, already accounting on average for 20% of the market revenues, and increasing. It is therefore important to understand how subsidies affect those outcomes and also how the capacity market reforms affect the functioning of subsidies. Our model framework allows us to do both, thereby enabling us to evaluate the justification for the reforms.

If, indeed, generation subsidies harm the economic efficiency of wholesale markets and MOPR-style policies prevent that effect from occurring, mitigation of the effects of generation subsidies should be undertaken in other trading regions as well. However, if such policies reduce social welfare, their implementation is not justified on economic efficiency grounds.

First consider the argument that subsidies lead to price suppression in capacity markets. As we show in Sections 3.2 and in the appendix D.1, energy prices in states when the subsidized resources are the marginal resources fall as a result of the subsidy due to the equilibrating process in the energy market. The price decrease continues to the point where, given the revenue from subsidies, the resource breaks even. Given this process, the equilibrium bids of subsidized resources in capacity markets continue to be defined by the "missing money" as described by Equation (11). In other words, the capacity bids of the subsidized resource types are not affected unless they are the peaker plant.

Consequently, if subsidies are given to low-merit order resources, as is currently the case for programs like Zero-Emission Credits or Renewable Energy Credits, the long-term

[31] In other words, new, subsidized resources are allowed to submit bids corresponding to the difference between the energy market revenues the regulator expects them to earn and their private costs, but without taking into account the subsidies they receive.

equilibrium capacity bids of all resources that clear the energy markets stay the same with or without subsidies. In other words, in this setting, there is no long-time capacity price suppression effect from generation subsidies when they are given to non-marginal units.

The only cases in which subsidies decrease capacity prices would be when subsidies are given to the peaker or when subsidies change the type of technology serving as a peaker. In the period immediately following the introduction of such subsidies, the bids of the subsidized resource would decline compared to the equilibrium bid. At the same time, though, capacity bids of other resource types would (weakly) increase by $\Delta\Pi_j$ as defined in Equations (9) and (12) as subsidies for the peaker reduce peak energy market prices. As a consequence, the subsidized resource is no longer the price-setting unit in the capacity market and the capacity price (weakly) increases.[32] Our framework shows that "price suppression" in capacity markets does not occur even when the peaker plant receives a subsidy. The market reforms in this case are also not supported by our framework.

Overall, our results show that when the interactions between the energy and the capacity markets are taken into account, generation subsidies do not lead to price suppression in the capacity markets. On the contrary, we show that capacity prices might increase under certain circumstances. Hence, our framework shows that these capacity market reforms are not supported by economic theory.

Then, consider the effects of subsidies and capacity market reforms on the total social welfare. As we show in Section 3.3, there exists a range of subsidies that could bring the market closer to the socially efficient outcome. Assume a subsidy rate s^* has been introduced that enhances the efficiency of the market as discussed in Subsection 3.2. Assume also that the sector has transitioned to the new equilibrium given the subsidy.

In the short run, implementing MOPR could drive up the capacity prices towards $\pi^{loss,MOPR} = \pi^{loss} + s^* \sum_{k=i}^{N} f_k$, where k is the lowest demand state in which a subsidized resource is marginal. Such capacity prices would lead to extra profits for non-subsidized resources, and reshuffle the energy prices again, partly, through new entry of non-subsidized resources. This new entry, in turn, could prevent the subsidized resources from clearing the capacity markets. The aggregate costs of energy and capacity procurement would increase, reducing welfare. And, if the non-subsidized resources are also emitting resources, the social welfare shrink even further due to increased emissions. In other words, our framework shows that these reforms would lead to decreases in social welfare, a result that is the exact opposite of their intended effect.

[32] A subsidy given to a resource type marginal in the lowest states would leave the capacity price unchanged in the very short term and cause it to increase only after the subsidized unit starts expending its capacity.

