Strategic Use of Forward Contracts and Capacity Constraints

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Abstract

Allaz and Vila (1993) argued that forward markets mitigate market power and enhance efficiency. This paper analyzes the implications of forward markets when oligopolistic firms endogenously choose capacity levels. The paper shows that the forward market that occurs after the investment decision is committed may discourage total investment and result in a Pareto-inferior outcome. However, the forward market could improve social welfare if the introduction of the forward market decreases spot market prices without negatively affecting investment levels. An increase in the number of firms decreases the likelihood that the forward market has a negative effect on social welfare. The findings have important policy implications for capital-intensive industries where capacity expansion requires long lead time.

Key words: capacity constraints, market power, forward market, spot market

JEL Classification: L00, L13

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1 Introduction

Contrary to a conventional belief that risk aversion is essential for the existence of forward markets, Allaz and Vila (1993)(AV hereafter) suggest strategic reasons for the existence of forward markets. According to AV, firms compete for forward contracts to enhance their market share in a spot market. This strategic use of forward markets arises only if firms have some market power in forward and spot markets, but disappears in a perfectly competitive market. The recent literature that adopts the AV framework suggests that forward markets decrease spot prices and enhance efficiency.[1] The approach exploits the similarities between a two-period durable goods monopolist's problem[2] and the effect of forward markets on spot prices. In the durable goods monopolist's problem, high product sales in the first period reduce the price in the second period. In the AV framework, after the forward market commitments are signed, firms compete for a residual demand in the spot market. Since the forward market prices are fixed, the firms behave aggressively and are more inclined to cut the price in the spot market. The firms cannot keep the spot prices high by restraining themselves from participating in the forward market since each firm is trying to increase its market share by increasing its forward market commitment levels. Therefore, an increase in forward market commitment levels reduces spot market prices and enhances efficiency.

A crucial assumption in the above analysis is that the firms are underutilizing their capacity levels in the absence of the forward market or that the firms can adjust their production levels costlessly. I endogenize firms' investment in capacity levels, and I study the effects of forward markets on competition and efficiency. In particular, I analyze the implications of the forward market that takes place after the investment decisions are committed but before the spot market. This is an important extension because

[1]See Allaz (1992), Green (1996), Ferreira (2001), Lien (2000), Le Coq and Orzen (2002), Newbery (1998), etc.

[2]See Coase (1972).

endogenous capacity choices significantly change firms' strategic behavior in forward and spot markets. Furthermore, the paper studies the relationship between uncertainty and the price-mitigating effects of the forward market.

I show that while the price-reducing effects of the forward market still exist, the firms' ability to choose capacity levels significantly changes the AV result. In particular, the analysis depends on the degree of a demand uncertainty. When the demand uncertainty is small, the introduction of a forward market after capacity investments does not change social welfare because the firms are already utilizing full capacities in equilibrium. As the demand uncertainty increases, the firms start underutilizing their capacities during the low demand periods. The introduction of the forward market induces the firms to utilize their capacity more often and to lower spot market prices. In order to counteract the price-reducing effect of the forward market, the firms decrease their capacity levels. I show that the firms' ability to restrict their capacity levels as a commitment to higher spot market prices could result in a Pareto-inferior outcome. As the demand uncertainty increases even more, the introduction of the forward market decreases spot market prices without inducing full capacity utilization. Thus, the firms find it more difficult to eliminate the price-reducing effect of the forward market by restricting their capacity levels. Therefore, the welfare-improving effect of lower spot market prices could overweigh the welfare-reducing effect of lower capacity investments.

The paper also explores the role of an increased competition on the effectiveness of the forward market to enhance social welfare. An increase in the number of firms diminishes the firms' ability to commit to lower capacity levels, and the firms find it more difficult to use capacity levels as commitment devices to higher spot prices. This, in turn, reduces the likelihood that the forward market has a negative effect on social welfare and increases the likelihood that the forward market has a positive effect on social welfare.

When contrasting the results of this paper with the findings of the models that utilize the AV framework, one needs to compare model assumptions. The AV results are most appropriate for forward markets that take place before capacity investments, i.e., the longer-term forward markets. Since capacity levels are flexible in the long run, firms cannot use capacities as commitment devices. The results of my paper are appropriate for forward markets that take place after the investment decisions, i.e., the shorter-term forward markets.

Although a strategic use of forward contracts might occur in many industries, much of the recent literature concerning the strategic implications of forward markets has focused on electricity markets. In the existing electricity markets in the United States, most forward markets take place one day to six months prior to the spot market, whereas the investment commitments are made at least three years ahead.[3] Since most forward contracts are "shorter-term" forward contracts, the findings of my paper also have important policy implications for the electricity markets.

The rest of the paper is organized as follows. Section 2 reviews the literature on strategic effects of forward markets. Section 3 presents the model. Section 4 studies the implications of forward markets under capacity constraints. Section 5 discusses the findings. Solutions to the model and proposition proofs are presented in the appendices.

2 Literature Review

The existence of forward markets can be easily explained by market participants' unwillingness to take risks. However, Allaz and Vila (1993) suggest strategic reasons for the existence of forward markets and show that uncertainty and hedging risks are not necessary.[4] Particularly, AV study the effect of forward markets on competition and

[3] An investment lead time for a power plant typically varies from 3 to 7 years.

