Forward Contracts and Generator Market Power: How Externalities Reduce Benefits in Equilibrium

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November 9, 2017

Abstract

Research has shown that forward contracts for electricity can reduce market power and increase producer output. This is frequently used as justification for policy interventions requiring that consumers purchase forward capacity, but it is not a sufficient justification because rational consumers can account for market power impacts when making forward contracting decisions. Advocates for capacity markets suggest that they are an important way to reduce generator market power in spot markets, but that reasoning does not explain why consumers would fail to take this rationale into account and under-procure forward contracts in the absence of regulation. This research attempts to fill that gap, by displaying how positive externalities for forward contract procurement can arise: the benefits of forward contracting to reduce market power lead to positive externalities because they are shared by all consumers, not just those who engage in the forward contract. As such, the total forward contracting level and total welfare decreases in the number of load-serving entities serving the consumer market. This insight suggests new areas for additional research, for instance to study empirical evidence of the described effects or to explore relevant policy interventions.

1 Introduction

Capacity markets for electricity provide a regulated market setting through which generating units are compensated for their contribution to power system reliability, the ability of the power system to meet peak demand. In many regulated markets, for instance in the U.S., the independent system operator (SO) sets a demand curve for capacity for the region, and then charges load-serving entities (LSEs) based on their contribution to the peak system

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[§]This work was supported, in part, by the U.S. Department of Energy and its Wind Power Program under DOE Contract No. DE-AC02-06CH11357 awarded to UChicago Argonne, LLC, operator of Argonne National Laboratory

load. As such, the capacity market essentially serves as a market for a specific type of long-term contract that consumers are required to purchase. The type of forward contract varies, but can be modeled similarly as a type of capacity certificate or reliability option, as demonstrated by an analytical comparison of forward contract types (**?**).

While capacity markets have diverse forms and requirements, compelled participation of demand is a key feature shared in many markets: customers, or LSEs acting on their behalf, are required to engage in a specified level of contracting by paying for the forward capacity quantity that has been determined in an auction process based on the SOs demand curve.

The main rationale for capacity markets is to help generators achieve revenue sufficiency in a market with price caps, which are used to mitigate generator market power. However, they also provides many of the benefits of financial forward contracts, including risk reduction.

Changing energy markets and increased penetration of variable renewable resources have strained capacity markets or led to apparent capacity shortages or excesses in some markets. This has driven increased focus on the benefits and costs of capacity markets (**?**), as well as additional efforts to define the market failures that capacity markets should and can seek to address (**?**).

Some researchers have advocated for scaling back capacity markets, arguing that social welfare would be better served by direct efforts to reduce market power (**?**). Others suggest that a combination of low price caps and higher capacity payments can actually increase market concentration (**?**). **?** has advocated for market design without capacity markets, and ERCOT has implemented an energy-only market design.

Many of the benefits of forward contracting in a capacity market can clearly be achieved by optional financial forward contracts in an energy-only market design. For instance, financial forward contracts can help reduce risks associated with price uncertainty and counterparty risk, and they can ease financing of lumpy generation investments. Forward contracting among market participants can still be expected to be an important component of an energy-only market design (**?**). Most of the benefits of forward contracting are not coupled with market failure problems that would compel mandatory participation in forward contracts or capacity markets; instead, we should expect LSEs to rationally select the appropriate level of forward contracts, taking into account the benefits they provide.

However, while research suggests that one significant benefit of forward contracting is its ability to help reduce generator spot market power, this work argues that positive externalities related to forward contracting and producer market power might limit the extent of forward contracting and reduce social welfare. This effect is not necessarily limited to electricity markets, but this research follows much of the literature in focusing in particular on the characteristics of forward and spot markets for electricity.

A rich literature suggests that forward contracting can reduce market power in electricity spot markets. **?** provided analytical evidence that forward contracting can impel producers to offer higher quantities in real-time markets. **?** provides empirical evidence in support of this conclusion, using data from the Australian market to show that forward hedging can reduce generator market power.

In a two-stage model with reliability options, a specific form of forward contract, **?** also shows that producers that have sold forward contracts have less ability to exercise market power in spot markets. **?**, **?**, and **?** argue that one of the major benefits of capacity markets using reliability options is their ability to help reduce generator market power.

Other research has questioned the impact of forward contracting on market power, for instance, when firms in a duopoly compete in prices instead of quantities (**?**) or when firms are capacity constrained (**?**). **?** question whether the model by **?** is a useful model for the California Electricity market, and suggest that the market-power reducing benefits of forward contracts might only hold when generators are forced to sign forward contracts.

