Nuclear Capacity Auctions

Sven-Olof Fridolfsson and Thomas P. Tangerås[*]

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Abstract

We propose nuclear capacity auctions as a means to correcting the incentives for investing in nuclear power. In particular, capacity auctions open the market for large-scale entry by outside firms. Requiring licensees to sell a share of capacity as virtual power plant contracts increases auction efficiency by mitigating incumbent producers' incentive to bid for market power. A motivating example is Sweden's policy reversal to allow new nuclear power to replace old reactors.

Keywords: Capacity auctions, investments, market power, nuclear power, virtual power plants.

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[*] Research Institute of Industrial Economics (IFN), Grevgatan 34, Box 55665, 102 15 Stockholm, Sweden. E-mail: sven-olof.fridolfsson@ifn.se, thomas.tangeras@ifn.se.

1. INTRODUCTION

The decision of the Swedish Parliament in 2010 to open up for new nuclear power marked a u-turn in the country's nuclear policy. The previous 30 years the official policy had been full abandonment. Reactors were to be phased out as fast as the energy system permitted, bearing in mind the consequences for employment and economic welfare. The fundamental role played by nuclear power – on average it accounted for 43.5% of Swedish annual electricity production from 2003 to 2012 – can help explain why only two out of twelve reactors have been shut down.[1]

The Fukushima meltdowns following a massive earthquake and tsunami brought renewed attention to the complexity and dangers of operating nuclear power plants. Furthermore, the profitability of investing in nuclear power has declined, not least owing to the decrease in wholesale electricity prices resulting from renewable electricity support schemes. These developments have caused observers to doubt the political and economic viability of nuclear power (e.g. Davis, 2012), and trigger two fundamental policy questions: How much new nuclear power should there be from a welfare point of view? How will investments, if socially desirable, come about?[2]

Prior to liberalization, investment incentives were shaped by regulation. A drawback was that policy makers lacked information about the socially optimal level of capacity. The difficulty with creating appropriate incentives by means of detailed regulations was one of the key arguments in favor of liberalizing the Swedish electricity market (Nutek, 1991).[3]

In a liberalized electricity market, investment decisions are delegated to the market participants who will invest in nuclear capacity if and only if doing so is privately profitable. Market external effects can be corrected by an appropriate menu of taxes. However, it is unlikely that investment decisions would be optimal even if the owners could be impelled to internalize the full social cost of nuclear power. Because of their size, every new reactor

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[1] The production data are from the PRIS database (www.iaea.org/PRIS). We refer here to the 12 reactors that were in commercial operation in Sweden subsequent to 1980. Number 13, the tiny Avesta reactor, had 12 MWe installed capacity and was shut down already in 1974.

[2] Framing our analysis in the legal context of new nuclear power in Sweden is mainly for illustration. Many of the world's nuclear plants will retire between 2035 and 2050 (Joskow and Parsons, 2012). With the long lead times in planning and construction, how to secure the desired level of investment is a problem countries with older nuclear power plants, like France, the UK and the US, need to address in the near future.

[3] As an indication of these problems, Davis and Wolfram (2012) find capacity utilization to be comparatively higher in the US nuclear power plants operating in deregulated wholesale electricity markets.

lowers market prices and decreases the profitability of other production. Three of the largest companies in the Nordic market, E.ON, Fortum and Vattenfall, share the ownership of all three Swedish nuclear plants and jointly decide about investment. Market concentration implies that the nuclear owners are likely to take the surplus reduction on existing generation into account in their investment decision. Exercise of such long-run market power leads to underinvestment and excessive electricity prices.

Long-run market power is usually curtailed by imports or by new producers entering the market. But import capacity is limited by bottlenecks in the transmission network. And entry barriers are significant, as incumbent producers in practice control nuclear investments even under the new Swedish legislation: At most ten new reactors can be built, one for each of the reactors currently in operation; a new reactor cannot be set into operation until an old one permanently shuts down; and all new reactors must be located at the three current nuclear sites owned by the incumbent nuclear producers.

We propose nuclear capacity auctions as the key to unlocking the market for nuclear investment. In a nuclear capacity auction, the seller, say a government agency, auctions off a license to build and operate a nuclear reactor. The winner commits to constructing and operating the reactor according to specifications. Compared to a situation where nuclear investment is delegated to incumbents, the auction mitigates long-run market power by introducing competition at the investment stage. Thereby the license may be allocated to a more efficient bidder - either in terms of lower investment costs or because the bidder expects to be able to produce more efficiently than its competitors. The bids also reveal information about the economic viability of nuclear power. In particular, the license remains unsold and no new nuclear power is built if bids are too low (they could even be negative).

An auction is likely to produce a more efficient result the larger the set of bidders because the expected minimum investment cost is lower and bidding competition is fiercer the more bidders are active in the auction. And the mere threat of entry mitigates incumbents' incentives to bid for market power. Still, producers usually fail to account for the effect of the investment on consumer surplus. A bidding consortium of producers and industrial consumers would partly align consumer and producer interests in the bidding process. Thus we recommend to encourage as many bidders as possible to participate in the auction, not only entrants but also incumbents and energy intensive industries, in bidding consortia for nuclear capacity.[4] Joint ownership by incumbent producers exacerbates underinvestment because the perceived opportunity cost of new nuclear power increases. We thus also recommend to avoid the participation of more than one incumbent producer in each bidding consortium, if possible.

Incumbent producers may be willing to pay a premium on the license for the opportunity to exercise short-run market power. Incumbents bidding for short-run market power distort the auction. The standard remedy is to modify the auction (e.g. Jehiel et al., 1996). We propose a simpler solution which requires the licensees to sell a significant share of their capacity as virtual power plant (VPP) contracts. A VPP contract is an option which gives the holder the right to purchase the contracted amount of electricity from the producer at marginal production cost. VPP contracts effectively delegate the production decision to the buyers of the contracts and thereby mitigate short-run market power and the incentives to bid for it.[5]

The profitability of nuclear investment depends not only on market conditions, but also on current and expected taxes. One problem is that policy makers have an incentive to increase taxes once the plant is in operation and the investment costs are sunk. Swedish authorities have for instance increased the tax on installed nuclear capacity several times over the years. A novel finding is that investors may protect themselves against tax expropriation by selling long term supply contracts at nuclear marginal production cost *prior* to setting the plant into operation. Long term contracts help investors secure financing of the power plant and simultaneously reduce the producer surplus susceptible to expropriation.