[4] There are other explanations for the existence of forward and futures markets in the absence of uncertainty. Williams (1987) argues that the following four features of commodity markets imply the existence of futures markets under risk neutrality: positive transactions costs, nonlinear total processing costs, lower transactions costs in the futures market than in the spot market, and a heterogeneity in

efficiency and conclude that more frequent forward markets make firms worse off. In the limit, the forward markets drive the spot prices to a competitive level. The following generalizes this intuition:

> When only one producer is given the opportunity to make forward sales, he actually benefits from a first mover advantage over his competitor and finds himself in the position of a Stackelberg leader on the spot market. When both firms can trade forward, the trading decisions give rise to a prisoner's dilemma: Each producer has incentive to trade forward but when they both do so, they end up worse off. (Allaz and Vila, 1993, p. 3.)

The AV model is one of a duopolistic Cournot competition with firms simultaneously selecting their production levels. In many industries, including the electricity industry, firms compete by means of selecting supply schedules as strategic variables. Thus, Klemperer and Meyer (1989) have developed a theoretical framework of supply function equilibria under uncertainty. The supply function models have been widely applied in electricity markets. Newbery (1998) and Green (1999) study the implications of electricity (forward) contract markets in a spot market supply function equilibria framework to analyze the effects of forward markets on competition. Both authors study a two-stage game, where firms make quantity commitments at a forward price in the first stage, and the firms compete in a spot market by choosing supply schedules in the second stage. Newbery uses constant marginal cost curves, whereas Green uses linear marginal cost curves. Newbery confirms the AV conclusions that forward markets decrease the ability of firms to raise prices in the spot market. Green's assumption of linear marginal cost curves results in a special case when one firm's forward market commitment level does not affect the other firms' behavior in the spot market. This eliminates the Stackelberg

processors' initial economic circumstances. In the markets that display the above features, it might be advantageous for the processor to use the futures contacts since the futures markets reduce the expected transactions costs in the spot market.

leader advantage from engaging in the forward market. Clearly, without a strategic advantage from engaging in the forward market, the AV results do not hold. Nevertheless, when the firms engage in the forward market due to risk hedging reasons, an increase in the forward market commitment levels decreases the spot prices.

Lien (2000) studies the role of forward markets when a large firm has significant market power. Lien argues that a large firm uses its capacity less profitably than smaller firms due to the large firm's desire to increase prices. Small firms, behaving competitively, benefit from the large firm's ability to increase prices. Lien suggests that the large firm can eliminate the negative effects of its size by restricting excess entry through the sale of long term forward contracts. Thus, the existence of long term forward contracts enhances efficiency.

The predictions of the AV model concerning the efficiency-enhancing effects of forward markets have been tested experimentally as well. Le Coq and Orzen (2002) conduct forward market experiments with constant marginal costs in a Cournot duopoly framework. The authors confirm the AV predictions that forward markets increase competition and decrease spot market prices. However, Le Coq and Orzen conclude that the competition-enhancing effects of forward markets are weaker in their experimental settings than theoretically predicted.

Brandts, Pezanis-Christou and Schram (2003) conduct similar experiments to study forward markets considering both supply function and Cournot competitions. Consistent with the AV predictions, the authors find that the introduction of forward markets lowers prices both under the Cournot and the supply function competitions. Brandts et. al. also find that the supply function competition with two or three firms yields lower prices and higher efficiencies than the Cournot competition. This finding is consistent with Klemperer and Meyer theoretical predictions that the equilibrium in supply functions is between the Bertrand and the Cournot outcomes.

It is important to note an implicit assumption of public information in the models that use the AV framework. Bagwell (1995) and Hughes and Kao (1997) argue that when forward market outcomes are not observable by firms, there is no strategic incentive for the firms to engage in the forward markets – a Stackelberg leader advantage is lost if the second firm does not know that the first firm is the Stackelberg leader. Thus, under the unobservability assumption, firms undermine the competitive effects of forward markets by strictly preferring not to engage in forward trading. Hughes and Kao show that if risk hedging reasons are present, the firms nevertheless may engage in forward markets under the unobservability assumption. Ferreira (2001) studies various unobservable market structures and argues that given a choice between observable and unobservable forward markets, firms choose observable markets; hence, the AV results hold. The current paper assumes that firms' forward positions are known by all market participants. In a model with linear demand and constant marginal costs, the results hold even if firms only observe the aggregate forward market quantity commitment levels.

Some question the efficiency-enhancing effects of forward markets. Harvey and Hogan (2000), and Liski and Montero (2004) argue that firms might collude to soften competition, while Mahenc and Salanie (2004) present a model in which firms buy their own production forward in order to increase spot market prices, essentially, withholding the spot capacity. Mahenc and Salanie findings differ from the AV predictions because the firms compete in prices (strategic complements) rather than in quantities (strategic substitutes). Although the above three studies suggest that forward markets do not necessarily increase social welfare, it is not clear whether these results are still applicable in the presence of a regulator that monitors anticompetitive behavior and disallows firms to purchase their own production in the forward market.

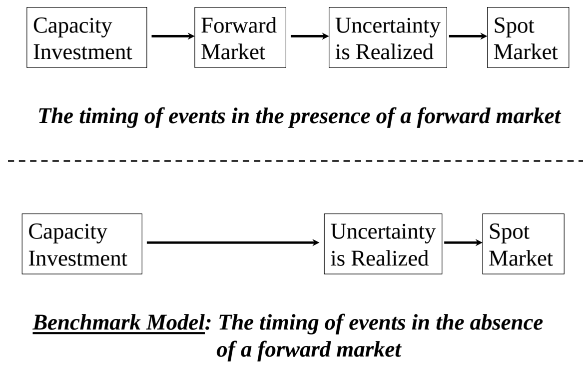

Figure 1: The Timing of Events in the Presence and in the Absence of a Forward Market

3 Model

There are three types of players in the market: firms, an intermediary and buyers. The firms produce and sell a product in forward and spot markets. There are n identical firms in the market. The buyers buy the product in the spot market for consumption purposes. It is assumed that the buyers are infinitesimal, always bidding their marginal valuation. The intermediary buys forward contracts from the firms in the forward market and resells the product in the spot market. It is assumed that the intermediary earns zero profits.[5] A zero profit (or a no arbitrage) condition can be motivated by free entry and exit assumption. The firms and the intermediary are rational forward-looking agents. Specifically, I consider a dynamic oligopoly model with three repetitive stages. First, the firms choose their capacity levels by selecting the level of capacity investment. Then, the forward market takes place. Last, the uncertainty is realized, and the spot market takes place. Graphical representation of this game is depicted at the top of figure 1.