Despite the uncertainty surrounding the extent to which forward contracting impacts market power, **?** present a useful model for understanding the ways in which this impact occurs. The research in this paper takes those effects as given in order to study the extent to which market concentration of consumer entities (the number of LSEs) impacts the extent to which forward contracts are procured for market-power reduction.

The main contribution of this research is to explain how competition amongst load-serving entities as buyers in the forward contract market impacts the overall level of forward contracts procured. Specifically, it is the first research, to our knowledge, that details the positive externalities of forward contract purchase, whereby forward contract purchases that reduce market power benefit all consumers, not just those represented by the individual LSE making the forward contract purchasing decision. This research shows that, in markets with several groups of sufficiently large LSEs, the effect of positive externalities serves to decrease the total forward contracting level and social welfare. In particular, when focusing on the effects of positive externalities, welfare is decreasing in the number of LSEs. The research posits that positive externalities of forward contract procurement, under certain assumptions, provide a rational for requiring consumer participation in forward contracting or capacity markets, or for internalizing the public benefits of forward contracting.

2 Model

We present an electricity market model that is significantly simplified for ease of tractability and clarity, but which retains the core features of demand uncertainty, competition among producers, and the presence of multiple retail electricity suppliers. The producer side of the model is similar to (**?**), but we allow producers to have generic valuations of forward contracts and then determine the level of forward contracting preferred by consumers in equilibrium.

Consider a model with generators $i \in \{1, 2, ..., N\}$ that sequentially offer C_i units of capacity in a forward contract and sells x_i units of energy in a given hour in the wholesale electricity spot market. Furthermore, let $q_i = C_i * (1 \text{ hour})$; consider this to be the hourly energy quantity contracted under a forward capacity contract of size C_i. Throughout the paper, we utilize q_i, so that all contracts are in equivalent terms of energy.

For simplicity, we ignore the distinction between short-term markets, like day-ahead and real-time markets, and we make the simplifying assumption that the real-time wholesale price is given by the linear inverse demand function $P(X) = t - bX$, where X is the total supply $X = \sum_{i \in N} x_i$ and with $b \in \mathbb{R}^+$.

The parameter t represents the realization of a random variable T; it corresponds to total net energy demand in a given period, based on the difference between the maximum energy demand and the realized renewable energy availability. Specifically, $\frac{t}{b}$ is the maximum net energy demand, the energy demand at a price of 0 minus the renewable energy supply. This model allows for the analysis of regions with large renewable energy supply, if renewable supply exceeds max demand, then $\frac{t}{b} < 0$ or some renewable energy is curtailed and $\frac{t}{b} = 0$ in the particular period under consideration.

Renewable energy generators are assumed to bid competitively at zero marginal cost, providing all available energy in every period with a positive price. The parameter $b \in \mathbb{R}$ is fixed and T is varied as a random variable, and realized in real-time. In practice, the inverse demand curve need not be linear, and its slope could vary with demand in addition to its intercept. In the forward contracting stage, uncertainty can be modeled by the cumulative distribution function $F(t)$ and the associated density function $f(t)$. Assume that T has finite support on $[\underline{t}, \bar{t}]$ with $\underline{t}, \bar{t} \in \mathbb{R}$. The expectations over T are all taken with respect to future demand over a generic time-period, so they only affect the forecast for the distribution $F(t)$. Since $F(t)$ is exogenous to the results, and considered fixed at the start of the contracting period, the length of the forward contract period is entirely generic; it does not impact the model and associated results described herein.

In our model, generators have a linear cost c_i for production of electricity in each hour; in practice, their production can include nonlinearities, for instance due to startup costs. Let $s_i = x_i - q_i$ represent producer i's net output sold in real-time. Let $p_W = P(x)$ be the wholesale spot market price for electricity in a given hour with production x. Then the profit for producer i in a given hour, who has previously sold q_i units of a forward contract at price p_F, is given by

$$\pi_i^W = p_W s_i + p_F q_i - c_i(s_i + q_i) \tag{1}$$

Based on the impact of forward contracts on their profits, and also on additional features like their own risk preferences, generators have a generic price that they demand per unit of forward contract sold. This price, for instance, could represent a small or a substantial discount from the average real-time price, or it could be higher than the real-time price in the case of much more risk-aversion for demand than for generators.

Furthermore, the model features load-serving entities (LSEs) $j \in \{1, 2, ..., M\}$ that procure forward contracts and spot-market electricity in order to maximize the welfare of consumers. Specifically, each LSE chooses a forward contract quantity q_j in order to maximize the expected welfare for its fraction of consumers. Each LSE services $\alpha_j \in (0, 1]$ fraction of consumers; we assume that the demand fractions are constant in time, so if the total consumption is $Z(t)$ in a specific period with $T = t$, then the consumption by LSE j is $\alpha_j Z(t)$. This is a reasonable assumption when the demand of consumers across retailers does not vary significantly.

