Manipulation of Power Markets

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Abstract The deregulation of wholesale power markets has sparked trading in power derivatives. Power markets are susceptible to manipulation by both large longs and large shorts when derivatives are traded. The non-storability of electricity implies that manipulation of power markets differs in many ways from manipulation of markets for traditional storable commodities such as copper. Because of non-storability, manipulators of power markets must be producers of power, so speculative corners are not possible. Moreover, a manipulator must have market power in generation. Unlike storables markets, power markets are simultaneously vulnerable to short and long manipulation. Manipulation is most likely when power output nears system capacity and can have dramatic effects on prices. The differences between manipulation in power and storables markets implies that different regulatory structures are required to reduce manipulation efficiently. Vertical disintegration (combined with limits on the size of the long positions owners of generation can acquire) is probably the most efficacious and efficient way to reduce manipulation in power markets.

1 Introduction

The process of deregulation and restructuring in the power industry has created a new, large, and growing market in electricity. This new market features trading in financial claims on power–futures, forwards, options, and other derivatives–as well as trading in physical power.

The existence of derivatives on power creates the potential for manipulation in the power market. In essence, manipulation involves the exercise of market power that the holder of a large derivatives position may possess due to various constraints and rigidities in the market. Manipulation has occurred periodically in traditional commodity derivative markets, such as the markets for grains and metals. As a result of the threat of manipulation, governments and exchanges have adopted numerous preventive and deterrence measures to reduce its frequency.

Is manipulation a concern in the burgeoning and as yet immature power industry? A cursory examination of the power industry suggests that it is. Manipulators exploit rigidities in the process of producing, transporting and marketing a commodity (Pirrong, 1993). The non-storability of electricity and generation and transmission capacity constraints create rigidities, so manipulation may well be a problem for power markets. Indeed, some market participants alleged that manipulation exacerbated the huge price spikes that occurred in the Midwest during June, 1998.

An analysis of the economics of manipulation of the power market shows that the holder of a large futures position can manipulate the market. The unique nature of power as a commodity implies, however, that the economics of manipulation in electricity are quite different from the economics of manipulation of a more traditional storable commodity such as copper.

In particular, power is not storable. Non-storability implies that a manipulator cannot buy and sell a particular unit of power at different prices as can the manipulator of copper or corn. This in turn implies that the power manipulator must produce electricity. As a result, a rogue speculator cannot manipulate a power market whereas this is possible in the market for a storable commodity. Moreover, non-storability also implies that the same conditions that make a market vulnerable to manipulation by the holder of a large long futures position make it vulnerable to manipulation by a large short. This is also quite different from the situation in storables markets. The analysis implies that the power market is most vulnerable to manipulation by both large shorts and large longs when the power system is operating near capacity. The pronounced differences between the economics of manipulation in power and traditional storables markets also implies that the regulatory responses that are most efficient in storables may not be efficient in the power market.

In brief, power markets are susceptible to manipulation by the holders of large derivatives positions, but the unique nature of power as a commodity makes the economics of power manipulation unique as well. Non-storability makes power manipulation easier in some ways and more difficult in others. Non-storability is a rigidity that can contribute to manipulative pressures (in conjunction with other constraints), but it also imposes constraints on the actions of would-be manipulators. Thus, any analysis of manipulation in power markets must explicitly recognize the role of this commodity's distinctive characteristics.

The remainder of this article is organized as follows. Section 2 presents a model of manipulation of a storable commodity by a large long; this serves as a standard case against which the analysis of manipulation of power can be compared. Section 3 analyzes the economics of long manipulation in the power market. Section 4 examines the economics of short manipulation in power. Section 5 describes briefly the role transmission constraints can play in power manipulation. Section 6 compares and contrasts the efficiency of prevention and deterrence of manipulation in power markets. Section 7 briefly summarizes the article.

2 Long Manipulation of a Storable Commodity

Before analyzing the economics of manipulation for a non-storable commodity such as power, it is helpful to review the more conventional case of manipulation of a storable commodity such as copper or corn. The comparison between storable and non-storable cases illuminates how the unique characteristics of electricity influence the economics of manipulation in power markets.

