“Optimal Market Grain Over Space and Time”*

by

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Abstract

Markets facilitate the exchange of precise quantities of goods and services at particular locations and times; yet for convenience and to reduce transactions costs, these markets customarily specify the terms (e.g. the price) uniformly over a substantial interval of space and time. If customers’ tastes and producers’ costs vary continuously over these dimensions, then assessing uniform prices within these market intervals leads to economic inefficiencies (marginal value unequal to marginal cost) for many participants, and it affords incentives for hedging at the boundaries of these market segments where prices differ. The determination of an optimal “grain” for market design, therefore, requires the balancing of four different categories of costs: (1) the inefficiency from not equating marginal benefit and marginal cost for every transaction, (2) the increasing transactions (decision) costs of having a larger number of market segments, (3) the increased hedging costs across the boundaries if there are fewer market segments and therefore greater price disparities, and (4) the increased opportunity for participants to exercise market power as fewer competitors are aligned with each segment of a more finely-grained market structure.

One practical application for these concepts is in the emerging markets for electricity where the spatial grain, locational marginal pricing (LMP) based on congested points in the transportation system, provides incentives for the geographic investment in new generation facilities that could ultimately alter line flows, and therefore congestion -- the rationale for the original spatial structure. These concepts also apply to the structure of forward markets, particularly if they can influence capacity investment and therefore, subsequently, spot market prices. As an example, it is shown that in markets with a limited number of suppliers, a forward market conducted before the required lead-time for investment in new capacity results in greater investment and lower spot market prices. Conversely, forward markets conducted only after the capacity-expansion is committed imply less capacity and higher spot market prices, even without risk-aversion.

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1. Introduction

Most markets are compromises between the economist's efficiency ideal of equating marginal benefits to marginal costs for all transactions, particularly where there are appreciable transactions costs, since in that case rather than assessing a different price to every buyer when the costs vary across buyers, in most cases the costs are "averaged" over some market segment in which a uniform market price is assessed. This averaging can be across a variety of dimensions: space, where typically transportation costs are averaged; product quality, where for most mass-produced products every customer does not receive a unique customized version, and time, although if the product is storable those costs may be individualized. But with the pressure for just in time manufacture, when the product's availability is essential for some customers, the existence of forward markets to increase the likelihood that delivery will take place when required, the frequency and duration of these forward markets may have substantial efficiency implications.

Nowhere are these considerations more important than when a new type of commodity is marketed for the first time. A clear example of the difficulties that may arise when details of markets for similar (but slightly different) commodities are applied to a new product have been demonstrated by the many problems that arose in the initial years of operating electricity markets in the U.S. Although this commodity's reliability (quality) is usually set by a regulatory body, since when electricity is provided over a network that reliability (and voltage) is a public good from the demand side since everyone in a neighborhood receives the identical reliability regardless of their individual preferences, costs do vary appreciably by location. And since electricity is not storable in large quantities, buyers want some assurance that they will receive their electricity when they want (need) it.

The general principle that must be considered when devising the optimal "grain" of any new market is to balance four different costs: 1) the inefficiencies of not precisely matching marginal benefit with marginal cost for all transactions as the market becomes larger, 2) the greater transactions costs incurred by having a large number of market segments (both price-posting and marketing costs for suppliers and decision costs for buyers), 3) arbitrage cost across the borders of market segments where substantial price-differences may exist (generally these differences become larger as the market segments become larger), and 4) the effect of the size of market segments on the ability of buyers and/or sellers to behave strategically and exercise market power (generally, the smaller the segments, the fewer the number of buyers and sellers in each). Implicit in this analysis are applications for large industrial economies that are characterized by some scale economies and therefore production is concentrated at finite locations for discrete product groups. In a "self-sufficient" society, by contrast, every buyer would provide everything they required so there would be no spatial markets; although if those individuals couldn't produce all goods they require instantaneously on-demand and the commodities were not storable, markets would still spring up. Add transportation costs if the buyers and producers are spread across the landscape and the question of market-grain again becomes relevant.

This analysis will be applied primarily to the electricity industry and its emerging markets, but it begins with a review of market structure over space and how that might be applied to the spatial grain of electricity markets. Then a model is presented that examines the optimal structure of forward markets which is particularly relevant for commodities produced by highly capital-intensive technologies whose creation requires substantial lead-times. Since electricity cannot be stored economically, getting the intertemporal market structure correct is particularly important if demand is to equal supply in real time without blackouts.