3 Equilibrium Spot Market Output by Producers

In this section, we find the symmetric Nash equilibrium strategy for producers in the spot market who have already sold a fixed level of forward contracts, in the case of linear inverse demand.

Proposition 1. The symmetric Nash equilibrium spot market output for all producers $i \in \{1, 2, ..., N\}$ market with prior forward commitments $(q_1, q_2, ..., q_N)$ is given by:

$$s_i = \frac{t - bQ + C}{b(N+1)} - \frac{c_i}{b} \tag{2}$$

where $Q = \sum_{i=1}^{N} q_i$ and $C = \sum_{i=1}^{N} c_i$.

Proof. Each producer seeks to maximize 1. Let $S = \sum_{i=1}^{N} s_i$. The spot price $p_W = P(S+Q)$. In the case of linear inverse demand, the first order condition with respect to net output s_i is given by:

$$bs_i = t - bS - bQ - c_i \tag{3}$$

Summing over all i, this condition requires that

$$S = \frac{Nt - bNQ - C}{b(N+1)} \tag{4}$$

By substituting this result into the original condition, and combing terms, we have 2.

Note that the second derivative of profit with respect to net output s_i

$$\frac{\partial^2 \pi_i^W}{\partial s_i^2} = -2b < 0 \tag{5}$$

Therefore, the individual optimization problems are unique [the NE is also unique but clarify and write the conditions that hold that are sufficient for uniqueness]. □

In the case where generators each have equivalent marginal costs, i.e. $(c_1, c_2, ...c_N) = (c, c, ..., c)$, then 2 simplifies to

$$s_i = \frac{t - bQ - c}{b(N+1)} \tag{6}$$

Going forward, we focus on generators with equal marginal costs.

4 Equilibrium Forward Contracting by Multiple Consumers

Now we consider the equilibrium forward contracting level by multiple entities representing consumers of electricity. Each LSE $j \in \{1, 2, ..., M\}$ chooses a forward contract level to maximize their consumer surplus,

$$\pi_j^F = \mathbb{E}_T[\alpha_j V(T) - (\alpha_j X - q_j) p_W(T) - q_j p_F] \tag{7}$$

$$= \int_{\bar{t}}^{\underline{t}} \left(\int_0^X \alpha_j (t - bz) dz - (\alpha_j X - q_j)(t - bX) - q_j p_F \right) f(t) d(t) \tag{8}$$

which is $\alpha_j V(t)$ the consumer's value of energy consumption at demand t for the LSEs fraction of customers, minus the LSEs real-time demand times the real-time price, minus the LSEs chosen level of forward contracts times the forward contract price. Note that the output / consumption level $X = S + Q$, where S is set by the Cournot competition amongst producers in real-time according to 2, and is itself is a function of t. Furthermore, we assume that $q_j \geq 0$ and focus on cases where firms each procure a positive amount of forward contracts in equilibrium.

Proposition 2. Assume that each firm $j \in M$ procures an unconstrained quantity of forward contracts, i.e. $q_j > 0$. Then, the equilibrium forward contract level for the sum of forward contracts from M LSEs is

$$Q = \frac{\mathbb{E}[T]}{b} + \frac{(MN(N+1) - N)c - M(N+1)^2 p_F}{b(MN + M + N)} \tag{9}$$

Proof. Each LSE simultaneously chooses the forward contract amount q_j to maximize their consumer surplus in 8. The individual first order conditions satisfy

$$\frac{\partial \pi_j^F}{\partial q_j} = \frac{\partial}{\partial q_j} \mathbb{E}_T[\frac{\alpha_j}{2} bX^2 + q_j(p_W - p_F)] \tag{10}$$

$$= \mathbb{E}_T[\frac{\partial}{\partial q_j}(\frac{\alpha_j}{2} bX^2 + q_j(p_W - p_F))] \tag{11}$$

$$= \mathbb{E}_T[\alpha_j bX \frac{\partial X}{\partial q_j} + p_W - p_F + q_j \frac{\partial p_W}{\partial q_j}] = 0 \tag{12}$$

Where the first line is due to 8, the second line is because we can move the integral inside the expectation because t and it's functions are bounded, and the third line is a computation of the derivative. Next, we solve explicitly for S and p_W, and the their respective derivatives for generic t in the support of T.