As a result, we conclude that these recently implemented reforms, contrary to their intended effect, could lead to economic inefficiency when there are generation externalities. If the subsidies in questions directly address an externality and are within a certain range, they enhance social welfare. Instead, measures like MOPR should be considered only when a particular generation subsidy is found to be too high and thus welfare-decreasing.

6 Conclusions

Despite the mounting concerns over unsustainable greenhouse gas emissions and the consequent climate change, the political will to implement pollution taxes has been lacking, especially on national levels. Consequently, policymakers have embraced generation subsidies for non-polluting generators as a remedy. As the subsidy approach is increasing in importance, both in terms of the number of various subsidies used and in terms of aggregate magnitude of the payments, concerns have arisen about its impact on the functioning of wholesale electricity and capacity markets. In the U.S., two market operators, PJM and ISO-NE, have implemented reforms to mitigate the effects of subsidies on capacity prices. At the same time, academic literature on the total welfare implications of subsidies is scarce.

We contribute to this discussion by developing a framework in which the effects of subsidies on energy and capacity markets can be analyzed. We first confirm that not addressing externalities in wholesale markets skews the generation mix toward polluting resources. We then show how prices in energy and capacity markets respond to additional payments to non-polluting generators. In particular, we demonstrate that, as long as the subsidized resource is not the marginal resource in the peak period, generation subsidies do not affect the equilibrium price in capacity markets. We prove that, due to heterogeneity of polluting resources, a uniform subsidy cannot restore the first-best outcomes, even when combined with an energy consumption charge. A better subsidy design would compensate resources for "avoidance" of pollution instead of paying them for "absence" of pollution. Consequently, the potential for a subsidy to enhance welfare depends largely on how the relative pollution footprint of resources is distributed over the merit order. However, even a uniform subsidy can improve the efficiency of the markets when pollution is not internalized, which we argue by showing the existence of an efficiency-enhancing subsidy rate. As a consequence, policies that indiscriminately mitigate any subsidy, without taking its welfare effect into account, harm the economic efficiency of wholesale electricity markets. Our results show, based on economic theory, the recent major reforms in energy and capacity markets, which significantly alter the functioning of the markets, were fundamentally flawed.

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A Proofs and derivations

A.1 Proof of Lemma 1

To prove that there exists a surjective mapping from the demand states onto the set of economic generators, we need to show that all economic generators are marginal in at least one demand state and that in each state at most one type of generation can join the merit.

For the first part of the proof, recall that each resource type has a unique marginal cost. This, combined with our competitive framework in which generators bid their true marginal costs in the auction, implies that no two bids are the same. Therefore, in each demand state there can be only one type of resource that sets the price and is thus marginal.[33]

For the second part, note that there cannot exist two i^{th}-merit of resources. Two i^{th}-merit resource types would receive the same revenue as they would clear the market in the same states but, by assumption, they would have different levelized costs of entry. Consequently, they cannot both be breaking even. As no generation type would be willing to incur losses in the long run, at least one type of the two resources must make profits. This would, however, induce new entry by the profitable resource type, thus reducing the prices until the level below which the other resource type makes loses and leaves the market.

We can thus conclude that in equilibrium, in state $i = 1$, only one type of resource provides electricity. As the demand increases (demand state switches from i to $i + 1$) at most one type of resource will join the group of resource types actively producing electricity. Consequently, we have that $m \leq N$. □

A.2 Proof of Lemma 2

Lemma 2 defines the marginal generator in state i as the generation type j for which the following inequality holds:

$$I_j + c_j \sum_{k=i}^{N} f_k \leq I_g + c_g \sum_{k=i}^{N} f_k \quad \forall g \in \mathcal{M}. \tag{13}$$

[33] There might be two or more states that have the same marginal type of resource, e.g. when $M < N$.

To show that this inequality indeed holds for i^{th}-merit generator, recall that the unit that is marginal in state i, clears also all states j where $j > i$. Consequently, the share of time that the i^{th}-merit generator is serving the market is $\sum_{k=1}^{N} f_k$, and the total costs associated with building 1MW of capacity of technology g and running it is given by the right-hand side of the inequality. In equilibrium, the technology for which those costs are the lowest becomes the i^{th}-merit generator, since, given the sequence of prices $\{p_j\}_{j=i+1}^{N}$, which are independent of characteristics of i^{th}-merit generator, this technology is associated with the lowest p_i.