A traditional long manipulation in the market for a storable commodity, also known as a corner or squeeze, results from the exercise of market power. The holder of a large long futures position exercises market power by standing for an inefficiently large number of deliveries against futures contracts.[1] By

[1]The term futures contract is typically used to refer to a contract for future delivery of a commodity that is executed on a centralized futures exchange and guaranteed by a

doing so, the long increases the marginal cost of producing the commodity. This in turn increases the price at which he can liquidate the remainder of his futures position. Taking excessive deliveries does impose some costs on the long, however, as he must dispose of those excessive quantities at sub-competitive prices. This is sometimes referred to as "burying the corpse" of the manipulation.[2]

To demonstrate these points formally, assume that the marginal cost of producing q units of the commodity is $MC(q)$ and the demand for the commodity is $D(q)$. Marginal cost is increasing in q whereas the demand curve slopes downward. That is, $MC' > 0$ and $D' < 0$. In a competitive market, $MC(q^*) = D(q^*)$ at the optimal quantity q^*.

If there is a delivery-settled futures contract on the commodity, the holder of $X > 0$ long futures positions can manipulate the contract by requiring shorts deliver more than q^* units.[3] This drives up the marginal cost of delivery and thereby increases the price shorts are willing to pay to liquidate their positions. The long chooses the number of deliveries Q to maximize:

$$(X - Q)MC(Q) + QD(Q) \tag{1}$$

The first term is the long's revenue from selling $X - Q$ futures contracts at the inflated price. The second term is the long's revenue from selling the Q

clearinghouse. A forward contract is a contract for future delivery that is executed over-the-counter rather than on an exchange. The analysis is applicable to both forward and futures positions. For simplicity, I will refer to any contract for future delivery as a futures contract.

[2] See Pirrong (1993, 1995) for models of manipulation.

[3] This analysis assumes that derivatives are physically settled. The analysis is unchanged if (a) the futures are cash- or financially-settled at the spot price and (b) the cash-settled futures contract is based on the spot price of a single variety of the commodity. See Pirrong (1999a) for details in this argument.

units delivered to him.

Implicit in (1) is the assumption that the large long can sell futures contracts and the commodity delivered to him at different prices. This is feasible for a storable commodity. If the manipulator takes delivery of Q units of the commodity at date t he can store them for resale at some later date. Indeed, the mechanics of taking delivery and transacting in spot and futures markets necessitate this. As will become apparent momentarily, this asynchroneity of purchase (via delivery) and sale creates a crucial difference between manipulation in a traditional commodity market and manipulation in the power market.

The first order conditions for this problem are:

$$MC(Q) - XMC'(Q) \geq D(Q) + QD'(Q) \tag{2}$$

This holds with equality if $Q > 0$. It is straightforward to show that there is some $X > q^*$ such that $Q > q^*$. Examination of (2) implies that if $Q > q^*$, then $MC(Q) > MC(q^*) = D(q^*) > D(Q)$. That is, during a corner the futures price at expiration exceeds the competitive price, which in turn exceeds the commodity's price after the manipulation is over. Again, this difference between the price at which the long liquidates futures (and implicitly pays for deliveries) and the price at which he sells the units delivered to him is a manifestation of the storability assumption.

3 Long Manipulation of a Power Market

Brief reflection on the nature of electricity reveals that the objective function (1) is inappropriate for power. Recall that (1) allows purchase and sale of the commodity at different prices. This is feasible because of storability. It is not feasible for power because electricity cannot be stored. That is, if the owner of a long futures position takes delivery of electricity when the spot price is P, he cannot hold it for some period and sell it at a different price P'. He can only resell it immediately at the prevailing price P. Alternatively, the long can consume the power delivered against futures contracts. Consumption of electricity could entail using it internally (e.g., to power a manufacturing facility). More plausibly, "consumption" would involve delivery to retail or industrial customers who then consume it. It must be true, however, that these customers cannot sell power on the spot market, as otherwise they could undercut the manipulator by selling power on the market.

Based on this understanding it is possible to construct a formal model of manipulation of a power market.

Several assumptions serve to simplify the exposition and focus attention on the key issues.