2. Markets over Space

When customers arrange for a product's transportation, as an example by driving to the shopping mall for purchases, the price is customarily quoted at the supply location and all buyers pay the same price at the same time (Mill Pricing (MP)). In this case, each buyer who utilizes the product somewhere other than at the store incurs the transportation cost and effectively pays a different delivered price at the point of utilization. However, when it is most effective to have the supplier deliver the product to each buyer, usually for technological reasons like electricity supply – particularly where there are large scale economies in hauling as well as in production – then spatial discriminatory patterns of pricing (SDP) may emerge, or uniform delivered pricing (UDP) may be employed as a simplified variant. Note, "postage stamp" pricing used by the U.S. postal service is an example of UDP where cost differences are not reflected in the prices paid by customers.

Because there are substantial physical barriers to transporting electricity where inadequate transmission line capacity exists, it is reasonable to have spatial price differences. Typically in electricity markets, different prices are allowed to emerge in different locations that are effectively separated by congestion (e.g. location-based marginal pricing (LMP)), but within an uncongested region all buyers may face the identical wholesale price even though the line-losses may differ slightly depending upon location (UDP within an uncongested zone). However, where different regions have different operating entities that dispatch and price power within their own jurisdictions, then attempts to transact electricity across the borders of these jurisdictions (Independent System Operators (ISO) or Regional Transmission Organizations (RTO)) confront many of the same problems encountered in international trade, but with the compounding problem of just-in-time delivery.

As an example, consider two uncongested power systems as shown in Figure 1 where there are line losses that result in transportation costs. Furthermore suppose each ISO contains a generator with different marginal costs and all customers are distributed uniformly across space with identical demand curves. Under UDP without trade across the border, generator #1 might charge P1A in its region and generator #2 might charge the slightly higher UDP of P2B in its own ISO-B's jurisdiction. Now, open the borders to bi-lateral transactions. In this case generator #1 might offer a lower price across the border, P1B, and try and serve all customer at least up to point R1. In fact, generator #2 may be induced to lower its UDP to P1B between R1 and R2 (note, #2 cannot compete against #1 between the border and R1 because of its higher marginal production costs); although it's ISO B might require #2 to charge this same lower price throughout ISO-B in the absence of congestion. Note, this cross-border transaction is beneficial to customers in ISO-B, but not to those in ISO-A. Second, the flow at the border runs from a high to a low price area after the exchange takes place; yet this counter flow has improved efficiency (obviously regulators in ISO-A would like to force their price down to P1B as well, if generator #1 could still recover its fixed costs). Similar patterns of flow from high to low-priced regions have been frequently observe in un-regulated international markets where producers like generator #1 would be accused of "dumping". In fact, it is a normal pattern of spatial price discrimination where there is competition at the borders (See Holahan and Schuler (1988) for a comprehensive discussion of competitive spatial pricing practices).