This inequality can also be seen by analyzing screening curves – curves plotting average cost of generation for individual technologies as a function of capacity factor.[34] □

A.3 Proof of Theorem 1

Recall that the peak equilibrium price is affected only by the cost characteristics of the N-merit generator, $p_N = c_N + \frac{I_N}{f_N}$. By definition, a non-disruptive subsidy will not change the identity of the peaker. Unless $i = N$, in which case the subsidy given to the peaker, the peak price remains unaltered. The equlibrium price in state $N-1$ depends on p_N and the characteristics of $(N-1)^{th}$-merit generator and thus does not change either, unless $i = N-1$. Similar logic applies to state $N-2$, $N-3$, and all other demand states k such that $k > i$.

As the subsidy effectively lowers the marginal costs of the i^{th}-merit generator by s, while the revenue per MW of capacity from all states $k > i$ remains constant, the rise in profits will attract new entrants of the i^{th}-merit generation type. Increasing capacity will suppress p_i to the point where new entry is not profitable anymore, i.e. $p_i^s = p_i^* - \Delta_i(s)$.

Given the decline in p_i, the price in state $i-1$ needs to rise by $\Delta_i(s)\frac{f_i}{f_{i-1}}$ for the $(i-1)^{th}$-merit generator to break even.[35] As the rise in p_{i-1} exactly compensates for the decline in p_i, the prices in states $k < i-1$ remain unaffected. □

A.4 Proof of Theorem 2

As we argue in Theorem 1, a subsidy received by an i^{th}-merit pollution-free resource decreases the clearing price in states i and raises the price in state $i-1$. To prove that

[34] For the logic of screening curves see Stoft (2002) and "efficiency ranges" in Oren et al. (1985).

[35] Note that we are looking at subsidies small enough to be non-disruptive. This, combined with the observation that with a competitive environment the resources just breaks even without the subsidy, guarantees that the subsidy does not decrease the price below marginal costs, i.e. $p_i - \Delta_i^s > c_i - s$.

those changes increase welfare, recall from Proposition 1 that, with a non-polluting i^{th}-merit resource, the price p_i is inflated whenever $(i+1)^{th}$-merit generator is polluting. At the same time, the price in state $(i-1)$ is below its optimal value whenever the marginal generator in that state is a polluting one. Consequently, a small enough generation subsidy brings prices closer to their optimal value whenever the technologies adjacent in the merit order are polluting. For instance, all subsidies in the range defined by:

$$\{s \in \mathbb{R}_+ \mid (\max_{j\in\mathcal{P}_{f,clean}} -\Delta_j(s) < \min_{j\in\mathcal{P}_{f,clean}} p_j^{\Delta}) \ \wedge \ (\max_{j\in\mathcal{P}_{f,dirty}} \Delta_{j,-1}(s) < \min_{j\in\mathcal{P}_{f,dirty}} -p_{j-1}^{\Delta})\},$$

where $\mathcal{P}_{f,clean}$ denotes the set of non-polluting economic resources, bring all prices they affect closer to their optimal value and thus unambiguously increase market efficiency.[36]

What happens if two or more pollution-free resource types follow each other in the merit order, e.g. when both i^{th}- and $(i-1)^{th}$-merit resources are pollution free, such that the competitive price p_{i-1} coincides with the optimal price p_{i-1}^*? In such a situation, the welfare change associated with the effect of a subsidy on p_{i-1} is negligible – when evaluated at the optimal price, the derivative of welfare with respect to price equals zero. Consequently, the subsidy will have a positive impact on market efficiency even if pollution-free resources follow each other in the merit order. □