2. NUCLEAR POWER IN THE NORDIC COUNTRIES

Sweden is part of the Nordic electricity market together with Denmark, Finland, Norway and the Baltic countries.[6] Bottlenecks in the transmission grid regularly divide the Nordic market into *price areas*. Over the last years, Finland and Sweden often have formed a joint price area against the other markets. Nuclear power accounts for roughly 22% of installed capacity in this Finnish-Swedish price area, whereas hydro power and thermal capacity other than nuclear

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[4] The pro-competitive effects of bidder participation are well-known and hold under general circumstances; see e.g. Milgrom (2004). More generally, our analysis and recommendations lean on a large body of literature on optimal auction design (e.g. Klemperer, 2004, Milgrom 2004). Many of the design issues pertaining for example to spectrum auctions - how to attract bidders, how to avoid collusion – are relevant also to nuclear capacity auctions. The possibility to attract large industrial consumers as bidders is specific to capacity auctions, however.

[5] Ausubel and Cramton (2010b) discuss VPP auctions at length, but without relating them to capacity auctions.

[6] The Nordic market is interconnected also with Germany, Poland, Russia and The Netherlands.

account for approximately 35% each. The rest is predominantly Swedish wind power (all data are from NordREG, 2013).

Table 1: Ownership shares of Nordic nuclear power

	Sweden			Finland	
	Forsmark	Oskarshamn	Ringhals	Loviisa	Olkiluoto
E.ON	10	55	30	-	-
Fortum	22	45	-	100	27
Vattenfall	66	-	70	-	-
Pohjolan Voima	-	-	-	-	57
Capacity - MWe	3138 (3)	2311 (3)	3702 (4)	1156 (2)	1540 (2)

Source: The websites of the respective nuclear plants.

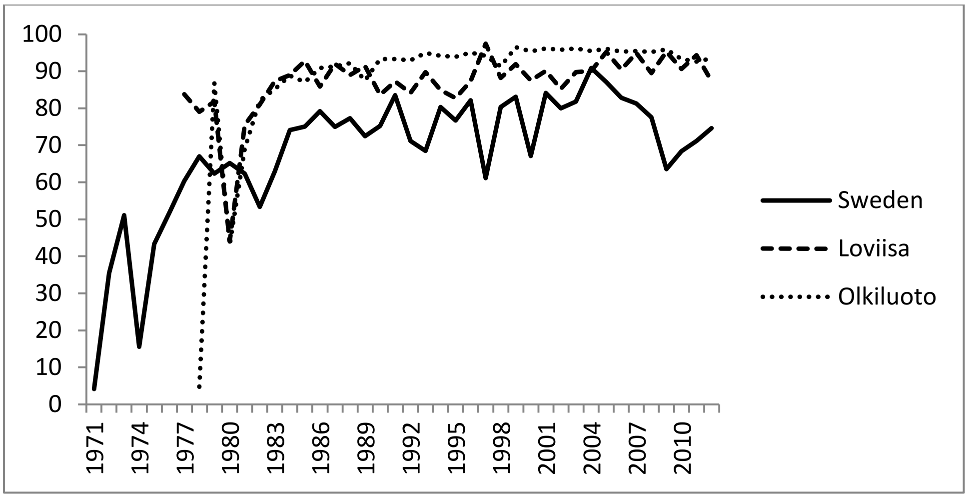
Table 1 identifies the companies with ownership shares above 10% in the five nuclear plants currently operating in the Nordic market, along with the net capacity of each plant (the number of reactors is in parenthesis). All three Swedish plants are owned jointly by two or more large generation companies. This is not the case in Finland, where Fortum owns Loviisa on its own and Olkiluoto jointly with smaller energy companies and the energy intensive industry. Pohjolan Voima is controlled by the pulp and paper manufacturers United Paper Mills and Stora Enso.

All reactors in Table 1 were phased in between 1971 and 1985. Estimates of their lifespan range between 40 and 60 years. Several of them are therefore likely to be phased out by 2030. The two reactors at the Barsebäck plant were shut down in 1999 and 2005 as a consequence of the Swedish decision to abandon nuclear power. Finland has remained generally positive to nuclear power and has instead decided to expand nuclear production. A third reactor is under construction at the Olkiluoto site, and the Finnish government has since then authorized the construction of two additional reactors.

Operating performance displays substantial variation between the different plants. Figure 1 displays the aggregate annual capacity utilization of the ten active Swedish reactors compared to the two Finnish plants. Swedish nuclear power has systematically underperformed relative to both Finnish plants from the outset, even predating market liberalization in 1996. From 1981 and onwards, annual capacity utilization in the Swedish plants on average was 16.68 percentage points lower than in Olkiluoto. This amounts to a full reactor of the size currently under construction at Olkiluoto, assuming a capacity utilization of 87%. Note also that

Olkiluoto has outperformed Loviisa for most of the period since 1981. The average difference in capacity utilization between the two plants is 3.38%.

Figure 1: Nuclear capacity utilization Sweden versus Finland 1971-2012



Source: IAEA- PRIS database. Data from the closed Swedish plant Barsebäck are excluded.[7]

3. THE INCENTIVES FOR INVESTING IN NUCLEAR POWER

Nuclear power represents the archetypical base load generation. The fixed cost constitutes the major portion of the total cost and is made up of the construction cost plus incremental capital costs, discounted fixed O&M expenditures and decommissioning costs. The construction cost itself is usually calculated as an overnight cost which accounts also for the interest and equity payments that accrue during the construction of the plant. The variable cost consists of fuel costs, variable O&M and waste funds and is comparatively small.[8] The cost structure of nuclear power implies that profitable investment requires wholesale electricity prices substantially and consistently above the marginal (i.e. variable unit) cost.