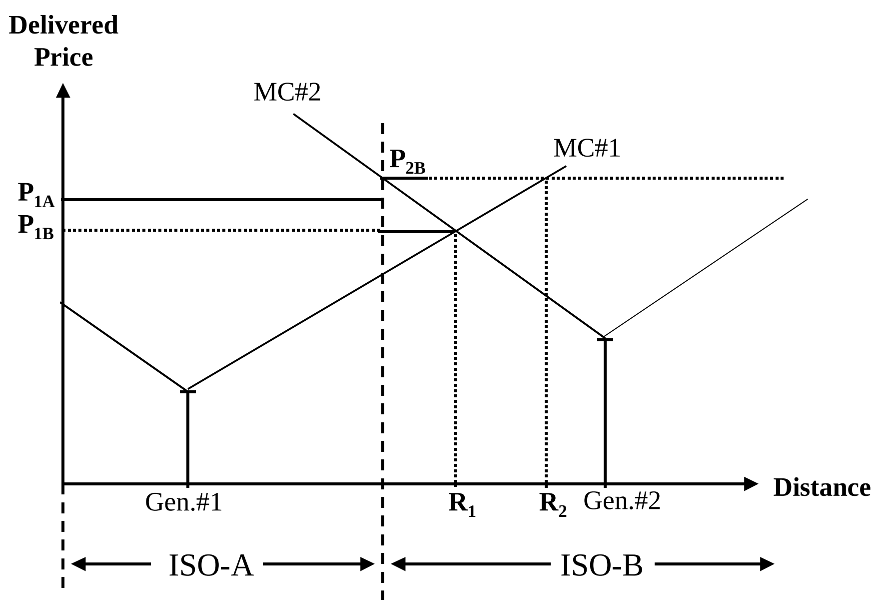

Figure 1. Competition at Border Under Uniform Delivered Pricing

A key attribute that determines the borders of segmented markets is the existence of some physical barrier that might be modified by an additional expenditure. Thus, a congested transportation network can always be improved by building more facilities (e.g. roads, terminals, or transmission lines, etc.), and those price differences across the boundary provide a clear signal of the benefits to be derived by reducing that congestion. But, the market boundary needs to be specified at the point of congestion. Similarly, if for managerial and reliable operation purposes, the entire U.S. is not operated as a single power grid, then it may make sense to have separate markets in each operating jurisdiction, and to the extent that price differences exist across those "seams", they may be warranted, in part, by added internal congestion costs that might result from attempts to arrange large transfers across those boundaries. And, to the extent those price differences exist, they provide powerful incentives to make the arrangements and investments to reduce those physical and operational procedure barriers. Finally, if for capital intensive industries, a long gestation period is required between the time when a capacity addition is begun and it is available to produce, then the timing of forward markets around that decision point to commit physical resources may be helpful to promote economic efficiency.

3. Markets Over Time

3.A. Model

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 argue that firm with market power engage in forward contracts to enhance their market share in spot markets. Allaz and Vila conclude that more frequent forward markets make firms worse off and drive the spot prices down. Models that adopt the Allaz and Vila framework suggest that forward markets decrease spot prices and enhance efficiency as well.[1] A crucial assumption in their analyses is that firms are underutilizing their capacity levels in the absence of forward markets or that firms can adjust their production levels costlessly. In what follows, we present a model that endogenizes firms' investment in capacity levels and study the effects of the timing of forward markets has on competition and efficiency.[2]

There are three types of players in the market: firms, an intermediary and buyer (see Figure 2). Firms produce and sell the product in forward and spot markets. There is a finite number of firms, and thus the firms have some market power. In the electricity markets, firms are represented by generators that produce and sell electricity. Buyers buy the product in spot markets for consumption purposes. It is assumed that buyers are infinitesimal, always bidding their marginal valuation. Buyer valuation is stochastic. In the electricity markets, buyers are represented by residential and industrial electricity consumers. The intermediary buys forward contracts from firms in forward markets and resells the product in the spot market. It is assumed that the intermediary earns zero profits due to free entry and exit. In a regulated electricity industry, an Independent System Operator that buys forward contracts and effectively sells the electricity at a spot market price in the spot market can represent the intermediary. We partition forward markets into shorter-term and longer-term forward markets based on their "length" relative to the physical lead time required to complete investment. Forward market length denotes a time frame between when the forward market takes place and the spot market opens. Investment length denotes a minimum time frame between when the investment in capacity begins and that newly installed capacity becomes operational. In other words, shorter-term forward markets take place after investment decisions, and longer-term forward markets take place before investment decisions and the commitment of capital.

[1] See Green (1999), Ferreira (2001), Lien (2000), Le Coq and Orzen (2002), Newbery (1995).
[2] More technical version of the model is given in Adilov (2005).