Assumption 1 *Transmission is costless and there are no transmission constraints.*[4]

Assumption 2 *A single firm–"Firm 1"–has accumulated $X > 0$ long futures positions in power for delivery at time t.*[5]

Assumption 3 *Firm 1 has an obligation to service a load of $L \geq 0$ units at time t.*

[4] I consider the role of transmission costs and constraints below.

[5] This analysis also assumes that futures positions can be off-set. That is, a firm that buys futures at t' can re-sell them at $t > t'$. Some forward obligations cannot be off-set. For instance, a firm that buys in the California Power Exchange day ahead market cannot re-sell them the next day.

Assumption 4 *Firm 1 can generate w units of power at cost $C(w)$. $C' > 0$, $C'' > 0$.*

Assumption 5 *All other futures traders are atomistic competitors.*

Assumption 6 *The net supply curve for power facing Firm 1 is given by $Q = S(P)$. That is, if the price of power at t is P, the output of electricity by firms other than Firm 1 net of the quantity demanded at P is $S(P)$. The function $M(Q) = S^{-1}(Q)$ gives the marginal supply price for Q units delivered to buyers in the market. $M'(Q) \geq 0$, and $M''(Q) \geq 0$.*

Given these assumptions, it is possible to analyze Firm 1's profit maximization problem. Firm 1 can choose how much physical power to purchase at the spot price. Call this quantity Q. A $Q > 0$ indicates that the firm is a net purchaser of spot power. A firm that is long futures can acquire spot power either by purchasing on the spot market, or taking delivery against the futures position. A $Q < 0$ indicates that the firm is a net seller of spot power. Given a choice of Q, the firm sells $X - Q$ units of power; this represents the sales of X expiring futures positions net of the Q units of power purchased on the spot market. The spot price of power at the expiration of the futures position is at a price equal to $M(Q)$. This follows from the fact that atomistic futures market participants will pay no more than the marginal supply price to repurchase their short futures positions (or spot power to deliver against futures). Therefore, the shape of the $M(Q)$ function is a crucial determinant of Firm 1's decison.

The load constraint (Assumption 2) influences Firm 1's decision problem as well. If the firm takes delivery of Q units, it must generate $L - Q$ units.

Note that if Firm 1 cannot generate power, then the load constraint deprives the firm of the ability to choose net purchases/sales. Therefore, to manipulate the market, it must be the case that a firm has generating capacity.

Result 1 *Given assumptions 1-6, only firms that own generating capacity can undertake a long manipulation of a power market. That is* $C(Q) < \infty$ *for some* $Q > 0$ *is a necessary condition for manipulating the power market.*

This implies that a speculative corner of the type sometimes observed in storables markets cannot occur in the power market. A speculative corner occurs when a firm that has no underlying position in the physicals market acquires a large long futures position and exploits the market power inherent in this position to cause the price of the expiring future to become artificially high. That is, in a storables market, acquisition of a sufficiently large futures position is all that is required to execute a manipulation. In electricity, in contrast, acquisition of a large long futures position is useless unless the large long also owns generation.

Taking these considerations together, Firm 1 chooses Q to maximize:

$$(X - Q)M(Q) - C(L - Q) \tag{3}$$

In this expression, $(X-Q)M(Q)$ is Firm 1's revenue from liquidating $X-Q$ futures contracts and $-C(L-Q)$ is the firm's cost of generating sufficient power to satisfy its load obligation. Note that $Q < 0$ is admissable. A negative Q indicates the sale of power on the spot market. In this case, the long takes no deliveries against futures, but sells the entire X units of futures and the $|Q|$ units of physical power into the spot market at the spot price.[6]

[6]This analysis assumes that the futures contract is delivery settled. Identical results

The first order conditions for this problem are:

$$M(Q) - (X - Q)M'(Q) = M(Q) + QM'(Q) - XM'(Q) = C'(L - Q) \quad (4)$$

This first order condition implies several important results.

Result 2 *Firm 1 must face an upward sloping marginal supply price (i.e., $M'(Q) > 0$) in order to manipulate the market.*

To see why this is true, note that $M(Q) = C'(L - Q)$ if $M'(Q) = 0$. In this case, Q does not depend on X. That is, when facing a perfectly elastic supply curve Firm 1 takes the same number of deliveries as it would if it had no futures position. Therefore, for a futures position to distort Firm 1's choice of Q, the firm must possess some market power in generation.