Stage I: Capacity Choices. The firms simultaneously choose their capacity

[5]One might assume, in the spirit of the original AV model, a large number of speculators making competitive bids instead of the intermediary. The results will not be affected as long as there is no possibility for arbitrage.

levels.

Stage II: Forward Market. The firms and the intermediary simultaneously present their forward market quantity offers and forward market demand schedule, respectively. The forward market price and quantities are determined.

Stage III.a: Realization of Uncertainty. The uncertainty is realized and observed by all parties.

Stage III.b: Spot Market. After observing new capacity levels, the forward market commitments and the realization of uncertainty, the firms and the intermediary simultaneously choose spot market quantity offers. The spot market price and the firms' profits are determined.

Demand is stochastic and linear, $D(P) = \frac{a}{b} - \frac{1}{b}P + \frac{\epsilon}{b}$, where ϵ is a random variable. Due to its analytical simplicity, the choice of a linear demand is conventional in the recent literature of forward market models.[6] I assume that all parties are risk-neutral.[7] Production is assumed to have constant marginal cost, $C(q) = cq$. The firms' maximum output levels in the spot market are subject to capacity constraints. The firms' initial capacity levels are zero. The firms can invest in their capacity at stage I. Per unit capacity investment cost is $i > 0$. The restriction on parameters is that $a + \epsilon > c + i$ for all realizations of epsilon.[8] The following notation is used to denote other variables:

$P^f \equiv$ forward market price.

$P^s_\theta \equiv$ spot market price when the state is θ.

$q^f_h \equiv$ forward market quantity offer by firm h.

[6] See Laussel (1992), Allaz and Vila (1993) Newbery (1998), Green (1999), or Adler et. al. (2004).

[7] See Adilov (2005) for an analytically tractable way of introducing risk-aversion in these types of models. He also argues that the introduction of risk-aversion does not alter the intuition derived in these models in a significant way.

[8] This assumption, although stronger than needed, ensures that the firms produce positive quantities in equilibrium.

$q^s_{h,\theta} \equiv$ spot market quantity offer by firm h when the state is θ.

$Q^f \equiv$ quantity bought by the intermediary in the forward market and resold in the spot market.

$Q^s_\theta \equiv$ total spot market quantity offer by the firms when the state is θ.

$k_h \equiv$ capacity investment by firm h.

$K \equiv$ market capacity investment.

Firm h's problem can be described as the following dynamic programming problem:

$$V^c_h \equiv \max_{k_h \geq 0} -k_h i + V^f_h(k_h, k_{-h}) \tag{1}$$

$$V^f_h(k_h, k_{-h}) \equiv \max_{k_h \geq q^f_h \geq 0} [P^f - c]q^f_h + EV^s_{h,\,\theta}(q^f_h, q^f_{-h}, k_h, k_{-h}) \tag{2}$$

$$V^s_{h,\,\theta}(q^f_h, q^f_{-h}, k_h, k_{-h}) \equiv \max_{k_h - q^f_h \geq q^s_{h,\,\theta} \geq 0} (P^s_\theta - c)q^s_{h,\,\theta} \tag{3}$$

To simplify the analysis, I consider a specific type of uncertainty: $\epsilon \in \{0, \epsilon^*\}$, where $Prob\{\epsilon = 0\} = 1 - \varphi$ and $Prob\{\epsilon = \epsilon^*\} = \varphi$. Thus, there are two states: $\epsilon = \epsilon^*$ corresponds to the high demand state and $\epsilon = 0$ corresponds to the low demand state. To study the implications of the forward market, I compare social welfare levels of this model to a **benchmark model**. The benchmark model represents a model without the forward market. Graphical representation of the timing of events in the benchmark model is given in figure 1. More formally, firm h's problem in the absence of the forward market can be described as:

$$V^c_h \equiv \max_{k_h \geq 0} -k_h i + EV^s_{h,\,\theta}(k_h, k_{-h}) \tag{4}$$

$$V^s_{h,\,\theta}(k_h, k_{-h}) \equiv \max_{k_h \geq q^s_{h,\,\theta} \geq 0} (P^s_\theta - c)q^s_{h,\,\theta} \tag{5}$$

Since solving the benchmark model is straightforward, I only present equilibrium levels that arise from this game. If $\epsilon^* \in [0, i/\varphi]$, i.e., the demand uncertainty is small, the firms utilize their full capacities both in the high and low demand states. If $\epsilon^* \in (i/\varphi, \infty)$, the firms utilize their full capacities only in the high demand state. The equilibrium levels are presented in table 1.

Table 1: Benchmark Model: Equilibrium Levels.