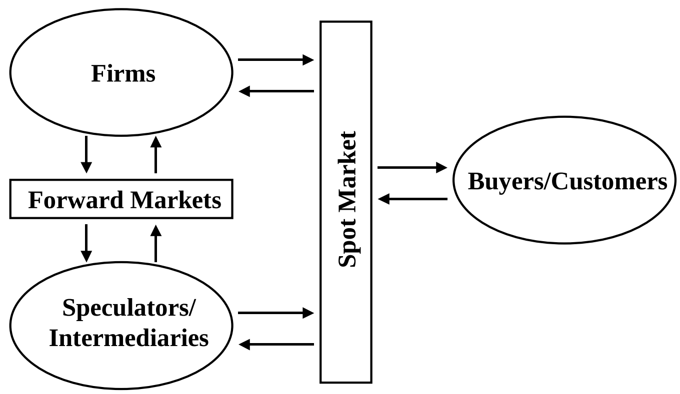

Figure 2. Market Structure and Market Participants

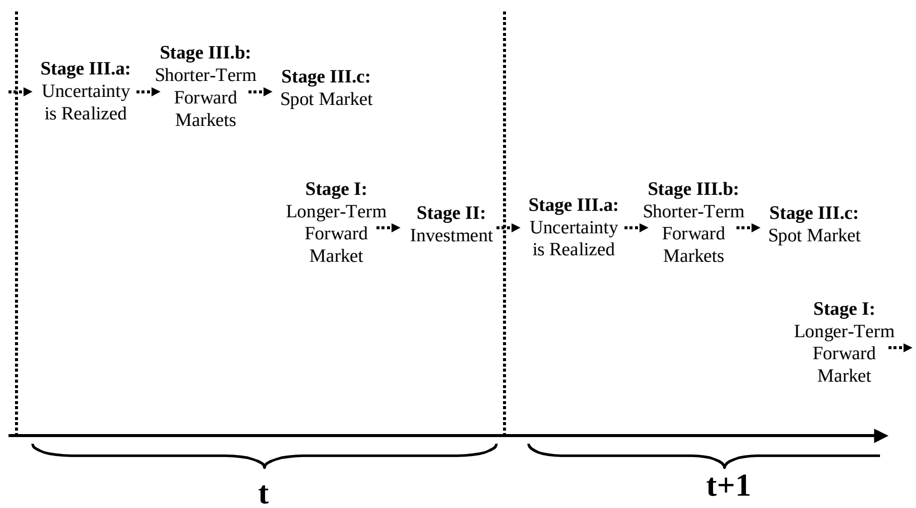

Figure 3. The Timing of Events

The game consists of three repetitive stages. Graphical representation of these stages is given in Figure 3. In stage I, the firms and the intermediary simultaneously present their longer-term forward market supply functions and longer-term forward market demand schedules, respectively. The forward market price and quantities are determined. In stage II, after observing forward market price and quantities, the firms simultaneously choose their new capacity levels. In stage III.a, demand uncertainty is realized. In stage III.b, the firms and the intermediary simultaneous choose shorter-term forward market supply functions and shorter-term forward market bid schedules.

Shorter-term forward market price and quantities are determined. In stage III.c, the firms and the intermediary simultaneously choose spot market supply functions. The spot market price and firms' profits are realized. Note that the firms compete in spot and forward markets by choosing price-quantity schedules, i.e., supply functions. An equilibrium price in the forward (spot) market is determined by the intersection of forward (spot) market supply and demand. Firms' maximum quantity sales in the spot market are subject to capacity constraints that are chosen simultaneously by the firms prior to the spot market. In what follows, we presents the results. Technical derivation of these results is given in Adilov (2005).

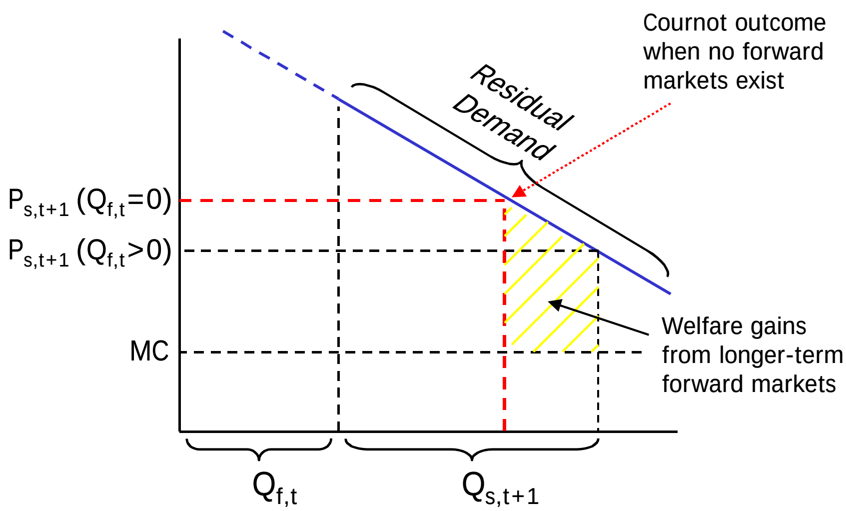

Figure 4. Residual Demand Competition

3.B. Implications of Longer-Term Forward Markets

Longer-term forward markets decrease spot market prices and enhance efficiency. This result is consistent with the existing literature because capacity levels are flexible in the long run. The intuition here is similar to that underlying the two-period durable goods monopolist's problem and the Stackelberg leader game. In the durable goods monopolist's problem, higher product sales in the first period reduce the price in the second period. In our model, after longer-term forward market commitments are signed, firms compete for residual demand in the spot market (see Figure 4). Since forward market prices are fixed, firms behave aggressively and are more inclined to cut the price in the spot market. Firms cannot keep spot prices high by restraining themselves from participating in forward markets although firms are jointly better off by not participating in longer-term forward markets. Similar to the Stackelberg leader logic, each firm is trying to increase its market share by increasing its forward market commitment levels. Thus, higher longer-term forward market commitments reduce spot market prices by encouraging more aggressive spot market behavior, which, in turn, encourages higher capacity choices.