Real-time production / consumption X is given by the sum of 6 over all N plus the total forward contract quantity, i.e.,

$$X = S + Q = \frac{N(t - bQ - c)}{b(N+1)} + Q = \frac{Nt + bQ - Nc}{b(N+1)} \tag{13}$$

where S is given by 6. Therefore, $\frac{\partial X}{\partial q_j} = \frac{1}{N+1}$. Given X, we can find p_W, which is given by

$$p_W = t - bX = \frac{t - bQ + Nc}{N+1} \tag{14}$$

Therefore, $\frac{\partial p_W}{\partial q_j} = \frac{-b}{N+1}$. Subbing this into 12, and noting that the expectation is now linear in t, we have that

$$0 = \alpha_j \frac{N\mathbb{E}[T] + bQ - Nc}{(N+1)^2} + \frac{\mathbb{E}[T] - bQ + Nc}{N+1} - p_F + q_j \frac{-b}{N+1} \tag{15}$$

Summing the above over j, and multiplying each term by $(N+1)^2$ gives

$$0 = N\mathbb{E}[T] + bQ - Nc + (N+1)(M\mathbb{E}[T] - MbQ + MNc - M(N+1)p_F - bQ) \tag{16}$$

Rearranging terms,

$$b(M(N+1) + N)Q = (M(N+1) + N)\mathbb{E}[T] + (MN(N+1) - N)c - M(N+1)^2 p_F \tag{17}$$

The final result 9 is due to a simple rearranging of the above.

Finally, we should show uniqueness based on second order conditions for an arbitrary consumer j. □

Remark 1. The first order condition for individual producers, 12, allows for additional insight into the minimum population fraction requirement for participators in the M producer equilibrium. The optimal equilibrium quantity $q_j > 0$ iff

$$\mathbb{E}[\alpha_j X + \frac{N+1}{b}(p_W - p_F) = \mathbb{E}[\alpha_j X + \frac{N+1}{b}(T - bX - p_F) > 0 \tag{18}$$

This is equivalent to the requirement that

$$\alpha_j > (N+1)\mathbb{E}[1 + \frac{p_F - T}{bX}] \tag{19}$$

The market price equation $p_W = t - bX$ and Assumption 1 imply that $\mathbb{E}[\frac{1}{bX}] > \frac{1}{\mathbb{E}[T]-c}$. This, and the fact that expected maximum willingness to pay $\mathbb{E}[T]$ is greater that p_F provide a sufficient condition for α_j,

$$\alpha_j > (N+1)\frac{p_F - c}{\mathbb{E}[T] - c} \tag{20}$$

If N is very high this will be hard to satisfy because the benefits of forward contracts for reducing market power are proportionally smaller. Similarly, if $p_F >> c$ this will be hard to satisfy because forward contracts will be expensive for consumers.

In general, however, markets that fulfill or approximately fulfill this condition represent typical (not extreme) examples. For instance, if there are 5 producing firms, the forward contract price is 20% higher than the cost of electricity, and the maximum peak willingness to pay is 10 times the marginal cost of electricity, then each LSE with at least $\frac{1}{9}$ of the population would procure a positive quantity of forward contracts. Our model focuses on the example where each LSE is sufficiently large; e.g., with up to 9 LSEs each representing at least $\frac{1}{9}$ of the total customers.

5 Demand Competition and Forward Contracting

This section presents two simple result that represents the key ideas of the paper. The equilibrium level of forward contracting is decreasing in M, suggesting that a competitive field of LSEs would, in competitive equilibrium, purchase a lower total level of forward contracts than a single buyer. Furthermore, due to this decreasing level of forward contracting, welfare is also decreasing in M.

The proofs makes use of a single assumption requiring that prices support market participation for suppliers with cost c.

Assumption 1. Competitive Market: The market is competitive for suppliers with marginal cost c, i.e. either $\mathbb{E}p_W > c$ or $p_F > c$.

Either the average real-time price or the price of forward contracts must exceed the producers' marginal costs of production. If this assumption was not true we would expect to see suppliers exit the markets. Note that using the results 6 and 9 we can make the assumption $\mathbb{E}[p_W] > c$ explicit in terms of the problem parameters.

$$\mathbb{E}p_W - c = \mathbb{E}[\frac{t - bQ - c}{N+1}] = \frac{M(N+1)p_F - M(N+1)c}{MN + M + N} > 0 \tag{21}$$

Which is clearly true iff $p_F > c$. Therefore, the two statements are equivalent and the competitive market Assumption 1 is equivalent to the requirement that $p_F > c$.