	$\epsilon^* \in [0, i/\varphi]$	$\epsilon^* \in (i/\varphi, \infty)$
P_0^s	$(a + n(c + i - \varphi\epsilon^*))/(n + 1)$	$(a + nc)/(n + 1)$
$P_{\epsilon^*}^s$	$(a + \epsilon^*\varphi + n(c + i))/(n + 1)$	$(a + \epsilon^* + n(c + i/\varphi))/(n + 1)$
Q_0^s	$n(a + \varphi\epsilon^* - c - i)/((n + 1)b)$	$(n(a - c))/((n + 1)b)$
$Q_{\epsilon^*}^s$	$n(a + \varphi\epsilon^* - c - i)/((n + 1)b)$	$n(a + \epsilon^* - c - i/\varphi)/((n + 1)b)$
K	$n(a + \varphi\epsilon^* - c - i)/((n + 1)b)$	$n(a + \epsilon^* - c - i/\varphi)/((n + 1)b)$

Solution to the model in the presence of the forward market is given in appendix A. The equilibrium levels are given in table 2. Similar to the benchmark model, there is an equilibrium where the capacity constraints are binding during the both demand states, and there is an equilibrium where the capacity constraints are not binding in the low demand state. There is also a region of $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(n^2+1), i/\varphi + (n-1)(a-c)/(\varphi(n^2+1))]$ where the both types of equilibria are possible. The next section further explores the implications of the forward market in the presence of the capacity constraints.

4 Implications of Forward Markets under Capacity Constraints

The following proposition shows how the introduction of the forward market affects social welfare. The proof of proposition 1 is given in appendix B.

> **Proposition 1:** Fix all parameters except ϵ^*. The introduction of the forward market:
>
> **a.** does not alter social welfare if $\epsilon^* \in [0, i/\varphi]$;
>
> **b.** reduces both seller and consumer surplus (thus, results in a Pareto-inferior outcome) if $\epsilon^* \in (i/\varphi, i/\varphi + (n-1)(a-c)/(n^2+1)]$;

Table 2: Equilibrium Levels in the Presence of the Forward Market.

	$\epsilon^* \in [0, i/\varphi + (n-1)(a-c)/(\varphi(n^2+1))]$
P_0^s	$(a + n(c + i - \varphi\epsilon^*))/(n+1)$
$P_{\epsilon^*}^s$	$(a + (n+1)\epsilon^* + n(c + i - \varphi\epsilon^*))/(n+1)$
P^f	$(a + \varphi\epsilon^* + n(c+i))/(n+1)$
$Q_0^s + Q^f$	$n(a + \varphi\epsilon^* - c - i))/((n+1)b)$
$Q_{\epsilon^*}^s + Q^f$	$n(a + \varphi\epsilon^* - c - i))/((n+1)b)$
K	$n(a + \varphi\epsilon^* - c - i))/((n+1)b)$
	$\epsilon^* \in (i/\varphi + (n-1)(a-c)/(n^2+1), \infty)$
P_0^s	$(a + n^2 c)/(n^2+1)$
$P_{\epsilon^*}^s$	$(a + \epsilon^* + n(c + i/\varphi))/(n+1)$
P^f	$\varphi(a + \epsilon^* + n(c + i/\varphi))/(n+1)$
	$+(1-\varphi)(a + n^2 c)/(n^2+1)$
$Q_0^s + Q^f$	$n^2(a-c)/((n^2+1)b)$
$Q_{\epsilon^*}^s + Q^f$	$n(a + \epsilon^* - c - i/\varphi)/((n+1)b)$
K	$n(a + \epsilon^* - c - i/\varphi)/((n+1)b)$

c. increases social welfare if $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(\varphi(n^2+1)), \infty)$;

d. has an ambiguous effect on social welfare if $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(n^2+1), i/\varphi + (n-1)(a-c)/(\varphi(n^2+1))]$.

The intuition behind the above proposition is the following. When the demand uncertainty is small, i.e., $\epsilon^* \in [0, i/\varphi]$, the introduction of the forward market has no effect on social welfare. For these parameter values, the firms utilize full capacities both in the presence and in the absence of the forward market under all demand realizations. Thus, the equilibrium price is solely dictated by the capacity levels. There can be no spot price-reducing effect of the forward market because the firms commit to the capacity levels that are above the spot market Cournot quantity levels. This fully eliminates the firms' price-undercutting behavior in the spot market. One should note that this result is similar to Kreps and Scheinkman's (1983) findings that under certainty, firms can eliminate the price-reducing effects of the Bertrand competition if the firms choose quantity production levels before engaging in the Bertrand competition. The Kreps and Scheinkman intuition holds here because the demand uncertainty is small enough.

Next, consider a case when $\epsilon^* \in (i/\varphi, i/\varphi + (n-1)(a-c)/(n^2+1)]$, case b. Under the benchmark model, the firms utilize their full capacity only during the high demand state. Following the AV logic, the introduction of the forward market increases competition in the spot market and decreases the spot market prices. Under these parameter values, the forward market decreases the spot market price during the low demand state until the firms reach their full capacity levels. Thus, the introduction of the forward market forces the firms to fully utilize their capacity in the low demand state. Moving back to the capacity investment stage of the game, the firms foresee their price-undercutting behavior in the low demand state. Therefore, the firms select lower capacity levels in the presence of the forward market. This decreases social welfare.

One should note the relationship between capacity utilization and capacity investment. On the one hand, the forward market increases social welfare by increasing capacity utilization. The forward market, however, might also have a negative effect on social welfare because of a decreased capacity investment. In general, the sum of these two opposing effects is ambiguous. For the parameter values in case b, the overall effect from introducing the forward market is negative. Furthermore, both consumer and producer surplus levels decrease due to a higher price volatility in the presence of the forward market.

Next, consider a case when the demand uncertainty is high, i.e., $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(\varphi(n^2+1)), \infty)$. Similar to the earlier case, the introduction of the forward market decreases the spot market prices during the low demand state. However, the firms are still underutilizing their capacity levels during the low demand state because the demand variance is high. Since the firms are not utilizing their full capacity in the low demand state, the firms cannot use the capacity levels to counteract the price-reducing effects of the forward market. Thus, the forward market decreases the spot market prices in the low demand state without negatively affecting capacity investments. Therefore, the introduction of the forward market increases social welfare.