Figure 2 illustrates the market effects of an investment in new nuclear power. The demand and supply schedules are for a representative year. An incumbent supplies base load (nuclear) power at constant marginal production cost c up to the capacity k. Additional supply is

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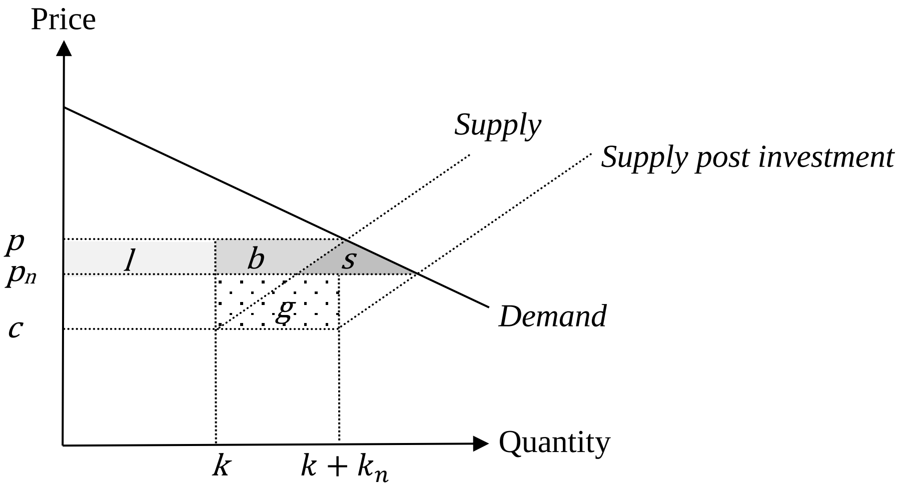
[7] Our measure of capacity utilization is the load or capacity factor as defined in the PRIS database: Actual output divided by the maximum that could be maintained continuously throughout a prolonged period of operation. We exclude Barsebäck because PRIS does not report that plant's capacity factor for the years 1995-2003. Adding it would not alter the conclusion that Swedish nuclear power has underperformed relative to that in Finland. This underperformance holds uniformly also at individual plant level, although we do not report it here.

[8] This decomposition builds on the classification in MIT (2003). Du and Parsons (2009) estimate in an updated report a levelized (average) cost of nuclear power in the range of 35-48 Euro per MWh (EUR/MWh), of which the variable unit cost constitutes around 7 EUR/MWh.

covered by increasingly costly peak load production. The market clearing price equals p. Consider an increase in nuclear capacity by a modern reactor of capacity k_n. The magnitude of the new reactor represents a substantial outward shift in the supply curve, subsequent to which the market price falls to p_n. The dotted area $g = (p_n - c)k_n$ represents the producer surplus of the new reactor, whereas the light-shaded area $l = (p - p_n)k$ depicts the incremental loss suffered by the incumbent on current nuclear capacity owing to the lower market price. The investment has consequences also beyond the effect on base load. The price reduction from p to p_n inflicts a loss on peak load production equal to the darker area b, whereas consumer surplus increases by a total of $l + b + s$.

Figure 2: Nuclear investment incentives



Nuclear reactors have a technical lifetime of 50 years or more. Let G be the discounted producer surplus of the new reactor over its entire lifetime, L the discounted incremental loss on other nuclear power, and with B and S analogously defined.[9]

The new reactor has a positive net present value (NPV) if the discounted producer surplus G is sufficient to cover the incumbent's fixed cost F_I of the new plant. However, an incumbent concerned with the maximization of its total profit would also take the loss L on its existing nuclear capacity into account and make the investment if and only if $G - L \geq F_I$.[10,11]

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[9] Strictly speaking, all areas in Figure 2 should have time indexes because the numbers are likely to change from year to year. G, L and so on should thus be interpreted as the expected discounted gains and losses.

[10] Profit maximization is a realistic assumption, not only for the privately held companies. An example is state-owned Vattenfall, whose mission statement stipulates that the objective of operations is to generate a market-based return on capital. Profit maximization implies that management exercises market power to its full extent within the company's legal boundaries. We do not mean to suggest that managers thereby engage in market

The welfare effect of the investment equals the net increase S in consumer surplus plus the increase G in producer surplus minus the fixed cost F_I. The terms $L + B$ represent pure redistribution from producers to consumers and have no welfare effect. Profit maximization tends to cause underinvestment because incumbents fail to internalize the positive effect S on consumers and exercise long-term market power by accounting for the loss L on existing capacity. In particular, investment by the incumbent is socially desirable, but privately unprofitable if

$$G - L < F_I < G + S. \tag{1}$$

As we can see, underinvestment is more severe the larger is the generation portfolio of the incumbent, as L increases. Joint ownership of nuclear capacity would further exacerbate underinvestment because the decision to build new nuclear power most likely would also account for the effect on the generation portfolio of the other owners.

The exercise of market power would be mitigated by entry.[12] An entrant planning a nuclear facility with capacity k_n would consider the surplus G, ignore the consumer gain S and also the loss L on existing capacity. Entry would be profitable if the reactor had a positive NPV, i.e. $G > F_E$, where F_E is the entrant's fixed cost. Note also that a mere threat of entry could induce investment. By investing k_n, the incumbent recovers G and does not only suffer the loss L.

Entry generates potential welfare gains other than mitigating long-run market power. In a competitive market, entry occurs and is successful if and only if entrants are more efficient than the incumbents, either in terms of lower fixed costs ($F_E < F_I$) or because they produce

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manipulation or any unlawful conduct such as abuse of dominant position or collusion. Furthermore, it is not necessary for the subsequent analysis that firms' *only* objective is to maximize profit. Inefficiencies arise as long as firms place more weight on their own profit than what a benevolent social planner would do.

[11] The exercise of short-term market power, whereby production is withheld to increase the price of electricity, has been established in the UK (e.g. Wolfram, 1999) and California wholesale electricity markets (e.g. Borenstein et al., 2002). We analyze the consequences of short-term market power, in Section 4.2. There have been no studies quantifying long-term market power. One explanation could be measurement problems. Typical market power measures are based on the wedge between price and marginal cost. To estimate long-run marginal cost, one also has to estimate the competitive returns to capital. Estimates based upon historical data are of limited value, either because historical returns reflect market power or because they reflect regulatory policy when estimated on pre-liberalization data. The typical approach taken by papers estimating investment costs (e.g. MIT, 2003) is to apply an ad hoc rate of return.