3.C. Implications of Shorter-Term Forward Markets

Similar to longer-term forward markets, shorter-term forward markets push spot markets prices down, however, firms can respond to this price pressure by altering their capacity investments. The overall effects of shorter-term forward markets on prices and efficiency depend on the degree of demand uncertainty. When the *demand uncertainty is small or absent*, spot price-reducing effects of shorter-term forward markets disappear because capacity investment serves as a commitment device. The firms commit to capacity levels that fully eliminate the firms' possible undercutting behavior in the spot market. The intuition behind this result is similar to Kreps and Scheinkman (1983) in that if firms simultaneously choose quantity production levels before engaging in Bertrand competition, then the Cournot outcome prevails. In our model, firms choose capacity levels before engaging in shorter-term forward markets. Introducing shorter-term forward markets puts downward pressure on spot market prices subject to the capacity constraints. This implies that the firms' total capacity levels determine the spot market price. Therefore, the unique outcome for optimal capacity choices in the absence of demand uncertainty is the Cournot outcome.

Under uncertainty, the investment in capacity choice becomes an imperfect commitment device because the firms might choose to underutilize their capacity levels during the periods of low demand. Similar to the certainty case, shorter-term forward markets induce more aggressive behavior in the spot market, forcing the firms to decrease spot market prices. However, spot market price decrease has a lower bound that is determined by the firms' overall capacity levels. Thus, from the firms' perspective, the introduction of shorter-term forward markets imply that the firms utilize their capacity levels more often at lower spot market prices. To counteract this spot market price-reducing effects of shorter-term forward markets during excess capacity periods, the firms decrease capacity investments more in the presence of shorter-term forward markets. In sum, shorter-term forward market under uncertainty increase capacity utilization, but decrease capacity investment. The overall effect of the two factors – higher capacity utilization and lower capacity investment – on social welfare depends on the shape of demand and the firms' marginal cost curves. With linear demand and constant marginal costs, the presence of shorter-term forward markets results in a Pareto inferior outcome reducing both consumer and producer surplus. The intuition why shorter-term forward markets might decrease social welfare can be explained by observing the spot market prices. Lower capacity levels and high spot market price volatility in the presence of shorter-term forward markets contribute to lower expected social welfare because social welfare is concave with respect to spot prices.

3.D. Forward versus Futures Contracts

The implications of the model are the same whether one considers forward contracts for a physical delivery of the commodity at a specified time in the future or futures contracts that are solely financial transactions with no physical commitments. The intuition behind this is following. Consider a firm that holds one unit of a futures contract to buy, i.e., "short" futures contract. If the spot price is above the futures price, then the firm suffers a financial loss equal to the price difference from holding this futures contract. When the amount of financial loss is subtracted from the revenue received from the physical delivery of one unit of commodity in the spot market, the net revenue equals the futures price. On the other hand, if the spot price is below the futures price, then the firm has a financial gain equal to the price difference from holding one unit of a futures contract. When this financial gain is added to the revenue received from physical sales of one unit of commodity, the net revenue for that unit equals the futures price. Thus, from the firm's perspective, holding one unit of a futures contract to buy is just like selling one unit of a forward contract. Similarly, holding one unit of a futures contact to sell, i.e., "long" futures contract, is just like buying one unit of a commodity in the forward market.

3.E. Policy Implications

The existing literature on strategic use of forward markets suggests that forward markets either enhance efficiency or make producers better off if they collude. While these welfare-enhancing effects of longer-term forward markets are well known, the effects of shorter-term forward markets in relation to firms' investment decisions have not been analyzed in depth previously. Our findings imply that under some circumstances, a regulator can make both consumers and firms better off by eliminating shorter-term forward markets. In existing electricity markets in the United States, all 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. Therefore, it is crucial to develop longer-term forward markets in the electricity industry to maintain adequate investment levels and to sustain low spot market prices. One of the difficulties a regulator faces when introducing longer-term forward markets is the inability of some market participants to commit to specific long-term physical consumption levels. Then, a regulator might develop financial futures markets, since the analysis indicates that financial futures markets have the same effects on prices and social welfare as forward markets do.

It is realistic to assume that firms choose supply schedules in forward and spot markets, yet the findings hold for both supply function and Cournot quantity competition. This implies that Cournot framework is a good approximation for studying analytical implications of forward markets. The multiplicity of equilibria under the supply function competition, however, yields a rich variety of outcomes. Also note that our analytical results hold both for risk-neutral and risk-averse market participants.

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