Finally, consider a multiple equilibria case – case d. This case occurs when ϵ^* is increasing and moving from case b to case c. Since both types of equilibria might occur in this region, it is not clear whether the introduction of the forward market enhances or diminishes social welfare.

Although the above model is simplistic in many ways, it captures an important relationship between the degree of demand uncertainty and the effectiveness of a forward market for efficiency improvement. Consider more realistic types of demand fluctuations instead of the simple two-state demand realizations. If the demand uncertainty is very small, the firms utilize all of their capacity most of the time in the absence of the forward market. Then, consistent with the Kreps and Scheinkman intuition, the introduction of the forward market would not affect market outcomes. As the demand uncertainty increases, the firms start utilizing full capacity less often in the absence of the forward market. Then, the introduction of the forward market will induce the firms to utilize their capacity levels more often. The firms would react by decreasing their capacity investments. This might reduce social welfare. Now, suppose that the demand uncertainty increases even more. The introduction of the forward market decreases spot market prices but this price decrease induces full capacity utilization less frequently. Thus, the firms cannot fully eliminate the price-reducing effects of the forward market by restricting their capacity levels. Therefore, the welfare-improving effects of lower spot market prices could overweigh the welfare-reducing effects of lower capacity investments.

Next, consider how an increase in the number of firms affects the likelihood that the forward market has positive impact on social welfare. Let $A(n)$ denote the region of

ϵ^* values in which the forward market has *no effect* on social welfare when the number of firms is n. Let $B(n)$ denote the region of ϵ^* values in which the introduction of the forward market has a *negative effect* on social welfare when the number of firms is n. Similarly, let $C(n)$ denote the region in which the forward market has a *positive effect* on social welfare, and let $D(n)$ denote the region in which the effect of the forward market is *ambiguous*. Then, the following proposition holds.

> **Proposition 2:** If $n \geq 3$ and m is a natural number, then $A(n+m) = A(n)$, $B(n+m) \subset B(n)$, $C(n) \subset C(n+m)$, and $B(n+m) \cup D(n+m) \subset B(n) \cup D(n)$. Furthermore, if $n = 2$, then $A(n+1) = A(n)$, $B(n+1) = B(n)$, $C(n+1) = C(n)$, and $D(n+1) = D(n)$.

Proof to proposition 2 is given in appendix B. The proposition states that as the number of firms increases from three on, the region where the introduction of the forward market reduces social welfare, region $B(n)$, shrinks and the region where the introduction of the forward market enhances social welfare, region $C(n)$, expands. One intuition for this result is that as more firms compete in the market, the firms find it more difficult to use capacity levels as commitment devices. This shrinks the area where the presence of the forward market decreases social welfare. On the other hand, the area where the forward market has a positive impact on social welfare expands with the number of firms. Also note that the area where the forward market might have a negative impact on social welfare, the union of regions $B(n)$ and $D(n)$, shrinks as the number of firms increases. Figure 2 plots the four regions as a function of the number of firms in the market.

One should also note that the region where the forward market has no impact on social welfare stays the same. This is the region where the uncertainty is small enough, and the firms utilize their capacities in the both states, even in the absence of the forward market. Thus, the size of this area depends on the degree of demand uncertainty but not on the number of firms. The second part of proposition 2 states that the sizes of the four regions stay the same when the number of firms in the market increases from two

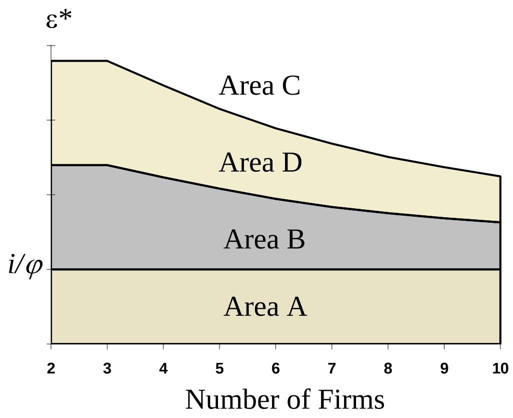

Figure 2: The Effect of an Increase in the Number of Firms

to three. This could be a special result for linear demand and constant marginal cost curves.

5 Discussion

Allaz and Vila have shown that forward markets decrease spot market prices and enhance efficiency by increasing firms' investment levels and by making the spot market competition fiercer. My analysis suggests that while this intuition might hold for the forward market that take place before capacity levels are committed, it does not necessarily hold for the forward market that take place after the capacity levels are committed. The AV intuition that forward markets induce more aggressive behavior in the spot market still exists in the presence of capacity constraints; however, the firms' ability to pre-commit to the capacity levels could undermine the price-reducing effects of forward markets. The firms anticipate their future aggressive bidding tendencies and respond by decreasing their capacity levels. In general, the effect of the forward market on social welfare is ambiguous and depends on the degree of demand uncertainty. Under the conditions outlined in section 4, the forward market that takes place after investment might increase price volatility, discourage capacity investment, and result in a Pareto-inferior outcome. This is an interesting finding in the light of a conventional wisdom that forward transactions improve the overall performance of markets.

An increase in the number of firms in the market strengthens competition in the capacity stage and increases the likelihood that the forward market has a positive effect on social welfare. However, as the number of firms increase, social welfare gain from the introduction of the forward market also diminishes. In the limit, the introduction of the forward market has no effect on the capacity levels and spot prices since the strategic effects of forward contracts and capacity investments disappear in a perfectly competitive market.