[12] Another possibility would be increased imports. However, import competition is limited by bottlenecks in the international transmission interconnections that in Sweden are under monopoly control of the Transmission System Operator (TSO), Svenska Kraftnät.

more efficiently. The low capacity utilization in Swedish nuclear power plants (see Figure 1) suggests a potential for improved productive efficiency through entry.

To illustrate the magnitudes involved and that entry might be socially beneficial, consider a hypothetical investment in a reactor of the same type as Olkiluoto 3 in the Nordic market. An installed capacity of 1600MWe generates $k_n = 12.6$ TWh annually at 90% capacity utilization. A price of $p_n = 37$ EUR/MWh and a marginal cost of $c = 7$ EUR/MWh yield an annual producer surplus of $g = 378$ million Euro (mEUR).[13] The discounted surplus of the reactor equals approximately $G = 4.4$ billion Euro (bEUR) with a life span of 60 years given a weighted average cost of capital (WACC) of 8.5%.[14] Incremental capital costs, fixed O&M and decommissioning amount to roughly 0.9 bEUR (MIT, 2003; Du and Parsons, 2009). With these numbers, the reactor has a positive NPV if the overnight cost is below 3.5 bEUR.

To estimate Vattenfall's associated loss L on installed capacity, let existing hydro capacity (or upgrades of it) remain operational for the life span of the new reactor, with annual production of 33 TWh; which equals Vattenfall's hydro output in 2012. Assume that the new reactor becomes operational in 2026, and that 5 out of their 7 Swedish nuclear reactors operate for 10 additional years, with a yearly output of 35.5 TWh.[15] Assume that the price of electricity drops by 1.25 EUR/MWh subsequent to investment.[16] Vattenfall's annual loss on installed capacity will then be 85.6 mEUR during the first ten years and 41.3 mEUR the fifty subsequent years. This yields a discounted loss of approximately $L = 0.8$ bEUR, or 18% of the discounted surplus of the investment.

Under the assumption that the investment cost is the same for the entrant and the incumbent, entry would yield socially optimal investment in the numerical example for overnight costs in

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[13] The average annual wholesale price of electricity in the Nordic market was 38.4 EUR/MWh during 2004-2013; see www.nordpoolspot.com.

[14] An assumed real interest rate on debt of 5% and cost of equity of 12% yield a WACC of 8.5% at a 50/50 debt to equity ratio. The numbers are from MIT (2003).

[15] Vattenfall estimates that Ringhals 1 and 2 will be decommissioned after 50 years of operation, that is in 2026. The other 5 reactors are younger, and Vattenfall estimates their life span to 60 years (Source: Press release on May 22, 2013 retrieved from www.vattenfall.com). If the latter estimate is correct, then the younger reactors will operate for at least 10 years beyond 2026. Vattenfall's total nuclear output in 2012 was 43.5 TWh, out of which Ringhals 1 and 2 contributed about 8 TWh. Assuming that the yearly expected production in the other reactors is the same as in 2012 gives residual nuclear production of 35.5 TWh per year.

[16] This amounts to a 3.25% price reduction at the hypothetical ex post price of 37 EUR/MWh. Estimations based upon historical supply and demand curves from the Nordic day-ahead market suggest that a new 1600 MWe reactor could decrease the annual average electricity price by as much as 5%, all else equal. The estimations are available upon request.

the range of 2.7 to 3.5 bEUR. As a comparison, the original contract for Olkiluoto 3 was for 3.2 bEUR.[17]

Public opposition to nuclear power and to the exploitation of unexplored river basins have provided entry barriers to the development of new nuclear and large scale hydro production in Sweden. The Swedish Parliamentary decision in 2010 to allow the replacement of the old reactors by new ones does little to reduce entry barriers. There are firm restrictions on the number of new reactors, the locations and when they are allowed to be put into operation. Effectively, nuclear investment still remains in the hands of E.ON, Fortum and Vattenfall. Our purpose is to study how a nuclear capacity auction may facilitate investment by reducing entry barriers.

4. A NUCLEAR CAPACITY AUCTION

A nuclear capacity auction sells the license to build and operate a nuclear reactor at a specific site to one of several bidders. Consider a set of J potential entrants bidding for the license to replace an old reactor with a modern one, assuming the old reactor is decommissioned by the time the new one starts operating. Assume that all investors would run the new reactor competitively. Marginal production costs are fairly stable and predictable. Hence, we assume that the producer surplus G is known and the same for all bidders. The viability of new nuclear power depends crucially upon capital costs. These costs have escalated over time, partly due to stricter safety standards, but also because the costs of large scale engineering projects have increased substantially. The ability to complete a project in time and at required specifications is crucial and probably varies across bidders. We therefore assume that bidder $j \in J$ has investment cost F_j and values the license at $G - F_j$. A purpose of the auction is to elicit information about investment costs.[18]

We use the Vickrey auction to illustrate the economics of the nuclear capacity auction. In a Vickrey auction, the license is sold if and only if at least one bid exceeds a threshold, the *reserve price*. The license goes to the highest bidder at the price of the second highest bid or the reserve price, whichever the highest. Bidding the true valuation is a dominating strategy in

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[17] Excessive delays and cost overruns have increased the cost estimate, possibly to 8.5 bEUR by some accounts; see www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Finland/, accessed May 21, 2014.

[18] As there are as many as ten licenses up for sale, the seller conceivably could sell multiple licenses in the same auction and even bundle them together. Given the economic magnitudes and uncertainties involved, the bidding process probably reveals important information about the profitability of nuclear investment. Owing to this price discovery process, we envision sequential auctions of single licenses to be the most practical. But we acknowledge that it could be optimal to bundle site-specific licenses if they display complementarities.

the Vickrey auction. Consequently, the license goes to the entrant with the lowest investment cost F_E if sold. The auction selects the most efficient bidder, but is not necessarily optimal as entrants do not account for the increase S in consumer surplus arising from increased production. However, a negative reserve price, $b^* = -S$, ensures that the investment is undertaken if and only if socially desirable, as $G - F_E \geq b^* \Leftrightarrow G + S \geq F_E$.