Proposition 3. Given a competitive market that satisfies Assumption 1, the sum of forward contracts procured by demand entities Q is decreasing in M, $\frac{\partial Q}{\partial M} < 0$.

Proof. We simply compute the derivative

$$\frac{\partial Q}{\partial M} = \frac{(N(N+1)c - (N+1)^2 p_F)b(MN+M+N)}{b^2(MN+M+N)^2} - \frac{(N+1)b((MN(N+1)-N)c - M(N+1)^2 p_F)}{b^2(MN+M+N)^2} \quad (22)$$

By simplifying the expression, it is clear that

$$\frac{\partial Q}{\partial M} = \frac{N(N+1)^2(c-p_F)}{b(MN+M+N)^2} < 0 \quad (23)$$

where the inequality is due to Assumption 1, $p_F > c$. □

5.1 Forward Contracting and Social Welfare

Now consider the effects of the forward contracting level and demand competition on welfare. Expected welfare $\mathbb{E}_T \Pi$ is given by

$$\mathbb{E}[\Pi] = \mathbb{E}[V(T) - (X-Q)p_W(t) - Qp_F + (X-Q)p_W(T) + Qp_F - Xc] \quad (24)$$

$$= \mathbb{E}[\int_0^X (T - bz)dz - Xc] = \mathbb{E}[TX - \frac{b}{2}X^2 - Xc] \quad (25)$$

which is the sum of the expected value of consumption for consumers with expectation taken over demand T minus the expected cost of energy at production level X, which is itself a function of T, again taken over demand T. The middle terms in the first line represent the transfers from consumers to producers for real-time energy and forward contracts, respectively; in terms of expected social welfare, these net to zero. Next we show that the expected welfare is decreasing in the number of LSEs.

Proposition 4. Under the competitive market Assumption 1, $\frac{\partial \mathbb{E}\Pi}{\partial M} < 0$.

Proof. The derivative of profit with respect to Q, is given by:

$$\frac{\partial \mathbb{E}\Pi}{\partial Q} = \mathbb{E}[\frac{\partial}{\partial X}(tX - \frac{b}{2}X^2 - Xc)\frac{\partial X}{\partial Q}] \quad (26)$$

$$= \frac{1}{N+1}\mathbb{E}[t - bX - c] \quad (27)$$

$$= \frac{1}{N+1}(\mathbb{E}[p_W] - c) > 0 \quad (28)$$

where the first line is due to the boundedness of expectation terms, the second line is a computation of the derivative, and the final line is due to the definition of p_W and Assumption 1, since the equivalence of the two statements in the assumptions requires that each is true.

Therefore,

$$\frac{\partial \mathbb{E}\Pi}{\partial M} = \frac{\partial \mathbb{E}\Pi}{\partial Q}\frac{\partial Q}{\partial M} < 0 \tag{29}$$

Because the first term of the product is positive and the second is negative. This completes the proof. □

Note that this proof is not intended to show generically that welfare is decreasing in the level of competition amongst LSEs. Competition amongst LSEs could provide many additional benefits to consumers through, for instance, better sorting into preferred product types and more competitive prices. However, the proof implies that due to its effect on reducing the equilibrium forward contract level Q, which subsequently reduces total electricity production, increasing the number of LSEs does serve to reduce average welfare.

6 Consumer Market Power: A Mitigating Effect

This section generalizes the results to the case when the price for forward contracts increases in the number of forward contracts procured. In this case, consumers have market power in the forward market because their consumption impacts the price of forward contracts. The results show that the presence of consumer market power reduces the total number of contracts purchased. This is especially true when the number of LSEs is small and firms quantity choices have a big effect on price.

When consumer purchases in the forward market impact price, then increasing the number of LSEs serves to increase the quantity of forward contracts by reducing the ability of individual firms to exercise buyer market power. This mitigates the effects of positive externalities described above, acting on the total quantity of forward contracts in the opposite direction.

When the impact of forward contract procurement on price is no too high, or if the forward contract price is very high, the effect of positive externalities dominates and welfare decreases in the number of firms. If forward contract quantities have a big effect on the forward contract price, then the market power effects dominate and welfare increases in the number of firms.

We define the derivative of the forward contract price with respect to the quantity procured $p'_F(Q) = 0$. Next, we generalize the results from Section 4 to account for the case where $\exists Q \mathbb{R}^+$ s.t. $p'_F(Q) > 0$. We assume that the price curve is weakly concave, i.e. $p''_F(Q) \geq 0$.