One might also study the implications of the forward market that takes place before the investment decisions are made. This extension is omitted from the current paper since it simply generates a variation of the AV result in a model with demand uncertainty. Note that the AV results are most appropriate for forward markets that take place before capacity investments, i.e., the longer-term forward markets. Since capacity levels are flexible in the long run, firms are not able use capacities as commitment devices. Thus, the results of my paper are appropriate for forward markets that take place after investment decisions, i.e., the shorter-term forward markets.

The findings of this paper have important policy implications for capital-intensive industries where capacity expansion requires long lead time. In the existing electricity markets in the United States, most forward markets take place one day to six months prior to the spot market, whereas, investment commitments are made at least three years in advance. Thus, the lead time of the forward markets are shorter than the lead time required to complete investment. A previous literature on forward markets argued that forward markets could be used to mitigate market power and to increase competition in the electricity markets. The findings of the current paper question the effectiveness of forward markets to achieve these objectives.

The paper did not specifically address the issue of product storability. In the electricity markets, where storage can be prohibitively expensive, and in other industries, where the product is perishable, this specification does not pose a problem. Yet, the results can be applied to the industries where the product is storable as well. For example, one can assume that the opportunity cost of reselling the product in the following period is included in the cost parameter c. Convexities related to inventory storage costs, however, might generate additional insights.

The paper exogenously separates forward markets into the longer- and the shorter-term forward markets. In many real world situations, however, firms have the ability to slow down or speed up the investment process. The firms' ability to affect their investment lead time will not have a significant impact on the results. A producer does not gain a strategic advantage from slowing down the investment process since the firm with the shortest lead time has the advantage. On the other hand, speeding up the investment process exhibits decreasing returns to scale. In the electricity industry, for example, shortening the investment lead time is economically inefficient.[9]

The intermediary plays an important role by efficiently allocating forward market purchases in the spot market. The implications of the model might change if the producers could sell forward contracts directly to consumers through bilateral contracts due to economic inefficiency associated with bilateral contracts. Furthermore, the bilateral forward prices may vary from the expected spot price because of buyer heterogeneity.

The qualitative results of the paper should not change much if the firms compete in supply functions rather than in quantities. However, as argued in Adilov (2005), the welfare analysis in supply function competition models is problematic due to the multiplicity of equilibria. One possible extension of the model is to analyze the robustness of the results to more general demand and cost formulations. Yet, the current paper provides a strong intuition regarding the implications of forward markets in the presence of endogenous capacity constraints and the relationship between uncertainty and the

[9]Some delays in power plant construction is due to the regulatory restrictions.

price-mitigating effects of forward markets. Another extension is to allow a free entry because the threat of an entry can significantly affect the firms' strategic behavior in the forward and spot markets.

A Solution to the Model in the Presence of the Forward Market

This appendix solves the model outlined in section 3. Because the firms are symmetric, I restrict the analysis to a symmetric equilibrium.

A.1 Stage III: Spot Market

Consider the firms' behavior in the spot market. Fix the firms' capacity levels and forward market quantity offers, and calculate the firms' optimal spot market quantity offers. Since capacity is costly, the capacity constraint should bind in equilibrium when the demand is high. The capacity constraint may or may not bind when the demand is low.

High Demand. The equilibrium spot market quantity offer by firm h is $q^{s*}_{h,\,\epsilon^*} = k_h - q^f_h$. The spot market price is $P^s_{\epsilon=\epsilon^*} = a + \epsilon^* - b\sum k_j$. Firm h's spot market profit is $V^s_{h,\,\epsilon^*} = [a + \epsilon^* - c - b\sum k_j][k_h - q^f_h]$.

Low Demand. Suppose the capacity constraint is binding. Then, the equilibrium spot market quantity offer by firm h is $q^{s*}_{h,\,0} = k_h - q^f_h$. The spot market price is $P^s_{\epsilon=0} = a - b\sum k_j$. Firm h's spot market profit is $V^s_{h,\,0} = [a + \epsilon^* - c - b\sum k_j][k_h - q^f_h]$.

Now suppose the capacity constraint is not binding when the demand is low, i.e., $q^{s*}_{h,\,0} \leq k_h - q^f_h$. Firm h chooses its spot quantity offer by maximizing its spot market profit, i.e., by maximizing $[a - c - b\sum q^f_j - b\sum q^s_{j,\,0}]q^s_{h,\,0}$. Firm h's equilibrium spot quantity offer is $q^{s*}_{h,\,0} = (a - c - b\sum q^f_j)/((n+1)b)$. The spot market price is $P^s_{\epsilon=0} = (a + nc - b\sum q^f_j)/(n+1)$. The firm's spot market profit is $V^s_{h,\,0} = (a - c - b\sum q^f_j)/((n+1)^2 b)$.

A.2 Stage II: Forward Market

First, consider the intermediary's bid in the forward market. No arbitrage condition implies that the forward market price is equal to the expected spot market price. When the spot market capacity constraint is binding in the both states, the intermediary's inverse demand in the forward market is as follows:

$$P^f = a + \varphi\epsilon^* - b\sum k_j \tag{6}$$

If the capacity constraint is not binding when the demand is low, the intermediary's inverse demand in the forward market is as follows:

$$P^f = \varphi(a + \epsilon^* - b\sum k_j) + (1-\varphi)\frac{a + nc - bQ^f}{n+1} \tag{7}$$

Next, consider the firms' behavior in the forward market.