The above auction is socially optimal (in a partial equilibrium sense) and illustrates how a nuclear capacity auction can improve welfare relative to a policy delegating the responsibility of building and operating new nuclear power to an incumbent. One problem is that b^* is unobservable to the seller, not least because the reserve price must be evaluated at the post-investment price p_n.[19] Another drawback is that the auction may generate very low revenues (as in the spectrum auctions in New Zealand). In fact, the investment could even be subsidized, as $b^* < 0$. Swedish law, however, precludes subsidies to nuclear power and therefore we simply assume that the reserve price is zero.

The Vickrey auction with zero reserve price produces the social optimum if the investment is privately profitable, $F_E \leq G$, or socially unprofitable, $F_E > G + S$. Entrants' previous experience in building and operating modern reactors yields a competitive advantage, a factor which may be particularly important for Sweden where two of the current owners have no such experience. But it is also conceivable that incumbents have lower capital costs than the other bidders ($F_I < F_E$) because of scale returns to operating multiple reactors on a single site, or superior knowledge about site specific constraints, local regulations and overall market conditions.[20] Let therefore the incumbent participate in the auction. Assume also that the incumbent knows whether $G > F_E$ (or infers so upon observing that entrants are preparing bids). Provided $G > F_E$, the incumbent's relevant alternative to winning the license is that the entrant does, and therefore the incumbent bids $G - F_I$ and wins the license if and only if $F_I < F_E$. (If $G < F_E$, the incumbent's investment incentives are the same as in the previous section. In this case the capacity auction has no welfare effect besides the cost of setting it up). Underinvestment occurs from a welfare viewpoint if and only if

$$G < \min\{F_E; \mathrm{F_I}\} < G + S. \qquad (2)$$

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[19] The reserve price could of course build on an estimate of S.

[20] Grubler (2010) compares US and French nuclear power and shows that construction costs were smaller in France where reactor designs were more standardized, nuclear sites had multiple reactors and were operated by a single owner. This evidence suggests a cost advantage of operating multiple reactors on a single site.

The auction improves welfare compared to the default situation in (1) where the incumbent controls the investment. The incumbent no longer internalizes the pure redistribution loss L because of the threat of entry. And the expected minimum investment cost is lower and bidding competition fiercer, the larger the set of bidders.

The failure of bidders to internalize the consumer surplus increase S remains problematic. Encouraging energy intensive industries to participate in bidding consortia could mitigate underinvestment. Energy intensive industries are valuable owners of nuclear power plants as they internalize consumer surplus, not only producer surplus. The least-cost entrant then values the investment at $G - F_E + \alpha(L + B + S)$, where α depends on consumer ownership share, the perceived probability that the nuclear power plant is not built, and electricity demand. If all bidders have formed symmetric bidder consortia, then the reactor is built by the least-cost consortium if $\min\{F_E; \mathrm{F_I}\} \leq G + \alpha(L + B + S)$. Private and social preferences are aligned in this (very) parametric case if $\alpha = S/(L + B + S) \in (0,1)$. The value of including industrial consumers, measured by α, increases when the investment's net effect S on consumer surplus is stronger. As an added benefit, expected auction revenues are higher, as valuations increase when bidders internalize the consumer surplus. And the high capacity utilization in Olkiluoto relative to Loviisa, see Figure 1, suggests a potential for improved productive efficiency through consumer ownership.

Recommendation 1: Encourage as many serious bidders as possible to participate in the nuclear capacity auction: incumbents, entrant utilities and energy intensive industries.

A serious bidder is an investor, or consortium of investors, with project proposals that meet relevant safety standards and with a credible commitment to safe disposal of radioactive waste. Investors must also have the financial resources to build the new reactor, operate (or subcontract) it according to market regulations and decommission it in a proper manner. A fairly large number of utilities worldwide have established track records for the safe and efficient operation of nuclear power plants. In Europe, these include EDF, Electrabel (GDF-Suez) and RWE. The energy intensive industry sometimes holds ownership shares, as in Olkiluoto. A consortium of large Swedish industrial consumers, Industrikraft i Sverige AB, has stated an interest in investing in new nuclear power plants in Sweden.

Project preparation is expensive and time consuming. Reducing project costs increase the attractiveness of the auction, the number of bidders, and thereby auction performance. To minimize bidder costs, investors should be subject to a transparent approval process prior to their acceptance. The rules of the auction should be clear and communicated well in advance. All aspects of project planning related to grid investment should be carried out by the system operator. This also avoids costly duplication.[21] A significant part of project planning falls upon the nuclear power plant manufacturers who could be contracted to deliver equipment to more than one consortium. The project risk facing an individual manufacturer could then be substantially smaller than the risk taken by individual bidding consortia. This serves to reduce participation costs further.

Joint ownership of production capacity implies that owners would internalize parts of the loss B in surplus on other production in the investment decision; see Figure 2. Incumbents fail to internalize this loss for the same reason they fail to internalize L if entrants participate in the auction. But if incumbents are the only participants, then joint ownership is likely to reduce auction efficiency through collusive bidding. In fact, the need for replacing the old reactors creates an opportunity to dissolve the current ownership structure in the Swedish nuclear plants. As an added benefit, this would increase competition in the auction by adding several incumbents to the stock of bidders.

Recommendation 2: Ideally, each bidding consortium should contain at most one incumbent producer as a major stakeholder.

Producers may prefer joint ownership of nuclear reactors for reasons other than internalization of losses in surplus. It can represent a risk-sharing mechanism in case of accidents or unexpected break-downs. But other solutions, such as nuclear pools wherein a larger set of producers shoulder the financial burden of nuclear disaster, appear superior in handling risks. Another motivation can be the magnitude of the investment. But in a global market there is no reason why capital necessarily should be raised jointly by incumbents. As an example, the Chinese nuclear companies CGN and CNNC will be minority shareholders in the UK Hinkley Point project lead by EDF. Joint ownership with the industry represents another attractive possibility. Either way, reactors are built without the involvement of multiple large incumbent producers, one of them being Olkiluoto 3 in Finland.