Proposition 5. The equilibrium level of forward contracting Q in the case of a generic demand curve is given by:

$$Q = \frac{(MN + M + N)\mathbb{E}[T] + (MN(N+1) - N)c - M(N+1)^2 p_F}{b(MN + M + N) + (N+1)^2 p'_F(Q)} \tag{30}$$

The proof follows from 4 but with the additional term since $p'_F(Q)$ is possibly nonzero. Note that $p'_F(Q) > 0$ at optimal Q necessarily implies that the forward contract price sensitivity reduces total forward contracting levels, since it increases the (positive) value of the denominator. Specifically, let $\tilde{Q}$ refer to the equilibrium forward contracting level for M producers as described in Section 4. Then $Q < \tilde{Q}$. When consumers' forward contract consumption levels have a proportionally bigger impact on the price of forward contracts, they reduce their total procurement of forward contracts in equilibrium.

Next, consider the effects on the number of LSEs M on the forward contract quantity and on welfare.

Proposition 6. The effect of the number of LSEs on the total equilibrium forward contract quantity $\frac{\partial \Pi}{\partial M}$ is ambiguous. For the forward contract quantity to increase in M, i.e. $\frac{\partial \Pi}{\partial M} > 0$, it is necessary that $p'_F(Q)$ is sufficiently large for some Q.

Proof. By differentiating 30, observe that

$$Q(b(N+1) + (N+1)^2 p''_F(Q)\frac{\partial Q}{\partial M}) + (b(MN+M+N) + (N+1)^2 p'_F(Q))\frac{\partial Q}{\partial M}$$
$$= (N+1)\mathbb{E}[T] + N(N+1)c - (N+1)^2 p_F(Q) - M(N+1)^2 p'_F(Q)\frac{\partial Q}{\partial M} \quad (31)$$

Rearranging the above shows that

$$\frac{\partial Q}{\partial M} = N+1\frac{\mathbb{E}[T] + Nc - (N+1)p_F(Q) - Qb}{b(MN+M+N) + (N+1)^2 p'_F(Q) + (N+1)^2 p''_F(Q) + M(N+1)^2 p'_F(Q)} \quad (32)$$

The results in Section 5.1 still hold exactly in the case described in this Section, because they do not depend on the forward price or the equilibrium result for Q. Therefore, $\frac{\partial \Pi}{\partial M} > 0 \iff \frac{\partial Q}{\partial M} > 0$.

The denominator in 32 is positive because each term is positive. Therefore, $\frac{\partial \Pi}{\partial M} > 0$ iff the numerator is greater than zero. Taking into account the result in 30 for Q, the numerator is equivalent to

$$\frac{(N+1)^2 p'_F(Q)(\mathbb{E}[T] + Nc - (N+1)p_F(Q)) + bN(N+1)(c - p_F(Q))}{b(MN+M+N) + (N+1)p'_F(Q)} \quad (33)$$

Again, the denominator is positive, so the sign is dependent on the numerator. By rearranging the numerator, observe that the requirement that the numerator is greater than zero is equivalent to

$$(N+1)p'_F(Q)(\mathbb{E}[T] + Nc - (N+1)p_F(Q)) > bN(p_F(Q) - c) \quad (34)$$

The sign of the left hand side is ambiguous. This implies two necessary conditions. First, $p_F(Q) < \frac{\mathbb{E}[T]+Nc}{N+1}$, i.e. the forward price is not too high. Second,

$$p'_F(Q) > \frac{bN(p_F(Q) - c)}{(N+1)(\mathbb{E}[T] + Nc - (N+1)p_F(Q))} \quad (35)$$

Therefore, if the forward price is not too high, but it's derivative with respect to Q is fairly high, then the output Q and welfare Π can be locally increasing in M. In the case where

