How does renewables competition affect forward contracting in electricity markets?

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Abstract

Higher renewables penetration reduces the incentive of conventional electricity generators to sell forward production. This can undermine the role of forward contracting in mitigating market power. More renewable energy *raises* wholesale electricity prices in states of the world where its capacity utilization is low due to intermittency.

Keywords: Electricity markets, renewable energy, forward contracting.

JEL codes: L13 (oligopoly), L94 (electricity), Q21 (renewables), Q41 (energy prices)

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1 Introduction

Renewables such as solar and wind already account for up to 30% of power generation in the UK, Germany and parts of the US (Pollitt & Anaya 2015), and global decarbonization objectives will require further large-scale investment. Due to near-zero marginal costs, renewables come with a "merit-order effect" of displacing conventional generators (Green & Léautier 2015; Liski & Vehvilainen 2015).

The literature on wholesale electricity markets emphasizes how forward contracting can mitigate market power (e.g., Wolak 2000; Ausubel & Cramton 2010). Such commitments can take the form of forward contracting (Allaz & Vila 1993) or retail sales (Bushnell, Mansur & Saravia 2008).[1] In practice, power generators indeed sell forward a significant fraction of production (Anderson, Hu & Winchester 2007).

This paper examines the interaction between renewables competition and forward contracting. The model generalizes Allaz & Vila (1993) to (i) incorporate the intermittent nature of renewables production, and (ii) allow for $n > 2$ strategic players, with cost heterogeneity to represent different generation technologies.

2 Model

Consider a wholesale electricity market with a set $N = \{1, 2, ..., n\}$ of $n \geq 2$ "incumbent" electricity generators. Renewables are installed with capacity R, with zero marginal costs.[2] Assume that the n firms are "active" (i.e., profitable); as will become clear, this holds as long as renewables capacity is "not too large", $R < \overline{R}$.

There are $M \geq 2$ states of the world, reflecting the intermittency of renewables production. State m occurs with probability $\delta_m \in (0, 1)$ where $\sum_{k=1}^{M} \delta_k \equiv 1$. In state m, the rate of capacity utilization of renewables is $\gamma_m \in (0, 1]$, ordered as $\gamma_1 > \gamma_2 > ... > \gamma_M$. Firm $i \in N$ sells x_i^m units at marginal cost c_i, so total conventional output $X_m \equiv \sum_{i \in N} x_i^m$.

Electricity buyers form a linear demand curve $p(Q) = \alpha - \beta Q$, where Q is consumption and $(\alpha, \beta) > 0$. There is market clearing in each state of the world, so prices are state-contingent: in state m, total output satisfies $Q_m = X_m + \gamma_m R$, and electricity trades at a price p_m.

The timing of the game is as follows. In Stage 1, each incumbent chooses its forward commitment y_i. Following Allaz & Vila (1993), Bushnell (2007), Fowlie (2009) and others, the contract market is assumed to be competitive with no arbitrage profits; as noted by Allaz & Vila (1993), this would be the case, e.g., in the presence of two Bertrand speculators.[3] Then the state of the world γ_m is revealed. In Stage 2, each incumbent chooses its output x_i^m. Incumbents each

[1] This paper takes the same approach as this literature in that it examines the *strategic* incentive for forward contracting rather than the hedging motive driven by risk aversion.

[2] For simplicity, renewables are grouped into a single capacity figure.

[3] Forward markets can be more competitive than spot markets due to the participation of financial players like banks and commodity traders (who do not own physical assets). In several major European systems, e.g., Germany and the Nordics, forward markets are highly liquid with traded volumes being 3-6 times larger than underlying consumption (ECA 2015). The Nordic financial electricity market has 400 participants and the Top 5 players' combined market share is only ∼25% (NordREG 2010). By contrast, wholesale spot markets are often still dominated by a small number of large players.

maximize profits while interacting strategically; renewables production is non-strategic. Firms' choices are assumed to be observable and there is no discounting. The game is solved for the subgame-perfect Nash equilibrium.