The Capacity Constraint is not Binding in the Low Demand State. Suppose in equilibrium, the spot market capacity constraint is binding in the high demand state but not in the low demand state. Then, firm h maximizes its expected profit by choosing the forward quantity offer, i.e.,

$$\max_{q_h^f \le k_h} (P^f - c)q_h^f + \varphi V_{h,\,\epsilon^*}^s + (1-\varphi)V_{h,\,0}^s \tag{8}$$

The substitution of equation (7) and firm h's spot market profits yields optimal forward quantity offer $q_h^{f*} = (n-1)(a-c)/((n^2+1)b)$. The corresponding forward market price is $P^f = \varphi(a+\epsilon^* - b\sum k_j) + (1-\varphi)(a+n^2c)/(n^2+1)$, and firm h's expected profit is $V_h^f = \varphi(a + \epsilon^* - c - b\sum k_j)k_h + (1-\varphi)n(a-c)^2/((n^2+1)^2b)$.

The Capacity Constraint is Binding in the Both States. Suppose in equilibrium, the spot market capacity constraint is binding in the both states. Then, firm h's optimal forward quantity offer q^{f*} is in region $[0, k_h]$. The forward market price is given by equation (6). Firm h's expected profit is $V_h^f = (a + \varphi\epsilon^* - c - b\sum k_j)k_h$.

A.3 Stage I: Capacity Investment

Now, consider the firms' optimal investments in the capacity stage. During the capacity stage, firm h chooses capacity level that maximizes its expected profit $-ik_h + V_h^f(k_h, k_{-h})$.

The Capacity Constraint is not Binding in the Low Demand State. Suppose in equilibrium, the spot market capacity constraint is binding in the high demand state but not in the low demand state. Then, firm h's optimal capacity level is $k_h^* = (a + \epsilon^* - c - i/\varphi)/((n+1)b)$. Next, I substitute this value in order to calculate the optimal spot and forward quantity offers. Checking for the non-binding constraint and the non-deviation conditions (in the spot and forward markets) yields that this capacity level is the equilibrium with non-binding capacity constraint if $\epsilon^* > i/\varphi + (n-1)(a-c)/(n^2+1)$. Firm h's expected profit in equilibrium is:

$$V_h^c = \frac{\varphi}{(n+1)^2 b}(a + \epsilon^* - c - i/\varphi)^2 + \frac{n(1-\varphi)}{2(n^2+1)^2 b}(a-c)^2 \tag{9}$$

The Capacity Constraint is Binding in the Both States. Suppose in equilibrium, the spot market capacity constraint is binding in the both states. Then, firm h's optimal capacity level is $k_h^* = (a + \varphi\epsilon^* - c - i)/((n+1)b)$. Next, I substitute this value to calculate the optimal spot and forward quantity offers. Checking for the binding constraint and the non-deviation conditions (in the spot and forward markets) yields that this is the equilibrium with binding capacity constraint if $\epsilon^* \leq i/\varphi + (n-1)(a-c)/(\varphi(n^2+1))$. Firm h's expected profit in equilibrium is:

$$V_h^c = \frac{1}{(n+1)^2 b}(a + \varphi\epsilon^* - c - i)^2 \tag{10}$$

Note that there are two symmetric equilibria when $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(n^2+1), i/\varphi + (n-1)(a-c)/(\varphi(n^2+1))]$: one with binding and one with non-binding capacity constraint. There is a unique symmetric solution for other ranges of ϵ^*.

B Proofs to the Propositions

B.1 Proof to Proposition 1

Case a. Note that equilibrium investments, consumption levels, and spot prices are the same both in the presence and in the absence of the forward market when $\epsilon^* \in [0, i/\varphi]$ (see tables 1 and 2). Thus, social welfare levels are the same.

Case b. Suppose $\epsilon^* \in (i/\varphi, i/\varphi + (n-1)(a-c)/(n^2+1)]$. Let $V_h^c(Benchmark)$ denote seller h's expected surplus (profit) in the benchmark model. Let $V_h^c(Forward)$ denote seller h's expected surplus when the forward market is present. The substitution of equation (10) yields the following difference between the two expected values:

$$V_h^c(Benchmark) - V_h^c(Forward) =$$

$$= \frac{\varphi}{(n+1)^2 b}(a+\epsilon^* - c - i/\varphi)^2 + \frac{1-\varphi}{(n+1)^2 b}(a-c)^2 - \frac{1}{(n+1)^2 b}(a+\varphi\epsilon^* - c - i)^2 \quad (11)$$

This difference can be rewritten as:

$$\frac{1}{(n+1)^2 b}(\varphi g(x_1) + (1-\varphi)g(x_2) - g(\varphi x_1 + (1-\varphi)x_2)) \quad (12)$$

where $g(x) = x^2$, $x_1 = a+\epsilon^* - c - \frac{i}{\varphi}$, $x_2 = a-c$. Since $g(x)$ is strictly convex, $\varphi g(x_1) + (1-\varphi)g(x_2) > g(\varphi x_1 + (1-\varphi)x_2)$. This implies that $V_f^c(Benchmark) - V_f^c(Forward) > 0$. Thus, the introduction of the forward market decreases seller surplus.

Now, let $ECS(Benchmark)$ denote the expected consumer surplus in the benchmark model. Let $ECS(Forward)$ denote the expected consumer surplus when the forward market is present. The difference between the two expected values is:

$$ECS(Benchmark) - ECS(Forward) =$$

$$= \frac{n^2\varphi}{2(n+1)^2 b}(a+\epsilon^* - c - i/\varphi)^2 + \frac{n^2(1-\varphi)}{2(n+1)^2 b}(a-c)^2 - \frac{n^2}{2(n+1)^2 b}(a+\varphi\epsilon^* - c - i)^2 \quad (13)$$

This difference can be rewritten as:

$$\frac{n^2}{2(n+1)^2 b}(\varphi g(x_1) + (1-\varphi)g(x_2) - g(\varphi x_1 + (1-\varphi)x_2)) \quad (14)$$

where $g(x) = x^2$, $x_1 = a + \epsilon^* - c - \frac{i}{\varphi}$, $x_2 = a - c$. Since $g(x)$ is strictly convex, $\varphi g(x_1) + (1-\varphi)g(x_2) > g(\varphi x_1 + (1-\varphi)x_2)$. This implies that $ECS(Benchmark) - ECS(Forward) > 0$. Thus, the forward market decreases consumer surplus as well.