A.5 Proof of Theorem 3

Assume for simplicity that the charge to finance subsidy, $t(s)$, is paid by generators for each MWh they produce. The revenue neutrality implies that the charge needs to meet the following condition:

$$t(s)\sum_{i\in\mathcal{M}} \hat{D}_i(p_i(s)) = s \sum_{j\in\mathcal{P}_{f,clean}} K_j(s) \sum_{k=j}^{N} f_k.$$

Any revenue-neutral subsidy in the set defined by:

$$\begin{aligned}\{s \in \mathbb{R}_+ \mid \max_{j\in\mathcal{P}_{f,clean}} -\Delta_j(s) - t(s) < \min_{j\in\mathcal{P}_{f,clean}} p_j^{\Delta} \\ \wedge \ t(s) + \max_{j\in\mathcal{P}_{f,dirty}} \Delta_{j,-1}(s) < \min_{j\in\mathcal{P}_{f,dirty}} -p_{j-1}^{\Delta}\},\end{aligned} \tag{14}$$

[36]The above set of subsidies is not empty since $\min_{j\in\mathcal{P}_{f,clean}} p_j^{\Delta}$ and $\min_{j\in\mathcal{P}_{f,dirty}} -p_{j-1}^{\Delta}$ are fixed, positive numbers, while $\|\Delta_j(s)\|$ can be set arbitrarily small by decreasing s.

brings each of the wholesale prices closer to their optimal values as it leads to a sufficiently small price decrease in states when pollution-free resources are marginal and a price increase lower than the smallest of price shortfalls in all other states.[37]

If pollution-free resources are marginal in two or more consecutive demand states, e.g. in i and $i-1$, the welfare effect of a price change will be negligible for state i. This implies that the subsidy identified by condition (14) will have a positive impact on market efficiency independent of relative location of pollution-free resources in the merit order. □

A.6 Proof of Theorem 4

To see that there exists a weakly welfare-increasing subsidy financed from a general budget, assume first that no pollution-free resource types are economic under the status quo but at least one of them is economic under first-best outcomes. Denote by $\mathcal{D}$ the set of demand states under which pollution-free resources are marginal under first-best. In such a case, the generation subsidy for pollution-free resources of rate

$$s = \min_{j \in \mathcal{D}} \{ s_j^{min} \} \tag{15}$$

is guaranteed to increase welfare as it corresponds to the lowest of minimum subsidies s^{min} for all pollution-free resources that are inappropriately included in the merit order.

If, on the other hand, at least one pollution-free resource type belongs to the set of economic resources under the status quo, $\mathcal{P}_N^{SQ}$, a subsidy defined by (15) might be too high. However, by Theorem 2, we can always find a subsidy rate that reduces the distortion on the intensive margin in a way that increases market efficiency. □

B Results including consumers on traditional meters

B.1 Optimal capacity charges for consumers

A simultaneous introduction of price cap $p_{N-1}^* < p^{max}$ and of a capacity market leads to the same economic outcomes as an electricity market without a price cap if generators are price-takers and if under the price-cap regime consumers on the real-time meters face a charge for every kWh they consume in the peak period, PC, equal to the capacity price,

[37] By definition, $\Delta_j(s) < 0$ and $\|\Delta_j(s)\| > t(s)$ whenever j-merit resource is of pollution-free type.

while an amount of $\gamma = \textit{capacity price} \cdot \frac{f_N D'_N}{\sum_{i=1}^{N} f_i D'_i}$ is added to the price p paid by consumer on traditional meters.

For consumers on traditional meters with constant price sensitivity, the adder γ simplifies to $\pi^{loss} f_N$.