3 Results

The main question is, what is the equilibrium impact of more renewables capacity R? This could arise because of renewables subsidies or due to technological progress which reduces their investment costs.

First-order conditions

In Stage 2, the state of the world m is known. Firm i's problem is to:

$$\max_{x_i^m} \{(x_i^m - y_i)p_m - c_i x_i^m\}$$

where y_i is its forward commitment made in Stage 1, and demand $p_m = \alpha - \beta(X_m + \gamma_m R)$. The firm here only makes revenues on its uncommitted units $(x_i^m - y_i)$. The first-order condition is:

$$0 = (p_m - c_i) - \beta(x_i^m - y_i) = [\alpha - \beta(X_m + \gamma_m R) - c_i] - \beta(x_i^m - y_i). \tag{1}$$

These n first-order conditions define incumbents' optimal output choices as a function of contracts. Let $\mathbf{Y}$ =$(y_1, y_2, ..., y_n)$ denote forward positions, leading to outputs $x_i^m = x_i(\mathbf{Y};\gamma_m)$ for each $i \in N$, and thus $X_m = X(\mathbf{Y};\gamma_m)$ and $p_m = p(\mathbf{Y};\gamma_m)$ for each state m.

In Stage 1, the state of the world is not yet known, so firm i maximizes its expected profits:

$$\max_{y_i} E\pi_i = \sum\nolimits_{k=1}^{M} \delta_k \left\{(p_k - c_i)x_i^k + (p^f - p_k)y_i\right\}.$$

The first term reflects spot-market profits and the second term represents forward-market profits at price p^f. With a competitive forward market, the latter is zero since $p^f = \sum_{k=1}^{M} \delta_k p_k$ by the no-arbitrage condition.

Thus firm i's problem boils down to:

$$\max_{y_i} E\pi_i = \sum\nolimits_{k=1}^{M} \delta_k \left[p(\mathbf{Y};\gamma_k) - c_i\right] x_i(\mathbf{Y};\gamma_k),$$

which makes explicit the dependencies on the contract position arising in Stage 2. The first-order condition is:

$$0 = \sum\nolimits_{k=1}^{M} \delta_k \left\{\left[p(\mathbf{Y};\gamma_k) - c_i\right] \frac{dx_i(\mathbf{Y};\gamma_k)}{dy_i} - \beta x_i(\mathbf{Y};\gamma_k) \frac{dX(\mathbf{Y};\gamma_k)}{dy_i}\right\}. \tag{2}$$

This reflects how firm i's forward commitment y_i affects its own subsequent production x_i^m as well as total output X^m in each of the M states.

Lemma 1. *In state m, the incumbent firms' output responses in Stage 2 satisfy:*

$$\frac{dX(\mathbf{Y};\gamma_k)}{dy_i}=\frac{1}{(n+1)}>0 \text{ and } \frac{dx_i(\mathbf{Y};\gamma_m)}{dy_i}=\frac{n}{(n+1)}>0.$$

Proof. Summing (1) over all n firms gives:

$$0=n\left[\alpha-\beta(X(\mathbf{Y};\gamma_m)+\gamma_m R)\right]-\sum_{i\in N}c_i-\beta[X(\mathbf{Y};\gamma_m)-Y].$$

Solving this for aggregate output gives:

$$X(\mathbf{Y};\gamma_m)=\frac{n(\alpha-\beta\gamma_m R)-\sum_{i\in N}c_i+\beta Y}{\beta(n+1)}\Longrightarrow\frac{dX(\mathbf{Y};\gamma_m)}{dy_i}=\frac{dX(\mathbf{Y};\gamma_m)}{dY}=\frac{1}{(n+1)} \tag{3}$$

since $Y\equiv\sum_{i\in N}y_i$, and so $dY/dy_i=1$. Rearranging (1) shows that for firm i:

$$x_i(\mathbf{Y};\gamma_m)=y_i+\frac{(\alpha-c_i)}{\beta}-[X(\mathbf{Y};\gamma_m)+\gamma_m R]\Longrightarrow\frac{dx_i(\mathbf{Y};\gamma_m)}{dy_i}=1-\frac{dX(\mathbf{Y};\gamma_m)}{dy_i},$$

which using (3) confirms that $dx_i(\mathbf{Y};\gamma_m)/dy_i=n/(n+1)$. ■

Lemma 1 shows that the pro-competitive effect of forward contracting (Allaz & Vila, 1993) survives under the presence of renewables. This reflects that competition in Stage 2 is in *strategic substitutes*: if firm i raises its output, then it is optimal for its rivals to cut back (and so $dx_i/dy_i>dX/dy_i>0$).

A key observation is that these output responses are *state-independent*: they do not vary with renewables utilization γ_m, which only has an impact on the levels of prices and quantities.[4]

Equilibrium

The equilibrium is defined by the $n\times(M+1)$ first-order conditions for $\{x_i^m\}_{i=1}^n$ in each of M states plus $\{y_i\}_{i=1}^n$. Label this as $\widehat{x}_i^m=x_i(\widehat{\mathbf{Y}};\gamma_m)$ and $\widehat{y}_i$ for each $i\in N$, and thus $\widehat{X}_m=X(\widehat{\mathbf{Y}};\gamma_m)$, $\widehat{Y}=\sum_{i\in N}\widehat{y}_i$ and $\widehat{p}_m=p(\widehat{\mathbf{Y}};\gamma_m)$.

Lemma 2. *In equilibrium, firm i engages in forward contracting according to:*

$$\widehat{y}_i=\frac{(n-1)}{n}\sum\nolimits_{k=1}^M\delta_k\widehat{x}_i^k.$$

Proof. By (1), optimality in Stage 2 implies $(\widehat{p}_m-c_i)=\beta(\widehat{x}_i^m-\widehat{y}_i)$, in equilibrium, for firm i, and using this in the first-order condition for Stage 1 from (2) gives:

$$\begin{aligned}0&=\beta\sum\nolimits_{k=1}^M\delta_k\left\{(\widehat{x}_i^k-\widehat{y}_i)\left.\frac{dx_i(\mathbf{Y};\gamma_k)}{dy_i}\right|_{\{\widehat{x}_i^k\}_{i=1}^n}-\widehat{x}_i^k\left.\frac{dX(\mathbf{Y};\gamma_k)}{dy_i}\right|_{\{\widehat{x}_i^k\}_{i=1}^n}\right\}\\&=\beta\sum\nolimits_{k=1}^M\delta_k\left\{\frac{n(\widehat{x}_i^k-\widehat{y}_i)}{(n+1)}-\frac{\widehat{x}_i^k}{(n+1)}\right\},\end{aligned}$$

[4] This is a feature of the linear-quadratic model setup.

where the second line uses Lemma 1. Further rearranging gives:

$$0 = \sum_{k=1}^{M} \delta_k \left\{ \frac{(n-1)}{n} \widehat{x}_i^k - \widehat{y}_i \right\} \Longrightarrow \widehat{y}_i = \frac{(n-1)}{n} \sum_{k=1}^{M} \delta_k \widehat{x}_i^k,$$

since $\sum_{k=1}^{M} \delta_k \equiv 1$. ■

Each firm would like to sell forward a fraction $(n-1)/n$ of its subsequent output in each state, which exceeds 50% but falls short of complete contracting. However, because of renewables intermittency, its optimal strategy is to sell forward this fraction of *expected* output.

Such forward contracting is in line with real-world practice: contract cover has ranged from 73 to 95% across the UK, New Zealand, and various US markets (Anderson, Hu & Winchester 2007).