The outcome of the nuclear capacity auction may imply that entrant(s) operate some reactors at a site while the incumbent operates others. Mixed operations should not cause substantial

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[21] Svenska Kraftnät has started to investigate the transmission requirements for new reactors in Sweden.

problems under normal operating conditions as the grid should optimally handle full capacity utilization of all reactors. Transmission failures may call for a coordinated reduction at a site. But a market mechanism, the real time market, is in place to handle interruptions efficiently. Another concern might be that multiple owners find it difficult to cooperate on sharing onsite safety equipment. But it would be in the long-term interest of owners to ensure a safe operation of all reactors because all of them are stuck in the same boat (site). Reactor-specific operating responsibilities may even provide a benchmark against which to compare individual reactor performance.

Construction delays are common, not least for new reactor designs.[22] In light of these uncertainties, reactor replacement should be spread over time to minimize shortage risk and excessive prices. Coordinating the substitution of old reactors for new ones is facilitated if reactors are owned by incumbent producers. Also, delays would be less of a problem in an integrated market, as the production in one reactor then plays less of a role for total supply.

An old reactor's remaining life time is uncertain and continued operation may be possible when the new reactor is built. An incumbent can inflict a serious loss on entrants by maintaining operations in an old plant, because the Swedish legislation forbids a new reactor to be put into operation until an old one shuts down. Continued production is credible because the opportunity cost to the incumbent is zero. Strategic deferral undermines the auction as no rational entrant would bid anything under those circumstances. The legal requirement that all new reactors must be built at a current site probably implies that they represent *essential facilities* under Swedish competition policy. Hence, current owners could be legally forced to relinquish control of their sites in exchange for a reasonable compensation. Ideally, the compensation should be based upon the NPV of continued operation. Applying this criterion is complicated by the incumbent's incentives to exaggerate the value of continued production so as to extract rents from the entrant or to deter entry. In practice, excessive compensation may well be less of a problem. Most of the reactors will probably be close to the end of their expected life time when they are up for replacement and therefore the value of continued production ought to be low.

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[22] As an illustrative case in point, Olkiluoto 3 was originally scheduled to start operation early 2009, but could be delayed until 2018 by the plant supplier's latest assessment (www.tvo.fi/news/303, retrieved September 9, 2014).

4.1. Safety Considerations

As the nuclear accidents in Three Mile Island, Tchernobyl and Fukushima have reminded us, safety is fundamental to the socio-economic viability of nuclear power. Projects should be required to meet strict safety regulations before being allowed to enter into the auction. In practice, there will only be a handful of relevant designs to consider because manufacturers develop standardized reactors as a response to global safety requirements and escalating R&D costs. Cutting safety corners comes at considerable financial risk as regulators could introduce new regulations or delay construction. The closure of the Shoreham nuclear power plant in 1989, which was ready, but never allowed to produce electricity, shows that regulators can even terminate projects if safety concerns become serious enough.

Swedish power plants pay a production tax and plant specific fees to cover nuclear waste storage costs. The Swedish Parliament is processing a law which will demand full liability for all costs arising from nuclear accidents. A substantial part of expected environmental cost thus should be internalized in operating and capital costs. Nuclear safety depends crucially on management. Hausman (2014) investigates the effect of deregulation in the U.S on nuclear safety and finds an economically (although not always statistically) significant reduction in safety incidents. As deregulation had a positive impact on nuclear capacity utilization (Davis and Wolfram, 2012), these results suggest that safety and nuclear operating performance are complements. Competition to build new nuclear power could thus improve safety insofar as bidding competition selects the most efficient producers.

4.2. Short-term Market Power

A fundamental problem is that incumbent producers have an incentive to underinvest in new nuclear power to maintain profitability on their remaining production portfolio. Entrants would profit from a comparatively larger investment because they do not suffer any loss on existing capacity. Incumbents would thus prefer to enter the nuclear capacity auction with a relatively small project. But small projects run a risk of being outperformed by larger projects in the auction.[23] Projecting a reactor of the same size as the competitors could be the only option for an incumbent to preempt entry. As the winning incumbent then would possess a reactor of excessive size for its own purposes, it has an incentive to increase profit by

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[23] In general, the auction would select between differentiated projects. Asker and Cantillon (2008) show that scoring auctions typically outperform alternative auction formats. In a scoring auction, the seller scores each project based on a ranking of the different attributes and awards the license to the bidder with the highest score relative to the price. A higher reactor capacity is an attribute which should increase the score of the project.

reducing output *ex post*, i.e. to exercise short-term market power. Also, investment is based on expected, and not realized outcomes. Demand fluctuations, transmission bottlenecks and hydro inflow sometimes create conditions under which it would be optimal to exercise nuclear market power. This happened, for example, in the extreme wet year of 2000 when nearly 14% of the Swedish nuclear capacity was withheld from the market (EME Analys, 2007). We now analyze the consequences of short-term market power for nuclear capacity auctions.[24]

It may sound counterintuitive to exploit market power by withholding nuclear production. But some producers have no other option. Vattenfall mainly keeps hydro, nuclear and wind power in its Nordic portfolio. Wind power has a lower marginal cost than nuclear power, and spilling water is illegal. Besides, nuclear withholding occasionally *is* the cheapest way of exploiting market power. Plants typically shut down for maintenance and reloading in off-peak periods. Rather than starting a nuclear reactor and shutting down other production, it is cost efficient to *prolong* maintenance stops. This is particularly profitable in a hydro-nuclear power system because storage effectively allows the owner to transfer nuclear market power from off-peak to peak demand. Finally, nuclear market power is difficult to detect. Standard measures rely on differences between price and marginal cost. But nuclear power is base load and usually priced above marginal cost at competitive equilibrium. Also, it is easy to mask production withholding as something else, for example safety concerns.

Assume that an incumbent owns two reactors with joint capacity $k_1 + k_2$. Reactor 2 is up for replacement by one with capacity $k_n > k_2$. Market performance depends on whether the license is acquired by the incumbent or an entrant. For the reasons discussed above, assume that replacement capacity is so high that the incumbent would exercise market power. Let $\pi^m = (p^m - c)q^m$ be the incumbent's annual surplus, where q^m is output, p^m the electricity price, and c marginal production cost, which for simplicity is the same in reactor 1 and the new one. Competition ensues if an entrant wins the license. Aggregate nuclear production is higher, $q^d > q^m$, the electricity price lower, $p^d < q^m$, and industry surplus lower, $\pi^d = (p^d - c)q^d < \pi^m$, under duopoly. Each duopoly earns $\pi^d/2$ by assumption.