B.2 Price distortions with energy-only markets and no merit-order change

What is the magnitude of price distortion p^{Δ} for consumers on traditional meters when externalities are not accounted for? Formula 5 describes the optimum price p^* as a weighted average of the (optimal) wholesale prices. If the utility decides to follow that formula using the wholesale prices that are not optimal (i.e. where the externalities are not accounted for), the distortion associated with energy consumption by consumers on traditional meters becomes:

$$p^{\Delta} = p^{SQ} - p^* = \frac{e_1 D'_1 + \sum_{i=2}^{N} e_i (D'_i - D'_{i-1}) \sum_{k=i}^{N} f_k}{\sum_i f_i D'_i}. \tag{16}$$

It thus depends on the magnitudes of the externalities and the price sensitivity of demand.[38]

On the other hand, if the utility computes the price for consumers on traditional meters based on the ideal wholesale markets and not on the observed ones, there will be no price distortion compared to the first-best.

C Energy-only market with continuum of states of nature

The following model incorporates a continuum of states of nature like in the benchmark model of Joskow and Tirole (2007). The notation follows the main body of the paper with the addiction of $u_i(j)$ denoting utilization rates of plant of type j in state i, with $u_i(j) \in [0, 1]$.

[38]Notice that if the slope of demand of the consumers on traditional meters does not change here across the demand states and wind is the lowest-merit resource, i.e. $e_1 = 0$, all terms in p^{Δ} cancel out in which case those consumers see the first-best prices. This is driven by the fact that the optimum prices account for the pollution content of the resource that is next in merit order and by the lowest merit-order resource being a pollution-free one. When the latter is not true, the distortion of p is proportional to e_1.

Social planner chooses prices for consumers on real-time and traditional meters, $\hat{p}_i$ and p respectively, the interruptibility parameters, α_i, the utilization rates and the amount of investment in each technology, $k(j)$ to maximize welfare:

$$\max_{p,\hat{p}_i,\alpha_i,u_i(c),K()} W = \int_0^1 S_i(p,\alpha_i) + \hat{S}_i(\hat{p}_i) f_i \,\mathrm{d}i - \int_0^\infty \int_0^1 (c_j + \mathbf{e_j}) u_i(j) f_i \,\mathrm{d}i \, dK(j)$$
$$- \int_0^\infty I_j dK(j)$$
$$\text{s.t. } D_i(p,\alpha_i) + \hat{D}_i(\hat{p}_i) = \int_0^\infty u_i(j) dK(j)) \ \forall i.$$

The associated first order conditions are as follows:

$$\mathbb{E}_i[\frac{\partial S_i}{\partial p} - \frac{\partial D_i}{\partial p}\frac{\lambda_i}{f_i}] = 0 \qquad \text{(F.O.C. wrt } p\text{)}$$

$$(c_j + \mathbf{e_j}))f_i = \lambda_i \qquad \text{(F.O.C. wrt } u_i(\cdot)\text{)}$$

$$I(c) = \mathbb{E}_{i:\lambda_i/f_i > c_j + e_j)} \left[\frac{\lambda_i}{f_i} - c_j - \mathbf{e_j} \right] \qquad \text{(F.O.C. wrt } k(\cdot)\text{)}$$

$$\frac{\frac{\partial S_i}{\partial \alpha_i}}{\frac{\partial D_i}{\partial \alpha_i}} = \frac{\lambda_i}{f_i} \qquad \text{(F.O.C. wrt } \alpha_i\text{)}$$

$$\lambda_i = \hat{p}_i f_i \qquad \text{(F.O.C. wrt } \hat{p}_i\text{)}$$

$$\int_0^\infty u_i(j) dK(j) = D_i(p,\alpha_i) + \hat{D}_i(\hat{p}_i), \qquad \text{(F.O.C. wrt. } \lambda_i\text{)}$$

where λ_i is the Lagrange multiplier associated with the need to have sufficient energy generation to cover the aggregate demand in state i. The above conditions determine the solution to the problem. In the optimum, the consumers on smart meters face the real-time wholesale energy prices and the traditional-meter consumers are charged a price that is a weighted average of the wholesale energy prices.

Importantly, pollution externalities affect both the optimal amount of capacity and the utilization rates of individual types of generators (the new elements compared to the model without environmental externalities are highlighted in bold). The direction and magnitude of that influence become clear when looking at closed form solutions, which we obtain when restricting the number of states of nature and generator types to be finite, as done in Section 3.3.