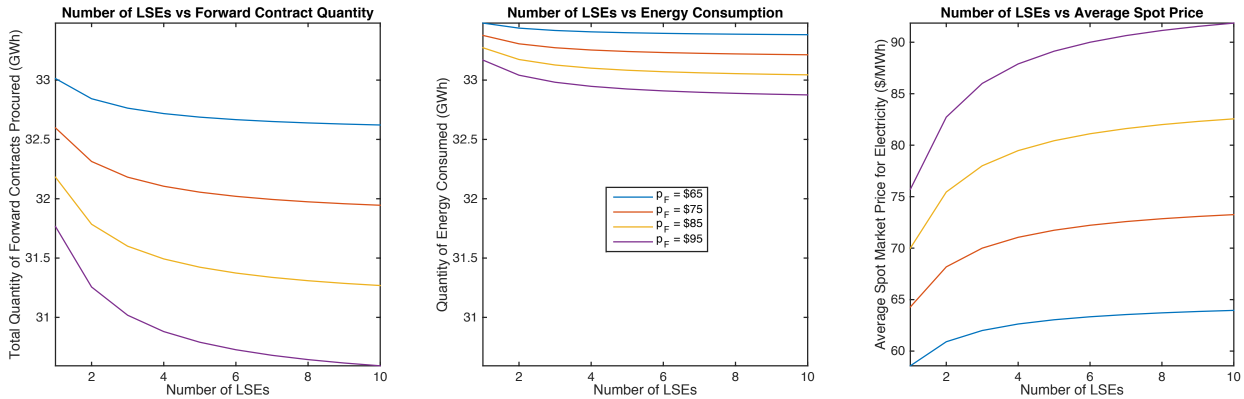

Figure 1: The effect on the number of LSEs, M, on forward contracting, energy consumption, and spot market prices, over a range of forward contract prices.

the price influence of individual purchasing decisions is high, the influence of increasing M has a larger impact on reducing buyer market power (and therefore increasing the quantity of forward contracts) than it does on increasing the effects of positive externalities (which decreases the quantity of forward contracts).

$\square$

This results explain how the price-effects of forward contracting decisions can impact the equilibrium quantity of forward contracts purchased. Buyer market power introduces a mitigating effect versus previous results. Specifically, if buyer market power is sufficiently high, then increasing the number of LSEs may have net positive effect on welfare because the equilibrium quantity effects due to a reduction of market power by purchasers of forward contracts outweighs the quantity effects due to the positive externalities of such contracts.

7 Case Study

This section presents a simple case study of the results. It helps illustrate the results of the analysis and the sensitivity of forward contracting and spot prices to the number of generators, the number of producers, and to the forward contract price and price slope. For the computations in this study, we use $b = 0.055$, based on the average of the low and high values for real-time price sensitivity found by **?**. The parameter T was fixed at $T = 1900$; it was chosen so that net consumption at the reference case was approximately equal to average net consumption in an hour in the ERCOT system, 34 GWh. This average hourly consumption was calculated as 349 TWh, the total ERCOT demand in 2016, minus 54 TWh, the total ERCOT renewable energy production in 2016, divided by 8760 hours per year. For the reference case the marginal cost of energy production is 50 $/MWh, the forward contracting price is 75 $/MWh, there are $N = 3$ producing firms, and the number of LSEs varies from one to ten, but these are varied in the sensitivity analyses.

In Figures 1 and 2, the forward contract has a fixed price, so it is based on the analysis from Sections 2-5. In each of the examples, the quantity of forward contracts and the total

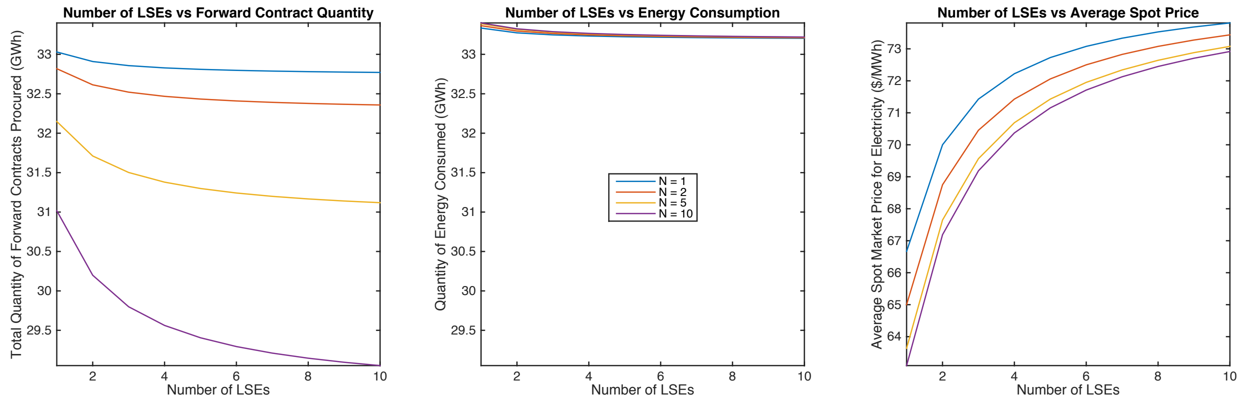

Figure 2: The effect of the number of LSEs on forward contracting, energy consumption, and spot market prices, as the number of producer firms, N, is varied.

amount of energy purchased are decreasing in the number of LSEs, as predicted by the analysis. As was shown previously, welfare is also decreases because its derivative with respect to M has the same sign as $\frac{\partial Q}{\partial M}$. Furthermore, the average spot price for electricity is increasing in the number of LSEs.