Let the surplus be sufficient to cover the entrant's annualized capital cost: $\pi^d/2 > f_E$. The incumbent's corresponding valuation of the license is $\pi^m - f_I - \pi^d/2$ because entry is the

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[24] Obviously, the concerns and remedies we identify in this section apply to all kinds of capacity auctions, and are relevant also for capacity auctions of peak demand generation currently under discussion in Europe.

relevant alternative to winning the auction. The auction awards the license to the bidder with the highest valuation, so the incumbent wins if and only if

$$\underbrace{\pi^m - \pi^d}_{Market\,power} + \underbrace{f_E - f_I}_{Cost\,advantage} > 0. \qquad (3)$$

The first term in (3) represents the value of market power. It could be so high that the incumbent wins the license even if at a cost disadvantage in building the new facility. Nuclear power is monopolized instead of exposed to competition, and it is more costly than necessary to build the new plant. We propose virtual power plant contracts as a solution to this problem.

Suppose the licensor requires whomever wins the license to sell the full capacity k_n as virtual power plant (VPP) contracts.[25] A VPP contract is a call option which gives the holder the right to purchase the contracted amount of electricity from the producer at strike price c. If the entire capacity k_n is sold as VPPs and exercised, then total nuclear production increases to $q^v > q^d > q^m$, and the price falls to $p^v < p^d < p^m$ because competing production is reduced less than one-for-one. This happens independently of who actually owns the new reactor.

An incumbent who wins the license retains the surplus $\pi_1^v = (p^v - c)q_1^v$ in reactor 1, where q_1^v is equilibrium production at p^v. The surplus from selling VPPs is $\pi_2^v = (p^v - c)k_n$ as the value of a single option with strike price c is $p^v - c$. An incumbent who loses the auction to an entrant earns π_1^v. The incumbent's valuation of the license becomes $\pi_2^v - f_I$. The entrant's valuation is the profit of selling the k_n VPP contracts less the investment cost: $\pi_2^v - f_E$. The incumbent wins the auction if and only if

$$\pi_2^v - f_I > \pi_2^v - f_E \Leftrightarrow \underbrace{f_E - f_I}_{Cost\,advantage} > 0.$$

VPP contracts for the full capacity of the new reactor have eliminated the value of market power present in (3). VPP holders de facto determine production in the new facility. A small

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[25] VPP contracts were first used in France in 2001 when the dominant producer EDF was forced to sell nuclear capacity in this manner. In the Nordic market, the Danish producer DONG regularly auctions off 600 MWe in the price area Denmark West where it holds a dominant position; see www.nordpoolspot.com/TAS/VPP-auction/. Ausubel and Cramton (2010b) give a detailed account of VPP auctions. They note that VPPs have accounted for small shares of the dominant firms' capacity and suggest that it would be difficult to increase that share. But VPP obligations have so far only been imposed on existing capacity and as such constitute an infringement on property rights. We propose to introduce VPPs ex ante, before property rights are allocated through the nuclear capacity auction. Presumably it would be easier to impose VPPs ex ante than ex post.

buyer without market power exercises the option if the expected price of electricity is higher than the strike price c. Hence, there is no market power to bid for.

Recommendation 3: Require owners of new nuclear capacity to sell a substantial share of their capacity as virtual power plant contracts.

Bidding for market power vanishes when options are exercised non-strategically and all new capacity k_n is contracted. A competitive VPP market appears reasonable because entry costs are small and buyers can contract on small volumes. The set of potential bidders is large: VPPs present an opportunity for new producers to gain a foothold in the market and for large industrial consumers to hedge electricity consumption. In practice, the contract volume is likely to be below the full capacity. If so, the incumbent may exercise market power on the share which is not sold as VPPs. Some buyers may also be able to amass a significant share of contracts if the market is thin. Incumbent producers in particular may pay a premium for VPP contracts to preserve market power and should probably not be permitted to participate.

In general, VPP contracts reduce the value of bidding for market power and eliminates this motive in the limit when the entire capacity is contracted. In principle, the share of VPP contracts could be allowed to differ between incumbents and entrants. An entrant without market power should not be affected by VPPs. Under perfect competition VPPs simply have no welfare effect besides the cost of setting them up. The licensor should thus decide the share of VPPs primarily with an eye to the incumbent's incentive to exercise market power.

The price reduction triggered by VPPs could be so large as to render investment unprofitable. If $\pi_2^v < f_E < \pi^d/2$, then the incumbent wins the license by default since the entrant does not participate in the auction. If also $\pi^v < f_I$, the incumbent abstains from bidding and monopoly prevails. The entrant would participate absent any VPPs and win the license if also (3) was violated. This drawback with VPPs hinges on the assumption of fixed capacity. In practice, entrants are likely to adapt the size of their project, which would facilitate entry.

A solution where incumbents control all nuclear power but sell capacity under VPP contracts might seem a superior alternative to nuclear capacity auctions. VPPs promote competition by limiting short-run market power. Under this alternative setup, the incumbent still could exercise long-run market power by underinvesting in capacity. And the solution foregoes the possibility of investment by more efficient entrants. We therefore view VPPs and nuclear capacity auctions as complements rather than substitutes.

4.3. Tax Expropriation

Swedish nuclear plants are subject to a nuclear tax in addition to property taxes and a tax on nuclear waste. In 2000, it shifted from a production tax to a tax on installed capacity and has increased on several occasions since then. Consider a nuclear plant operating at full capacity k with constant marginal cost c, selling at price $p > c$. The producer surplus equals $(p - c)k$ less the capacity tax tk. Capital costs being sunk, the government can expropriate the entire producer surplus by increasing the nuclear tax *ex post* until $t = p - c$. A private investor anticipating zero producer surplus would stay out of the market. However, the return on the investment is unaffected by the tax if nuclear power is state-owned. Producer surplus equals $(p - c)k - tk$, but is offset by tax revenue tk, so that the state earns $(p - c)k$ in total.