Lemma 3. *The equilibrium output choices for each state m and the equilibrium forward contracting position of firm i are given by:*

$$\widehat{y}_i = \frac{(n-1)}{\beta} \left[(\alpha - c_i) - \frac{n^2}{(n^2+1)} (\alpha - \overline{c}) \right] - \frac{(n-1)}{(n^2+1)} R \sum_{k=1}^{M} \delta_k \gamma_k$$

$$\widehat{x}_i^m = \frac{n}{\beta} \left[(\alpha - c_i) - \frac{n^2}{(n^2+1)} (\alpha - \overline{c}) \right] - \frac{R}{(n+1)} \left[\gamma_m + \frac{(n-1)}{(n^2+1)} \sum_{k=1}^{M} \delta_k \gamma_k \right],$$

where $\overline{c} \equiv \frac{1}{n} \sum_{i \in N} c_i$ is the (unweighted) average unit cost of firms.

Proof. See Appendix. ■

Firm i's output $\widehat{x}_i^m$ in state m depends individually on the renewable load factor γ_m, while its forward position $\widehat{y}_i$ can depend only on the average $\sum_{k=1}^{M} \delta_k \gamma_k$.

Firm i is indeed active in state m as long as it makes a positive margin $\widehat{p}_m > c_i \Longleftrightarrow \widehat{x}_i^m > \widehat{y}_i$. Using Lemma 3, a sufficient condition for all n firms to be active in all M states, as is assumed throughout, is thus given by:

$$R < \frac{\frac{(n+1)}{\beta} \left[(\alpha - \max_i \{c_i\}_{i=1}^n) - \frac{n^2}{(n^2+1)} (\alpha - \overline{c}) \right]}{\left[\max_k \{\gamma_k\}_{k=1}^M - \frac{n(n-1)}{(n^2+1)} \sum_{k=1}^{M} \delta_k \gamma_k \right]} \equiv \overline{R}.$$

Lemma 3 leads to the following main results:

Proposition 1. *More renewables competition:*
(i) reduces the equilibrium volume of forward contracting by firm i, $d\widehat{y}_i/dR < 0$;
(ii) leads to the equilibrium displacement of firm i's production in each state m, $d\widehat{x}_i^m/dR < 0$.

Proof. Follows by inspection of Lemma 3. ■

Proposition 1 identifies the *forward-contracting effect* of renewables competition. More renewables displace incumbent producers according to the well-known merit-order effect. However, this makes the market less attractive to incumbents, which reduces their incentive to make forward commitments.

Renewables thus *directly* raise the intensity of competition in the wholesale market but *indirectly* reduce the intensity of rivalry amongst incumbents.

Proposition 2. *(i) More renewables competition raises the equilibrium price in state m if and only if the forward-contracting effect outweighs the merit-order effect; this holds in all states of the world for which renewables' capacity utilization is sufficiently low:*

$$\frac{d\widehat{p}_m}{dR} > 0 \Longleftrightarrow \gamma_m < \left(-\frac{d\widehat{Y}}{dR}\right) = \frac{n(n-1)}{(n^2+1)} \sum\nolimits_{k=1}^{M} \delta_k \gamma_k \equiv \overline{\gamma},$$

while the equilibrium price falls in all other states, with $\gamma_m \geq \overline{\gamma}$.
(ii) More renewables decrease the average equilibrium price as measured by the forward price:

$$\frac{d\widehat{p}^f}{dR} = -\frac{\beta}{(n+1)}\left(1 - \frac{n(n-1)}{(n^2+1)}\right) \sum\nolimits_{k=1}^{M} \delta_k \gamma_k < 0.$$

Proof. For part (i), the price impact is given by:

$$\frac{d\widehat{p}_m}{dR} = \left.\frac{\partial \widehat{p}_m}{\partial R}\right|_{\widehat{Y}\text{ fixed}} + \left.\frac{d\widehat{p}_m}{dY}\right|_{Y=\widehat{Y}} \frac{d\widehat{Y}}{dR}. \tag{4}$$