In Figure 1, the forward contract price varies from \$65 to \$95 / MWh. As the forward contracting price increases, the total amount of forward contracting decreases and the average spot price increases. The effect of the number of LSEs on total contract procurement is especially pronounced when the forward contract price is much higher than the marginal cost of electricity.

In Figure 2, the number of producer firms varies from $N = 1$ to $N = 10$. The number of producer firms has a major effect on the extent of forward contracting, because LSEs contract at much higher levels when the number of producing firms is low in order to mitigate the higher levels of producer market power. The effect of N on total production and average spot price is less pronounced. As expected, increasing the level of producer competition decreases the average spot price.

Finally, Figure 3 allows the price of forward contracts to increase in the quantity of forward contracts procured, and varies the extent of this effect. This figure mirrors the analysis of Section 6. Increasing the supply curve slope also increases the average forward contract cost, which adds a second order effect to the changes depicted in the figure. To compensate for this, we adjusted the intercept of the forward price inverse supply curve such that the average forward contract price for each slope, taken over the range of the number of LSEs, is 124 \$ MWh. As shown in Figure 3, when the slope of the forward contract inverse supply curve is sufficiently high, contract quantity, total production, and welfare no longer decrease in the number of LSEs. In these cases, the effects of reducing buyer market power in the forward contracts market dominate, and increasing the number of LSEs reduces their ability to withhold forward contract purchases to keep the price low. Furthermore, when the inverse supply curve slope is sufficiently high, the average spot market price is also decreasing in the number of LSEs, as they procure a higher level of forward contracts.

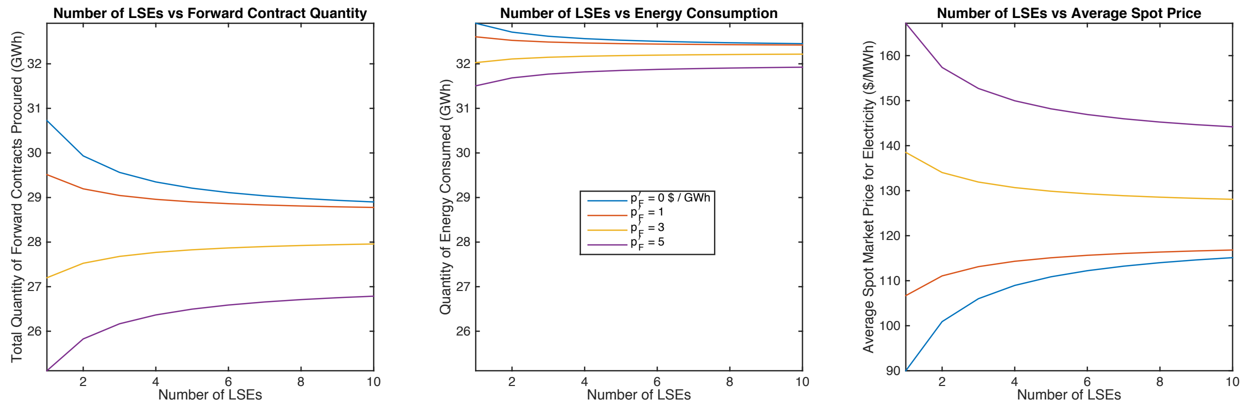

Figure 3: The effect on the number of LSEs on forward contracting, energy consumption, and spot market prices, over a range of slopes for the forward contract price supply curve.

8 Conclusions

Forward contracting can help reduce market power and supply withholding by producers. However, due to the positive externalities of consumer engagement in forward contracts, whereby the benefits of forward contracting and increased real-time supply are shared by all consumers, the level of forward contracting decreases in the number of load-serving entities. Therefore, in a competitive marketplace with many load-serving entities, each of whom pursue their own forward contracts, the level of forward contracts is below the level that maximizes social welfare. This implies that regulation may be required, for instance through mandated forward contracting or participation in capacity markets, in order to achieve the optimal level of forward contracting. This argument provides more compelling support for mandated forward contracting for electricity than the oft-repeated statement that forward contracting can help reduce market power, which itself does not imply a coordination problem nor compel regulation that is intended to increase the total level of forward contracting.

This work is based on a number of simplifying assumptions. Future work can extend this model for more generic inverse demand curves for real-time electricity and especially for forward contracts. It could also consider the risk preferences of the producers and LSEs in order to more accurately model the difference between forward and real-time prices and to examine the influence of risk-preferences on the features described here. Furthermore, future work could attempt to compare the effects discussed here to the risk-reduction benefits of forward contracting, or to estimate the level of the impact described in a real-world market.

References