State ownership can be a prerequisite for investment in industries where tax expropriation is expected to constitute a major problem.[26] Still, diversified ownership is desirable because it promotes investment and improves competition. Hence, short-run gains of tax expropriation are likely to be offset by the long-run costs of market concentration and foregone investment. It could then be in the government's self-interest to promote instruments that reduce expropriation. Long-term supply contracts constitute one such potential instrument.

Suppose private investors, prior to building the power plant, sell long-term supply contracts for x MWh electricity in the form of options with strike price c per MWh. When the plant becomes operational, it earns nothing on the x MWh of energy sold at marginal cost c. The surplus available for tax expropriation from the nuclear owners thus falls to $(p - c)(k - x)$. In the limit when the supply contracts cover the entire production, i.e. $x = k$, no surplus remains for expropriation. The revenue from selling the supply contracts can then be used to finance the construction of the nuclear power plant.

If the state can equally well expropriate contract owners, then long-term supply contracts cannot overcome tax expropriation of nuclear owners. However, in many cases buyers would be energy intensive industries with a desire to hedge their electricity consumption. Insofar as these industries are more prone to moving operations abroad, they probably are economically and politically more difficult to expropriate. Moreover, long-term supply contracts are only one of several instruments consumers can use to hedge their electricity consumption. Tax

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[26] We restrict attention to nuclear capacity taxes. Himpens et al. (2011) analyze commitment problems in relation to nuclear production taxes. They propose nuclear capacity auctions, too, but as a means to raising government revenue beyond what is possible by production taxes alone.

expropriation would be further limited if, for legal reasons, it is difficult to tax discriminate between different financial instruments. In the limit, as tax expropriation of buyers becomes impossible, producers can completely avoid tax expropriation by selling the entire production up front.

5. CONCLUSION

We propose nuclear capacity auctions as a means to correcting investment incentives. In particular, capacity auctions open the market for large-scale entry by outside firms. Capacity auctions are not conceptually new, although they have not been done specifically for nuclear power before. Brazil, Chile, Colombia and New England auction long-term supply contracts with the purpose of ensuring adequate reserve capacity for periods of scarcity and as a means to stimulating investment more generally (Ausubel and Cramton, 2010a; Moreno et al., 2010). Markets for reserve capacity are under discussion in several European countries.

The spot market for electricity alone is thought to provide insufficient investment incentives for reserve capacity because price ceilings or interventions prevent spot prices from reaching the levels necessary to render investment privately profitable. Nuclear marginal production cost is low relative to market prices, and provided nuclear power owners act competitively in the short run, reactors will produce at full capacity most of the time. Thus, new nuclear power would be profitable at prices way below any realistic price ceiling. Instead, investment incentives are distorted because of long-run market power, entry barriers and political risk. This paper has sketched some desirable properties of nuclear capacity auctions. More work needs to be done in pinning down the specific details of the auction design. In our view, a key factor to attract investors is a long-term commitment to a nuclear policy which enables entrants, not only incumbents, to profitably invest in nuclear power. Organizing nuclear capacity auctions could contribute to such a commitment.

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REFERENCES

Asker, J. and E. Cantillon (2008). “Properties of Scoring Auctions.” *RAND Journal of Economics*, 39(1): 69–85.

Ausubel, L.M. and P. Cramton (2010a). “Using Forward Markets to Improve Electricity Market Design.” *Utilities Policy*, 18(4): 195–200.

Ausubel, L.M. and P. Cramton (2010b). “Virtual Power Plant Auctions.” *Utilities Policy*, 18(4): 201–206.

Borenstein, S., J.B. Bushnell and F.A. Wolak (2002). “Measuring Market Inefficiencies in California's Restructured Wholesale Electricity Market.” *American Economic Review*, 92(5): 1376–1405.

Davis, L.W. (2012). “Prospects for Nuclear Power.” *Journal of Economic Perspectives*, 26(1): 49–66.

Davis, L.W. and C. Wolfram (2012): Deregulation, Consolidation, and Efficiency: Evidence from US Nuclear Power.” *American Economic Journal: Applied Economics*, 4(4): 194–225.

Du, Y. and J.E. Parsons (2009). “Update on the Cost of Nuclear Power.” CEEPR Working Paper 09–004.

EME Analys (2007). ”Varför är svenskar mycket sämre än finnar på att köra kärnkraftverk?” Document available online at: www.elbruk.se/k_kraft_PM_30_nov.pdf.

Grubler, A. (2010). “The Costs of the French Nuclear Scale-up: A Case of Negative Learning by Doing.” *Energy Policy*, 38(9): 5174–5188.

Hausman, C. (2014). “Corporate Incentives and Nuclear Safety.” *American Economic Journal: Economic Policy*, 6(3): 178–206.

Himpens, P., J. Morbee and S. Proost (2011). “Taxation of Nuclear Rents: Benefits, Drawbacks and Alternatives.” Center for Economics Studies DPS 11.16, KU Leuven.

Joskow, P.L. and J. Parsons (2012). “The Future of Nuclear Power After Fukushima.” *Economics of Energy & Environmental Policy*, 1(2): 99–113.

Jehiel, P., B. Moldovanu and E. Stacchetti (1996). “How (Not) to Sell Nuclear Weapons.” *American Economic Review*, 86(4): 814–829.

Klemperer, P. (2004). *Auctions: Theory and Practice*. Princeton, NJ: Princeton University Press.

Milgrom, P. (2004). *Putting Auction Theory to Work*. New York, NY: Cambridge University Press.

MIT (2003). “The Future of Nuclear Power – An Interdisciplinary MIT Study.” Document available online at: http://web.mit.edu/nuclearpower.

Moreno R., L.A. Barroso, H. Rudnick, S. Mocarquer and B. Bezerra (2010). “Auction Approaches of Long-term Contracts to Ensure Generation Investment in Electricity Markets: Lessons from the Brazilian and Chilean Experiences.” *Energy Policy*, 38(10): 5758–5769.

NordREG (2013). ”Nordic Market Report 2013.” Report 6/2013.

Nutek (1991). “Elmarknad i förändring – Från monopol till konkurrens.” B 1991:6.

Wolfram, C.D. (1999). “Measuring Duopoly Power in the British Electricity Spot Market.” *American Economic Review*, 89(4): 805–826.