Since demand curve in state m, at equilibrium, is $\widehat{p}_m = \alpha - \beta[\widehat{X}_m + \gamma_m R]$, it follows that:

$$\left.\frac{d\widehat{p}_m}{dR}\right|_{\widehat{Y}\text{ fixed}} = -\beta\left(\left.\frac{d\widehat{X}_m}{dR}\right|_{\widehat{Y}\text{ fixed}} + \gamma_m\right) = -\frac{\beta\gamma_m}{(n+1)} < 0,$$

and

$$\left.\frac{\partial \widehat{p}_m}{\partial Y}\right|_{Y=\widehat{Y}} = -\beta \left.\frac{d\widehat{X}_m}{dY}\right|_{Y=\widehat{Y}} = -\frac{\beta}{(n+1)} < 0$$

which both use (3), at equilibrium. Putting these results together in (4) yields:

$$\frac{d\widehat{p}_m}{dR} = -\frac{\beta}{(n+1)}\left(\gamma_m + \frac{d\widehat{Y}}{dR}\right).$$

Using the result for $d\widehat{y}_i/dR < 0$ from Proposition 1 confirms:

$$\frac{d\widehat{Y}}{dR} \equiv \sum_{i\in N} \frac{d\widehat{y}_i}{dR} = -\frac{n(n-1)}{(n^2+1)} \sum\nolimits_{k=1}^{M} \delta_k \gamma_k < 0, \tag{5}$$

and the claims follow. For part (ii), the equilibrium forward price equals the expected spot price, and so:

$$\widehat{p}^f = \sum\nolimits_{k=1}^{M} \delta_k \widehat{p}_k \Longrightarrow \frac{d\widehat{p}^f}{dR} = \sum\nolimits_{k=1}^{M} \delta_k \frac{d\widehat{p}_k}{dR}$$

Using (5) gives:

$$\frac{d\widehat{p}^f}{dR} = -\frac{\beta}{(n+1)}\left(1 - \frac{n(n-1)}{(n^2+1)}\right)\sum\nolimits_{k=1}^{M} \delta_k\gamma_k < 0, \tag{6}$$

which proves the result since $n \geq 2$. ■

Renewables can *raise* the electricity price. The merit-order effect is always present but weaker for states with lower γ_m. The forward-contracting effect is equally strong because commitments are not state-contingent. So prices rise for "low" γ_m, and fall for "high" values of γ_m.

Specifically, price rises if $\gamma_m < \varphi \sum_{k=1}^{M} \delta_k\gamma_k$ by the fraction $\varphi \equiv n(n-1)/(n^2+1) \in [\frac{2}{5}, 1)$. With six incumbents, states with utilization below $\varphi \approx 80\%$ of the average experience higher prices. In the binary case where renewables are either at capacity or inactive, the condition is always met in the inactive state (for any $n \geq 2$).

Large spreads in renewables' capacity factors are borne out in practice (Borenstein 2012; Pollitt & Anaya 2015). Averages for wind are typically $\approx$ 30–40% while they are as low as 10% for solar. Peak capacity factors for wind can exceed 80% while utilization in Germany has been as low as 5% on some days—with a zero contribution by solar.

4 Conclusion

Renewables competition can weaken the role of forward contracting in mitigating market power in wholesale electricity markets—and lead to higher prices in states with strong intermittency. These knock-on effects of renewables may deserve more attention from policymakers and analysts. The results should also lend themselves to empirical and experimental testing.

These insights are likely robust in various directions. Demand uncertainty in form of state-contingent $\{\alpha_k\}_{k=1}^{M}$ would also not affect strategic responses at the margin—so the comparative statics still hold. Renewables competition $R > \overline{R}$ could induce exit of higher-cost incumbents, altering the *set* of firms N. Exit raises prices across all states and reduces the degree of forward contracting—which would exacerbate the price-increasing effect. Increasing marginal costs would reduce forward contracting—relative to the standard Allaz-Vila model with constant unit costs (Bushnell 2007). This would likely dampen the comparative statics but not overturn them.

Future research could examine the impact of renewables in a model where strategic behaviour also prevails in the contract market, and pursue a welfare analysis that incorporates renewables' investment costs and the social value of emissions reductions achieved.