Case c. Suppose $\epsilon^* \in (i/\varphi + (n-1)(a-c)/((n^2+1)\varphi), \infty)$. Let $ETS(Benchmark)$ denote the expected social welfare in the benchmark model. Let $ETS(Forward)$ denote the expected social welfare when the forward market is present. The difference between the two expected values is:

$$ETS(Benchmark) - ETS(Forward) =$$

$$= -\frac{(1-\varphi)(a-c)^2}{2(n+1)^2(n^2+1)^2 b}[(n^4-1) + (n-1)^2] < 0 \qquad (15)$$

Thus, the forward market increases social welfare.

Case d. Suppose $\epsilon^* \in (i/\varphi + (n-1)(a-c)/(n^2+1), i/\varphi + (n-1)(a-c)/((n^2+1)\varphi)]$. Since both the binding and non-binding equilibria might result for these parameter values, one cannot imply whether the introduction of the forward market increases or decreases social welfare.

B.2 Proof to Proposition 2

Let $x(n) = (n-1)(a-c)/(n^2+1)$. Then, the four areas are given by $A = [0, i/\varphi]$, $B = (i/\varphi, i/\varphi + x(n)]$, $C = (i/\varphi + x(n)/\varphi, \infty)$, and $D = (i/\varphi + x(n), i/\varphi + x(n)/\varphi]$. In order to prove proposition 2, it suffices to show that $x(n) > x(n+1)$ for $n > 2$ and that $x(2) = x(3)$.

$$x(n+1) - x(n) = \frac{(n+1)(2-n)(a-c)}{((n+1)^2+1)(n^2+1)} \qquad (16)$$

Clearly, the above difference is negative for $n > 2$ and zero for $n = 2$.

References

[1] **Adilov, N.**, *"Essays on Market Design and Strategic Interaction,"* Ph.D. dissertation, Cornell University (2005).

[2] **Adler, I., Oren, S., and Yao, J.**, *"Computing Cournot Equilibria in Two Settlement Electricity Markets with Transmission Constraints,"* Proceedings of the 37th Hawaii International Conference on System Sciences (2004).

[3] **Allaz, B.**, *"Oligopoly, Uncertainty and Strategic Forward Transactions,"* International Journal of Industrial Organization 10 (1992), 297-308.

[4] **Allaz, B. and Vila, J.-L.**, *"Cournot Competition, Futures Markets and Efficiency,"* Journal of Economic Theory 59 (1993), 1-16.

[5] **Bagwell, K.**, *"Commitment and Observability in Games,"* Games and Economic Behavior 8 (1995), 271-280.

[6] **Brandts, J., Pezanis-Christou, P. and Schram, A.**, *"Competition with Forward Contracts: A Laboratory Analysis Motivated by Electricity Design,"* mimeo, University of Amsterdam, Netherlands, (2003).

[7] **Coase, R.**, *"Durability and Monopoly,"* Journal of Law and Economics 15 (1972), 143-49.

[8] **Ferreira, J.**, *"The Role of Observability in Futures Markets,"* mimeo, Departamento de Economia, Universidad Carlos III de Madrid, Spain, (2001).

[9] **Green, R.**, *"The Electricity Contract Market in England and Wales,"* Journal of Industrial Economics 47 (1999), 107-124.

[10] **Harvey, S. and Hogan, W.**, *"California Electricity Prices and Forward Market Hedging,"* mimeo, Center for Business and Management, Jonh F. Kennedy School of Government, Harvard University (2000).

[11] **Hughes, J. and Kao, J.**, *"Strategic Forward Contracting and Observability,"* International Journal of Industrial Organization 16 (1997), 121-133.

[12] **Klemperer, P. and Meyer, M.**, *"Supply Function Equilibria in Oligopoly under Uncertainty,"* Econometrica 57 (1989), 1243-1277.

[13] **Kreps, D. and Scheinkman, J.**, *"Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes,"* Bell Journal of Economics 14 (1983), 326-337.

[14] **Laussel, D.**, *"Strategic Commercial Policy Revisited: a Supply-Function Equilibrium Model,"* American Economic Review 82 (1992), 84-99.

[15] **Le Coq, C. and Orzen, H.**, *"Do Forward Markets Enhance Competition? Experimental Evidence,"* mimeo, Department of Economics, University of Stockholm, Series in Economics and Finance 506 (2002).

[16] **Lien, S.**, *"Forward Contracts and the Curse of Market Power,"* mimeo, Department of Economics, University of Maryland (2000).

[17] **Liski, M. and Montero, J-P.**, *"Forward Trading and Collusion in Oligopoly,"* mimeo, Department of Economics, Helsinki School of Economics and Catholic University of Chile (2004).

[18] **Mahenc, P. and Salanie, F.**, *"Softening Competition through Forward Trading,"* Journal of Economic Theory 116 (2004), 282-293.

[19] **Newbery, M.**, *"Competition, Contracts and Entry in the Electricity Spot Market,"* RAND Journal of Economics 29 (1998), 729-749.

[20] **Williams, J.**, *"Futures Markets: a Consequence of Risk Aversion of Transactions Costs,"* Journal of Political Economy 95 (1987), 1000-1023.