D Welfare comparisons when externalities create extensive distortions

The inefficiencies associated with not internalizing externalities are particularly pronounced when the externalities are disruptive, i.e. when they change the merit order defined by the mapping $h : \mathcal{N} \mapsto \mathcal{M}$. In such a case, the welfare losses under the status quo occur through two channels:

- distortion on the intensive margin where, for some of the consumed energy units, the social marginal costs of generation are higher than the utility from consumption
- extensive distortions where, in some of the demand states, the marginal technology is not the least expensive one from a social point of view, resulting in unnecessarily high social generation costs given the quantities produced.

D.1 Comparison of equilibrium outcomes in energy-only markets under status quo, emission tax and subsidies regime

The first-best generation mix differs from status quo generation not only in the shares of individual resource types but also in the merit order. The latter implies that the first-best set of economic resources, $\mathcal{P}_N^{FB}$, includes additional types of the relatively low polluting resource types or that the low polluting resources are marginal in more states under the first-best. Correspondingly, under first-best, some types of higher polluting resources that are in the merit order under the status quo are not economic or they have lower capacity utilization.

Given the high efficiency losses that occur when merit order is distorted by the markets not accounting for externalities, the potential gains from a subsidy are higher. However, unlike with subsidies aiming at intensive margin presented in the previous subsection, there exists a minimum subsidy rate, s^{min}, below which the subsidy is ineffective – it does not change the merit order.

To see that, assume that the status quo merit order consist of various polluting resources with the i^{th}-merit resource being of type q. However, under first-best, a pollution-free resource of type r is marginal in state i. In such a case, in accordance with Lemma 2, the minimum subsidy rate needed to correct the merit order is given by:

$$s_i^{min} = c_r - c_q + \frac{I_r - I_q}{\sum_{k=i}^{N} f_k} + \epsilon, \tag{17}$$

where ϵ is an arbitrarily small positive number. Under such subsidy, the prices and demands in individual states are the same as without the subsidy, but the technology q gets (partly) replaced by resources of type r.[39]

Obviously, a uniform subsidy is again unable to fix the distortions in the merit order when the inefficiency concerns two resources of differing pollution intensity.

Theorem 4. *When the merit order under the status quo deviates from the first-best merit order because of uninternalized pollution, there exist a subsidy for non-polluting resources financed from the general budget that weakly increases efficiency of the market compared to the status quo.*

Proof - see appendix A.6. □

When the subsidy is financed through a revenue-neutral electricity consumption charge, conditions parallel to those described in Theorem 3 are sufficient (but necessary) to ensure that the subsidy increases welfare.

D.2 Comparison of equilibrium outcomes in energy and capacity markets under status quo, emission tax and subsidies regime

As explained in Sections 4.2 and 4.3, an energy price cap combined with a capacity market can lead to the same outcomes and have the same welfare properties as an energy-only market. Therefore, the insights from energy-only markets on energy prices, resource mix and welfare under the status quo and generation subsidy in presence of extensive externalities (shown in Appendix D.1) are true also for energy and capacity market design.

Consequently, even with extensive externalities, the capacity prices are weakly lower under the status quo than under the first-best. This happens because capacity prices are determined by the difference between the competitive energy price in the highest demand state and the price cap. Emission pricing in the presence of extensive externalities increases the market peak price, unless, under the status quo, a pollution-free generator serves as a peaker.

[39] The replacement might not be full if technology q is marginal under the status quo in more than one state.

The results on capacity prices in the setting of intensive externalities extend to the extensive externalities case. The capacity price under the status quo is the same as that under the subsidy scenario as long as the peaker unit under the subsidy regime is not of pollution-free type (and thus does not receive payments). This happens when the status quo peaker unit is of polluting type and the generation subsidy does not cause it to be replaced by a pollution-free unit. Should this not be the case, the long-term capacity price goes down.