Appendix

Proof of Lemma 3. The proof first determines the market-level equilibrium quantities for $\widehat{X}_m$ and $\widehat{Y}$, and then derives the firm-level analogs. From (3), in equilibrium:

$$\widehat{X}_m = \frac{n\left[(\alpha-\overline{c})-\beta\gamma_m R\right]+\beta\widehat{Y}}{\beta(n+1)}, \tag{7}$$

where $\overline{c} \equiv \frac{1}{n}\sum_{i\in N} c_i$ is the average unit cost of firms. Lemma 2 implies $\widehat{Y} = \frac{(n-1)}{n}\sum_{k=1}^{M}\delta_k\widehat{X}_k$ at the market-level; using (10) repeatedly in it gives:

$$\begin{aligned} \widehat{Y} &= \frac{(n-1)}{n}\sum\nolimits_{k=1}^{M}\delta_k\frac{n\left[(\alpha-\overline{c})-\beta\gamma_k R\right]+\beta\widehat{Y}}{\beta(n+1)} \\ &= \frac{(n-1)}{\beta n(n+1)}\left(n\left[(\alpha-\overline{c})-\beta R\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]+\beta\widehat{Y}\right), \end{aligned} \tag{8}$$

which uses $\sum\nolimits_{k=1}^{M}\delta_k \equiv 1$. Solving (8) for $\widehat{Y}$ yields:

$$\widehat{Y} = \frac{n(n-1)}{\beta(n^2+1)}\left[(\alpha-\overline{c})-\beta R\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]. \tag{9}$$

Finally, using (9) in (7) and solving out gives:

$$\begin{aligned} \widehat{X}_m &= \frac{n(\alpha-\overline{c})\left[1+\frac{(n-1)}{(n^2+1)}\right]-\beta nR\left[\gamma_m+\frac{(n-1)}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]}{\beta(n+1)} \\ &= \frac{n}{\beta(n+1)}\left(\frac{n(n+1)}{(n^2+1)}(\alpha-\overline{c})-\beta R\left[\gamma_m+\frac{(n-1)}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]\right). \end{aligned} \tag{10}$$

Now turning to the firm-level, the first-order condition (1) for firm i in state m implies that, in equilibrium, $\widehat{x}_i^m = \widehat{y}_i + (\alpha-c_i)/\beta - (\widehat{X}_m+\gamma_m R)$. Inserting (10) and rearranging gives:

$$\begin{aligned} \widehat{x}_i^m &= \widehat{y}_i + \frac{(\alpha-c_i)}{\beta} - \gamma_m R - \frac{n}{\beta(n+1)}\left(\frac{n(n+1)}{(n^2+1)}(\alpha-\overline{c})-\beta R\left[\gamma_m+\frac{(n-1)}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]\right) \\ &= \widehat{y}_i + \frac{1}{\beta}\left[(\alpha-c_i)-\frac{n^2}{(n^2+1)}(\alpha-\overline{c})\right]-\frac{R}{(n+1)}\left[\gamma_m-\frac{n(n-1)}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right]. \end{aligned} \tag{11}$$

Recalling from Lemma 2 that $\widehat{y}_i = \frac{(n-1)}{n}\sum_{k=1}^{M}\delta_k\widehat{x}_i^k$, and using (11) in it repeatedly gives:

$$\begin{aligned} \widehat{y}_i &= \frac{(n-1)}{n}\left\{\widehat{y}_i+\frac{1}{\beta}\left[(\alpha-c_i)-\frac{n^2}{(n^2+1)}(\alpha-\overline{c})\right]-\frac{R}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right\} \\ &\implies \widehat{y}_i = (n-1)\left\{\frac{1}{\beta}\left[(\alpha-c_i)-\frac{n^2}{(n^2+1)}(\alpha-\overline{c})\right]-\frac{R}{(n^2+1)}\sum\nolimits_{k=1}^{M}\delta_k\gamma_k\right\}. \end{aligned} \tag{12}$$

Finally, using (12) in (11) and solving yields the formula for $\widehat{x}_i^m$.

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