Result 3 *At the profit maximizing choice of Q, then (a) $Q > q_0$, where $M(q_0) + q_0 M'(q_0) = C'(L - q_0)$ and (b) $dQ/dX > 0$. Moreover, if $M'(Q) + (Q - X)M''(Q) + C''(L - Q) > 0$, then $dQ/dX < 1$.*

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hold for cash- or financially-settled contracts. For example, consider a contract in which the long receives a payoff equal to the spot price at contract expiration (net of the initial futures price). If firm 1 holds $X > 0$ of these contracts, it can receive the same profit as implied by (3) by trading Q units of power on the spot market. If the firm does so, the spot price equals $M(Q)$. Thus, the firm receives a payment of $XM(Q)$ on its cash-settled contracts. Moreover, the firm pays $QM(Q)$ to purchase the Q units on the spot market, and incurs a generating cost $C(L-Q)$ to meet its load obligation. Since the firm's profit function is the same regardless of whether futures are cash- or physically-settled, the firm's incentives to exercise market power are identical under financially- and physically-settled contracts. (Results will differ if the physical contracts allow the seller to choose where to deliver power, and the cash-settled contracts are based on the prices of power in multiple locations. See Pirrong (1999a) for analysis of the importance of delivery options for contracts on storable commodities; a similar argument holds for power.) In a similar vein, Joskow and Tirole (1998a, 1998b) find that financially-settled and physically-settled contracts for power transmission (rather than contracts for the electrons themselves) have similar effects on the incentives of traders to exercise market power.

In this result, q_0 is the net quantity of spot market purchases or sales the firm takes when $X = 0$. Parts (a) and (b) of the first statement follow directly from the second order conditions for profit maximization. It states that if Firm 1 has some market power in generation, then its net sales (net purchases) of spot power are smaller (larger) when it holds a long futures position than when it does not. Part (b) of the statement implies that the increase will be less than one-for-one unless the marginal supply function is substantially more convex than Firm 1's marginal cost function. Note that (b) and Assumption 2 imply that the firm's generation is a *decreasing* function of its futures position. That is, a manipulator substitutes spot electricity (obtained via delivery, spot market purchases, or a reduction in its spot market sales) for its own generation.

This result has some interesting ramifications. There are two cases to consider. In the first case, $q_0 < 0$, i.e., absent a futures position the firm would be a seller of spot power. In the second, $q_0 \geq 0$, i.e., absent a futures position the firm would be a buyer of spot power. I examine each case in turn.

Figure 1 illustrates the first case where $q_0 < 0$. The line labeled M is the marginal supply price. The line labeled $QM' + M$ is the firm's marginal revenue (MR) for power sales (i.e., $Q < 0$) and the firm's marginal expense of input (MEI) for power purchases (i.e., $Q > 0$). The curve $C'(L - Q)$ is Firm 1's marginal cost curve. In Figure 1, the marginal cost curve intersects the MR curve to the left of zero, indicating that $q_0 < 0$. The price in this case is P_0 and is given by the point on the marginal supply price function M directly above q_0. A long futures position results in a shifted MR/MEI curve labeled

$(Q - X)M' + M$. As drawn, this curve intersects the marginal cost curve at $Q > q_0$, and results in a price $P_Q > P_0$. Moreover, since by Result 3 Q is increasing in X, the larger the futures position, the higher the price. Thus, in this first case the futures price is higher when the firm has a long futures position. The futures position causes Firm 1 to cut back on its open market power sales in order to increase the price at which it liquidates its futures position. Equivalently, the futures position distorts its output decision by causing it to reduce its own generation and substitute outside generation to serve its load obligation.

Figure 2 illustrates the second case where $q_0 > 0$. The labeling of the curves is the same in the two figures. Moreover, the basic conclusion of the analysis is the same: quantity Q and the market price P_Q are increasing functions of the futures price X.

The main distinction between the two cases centers on the interaction between Firm 1's futures position and its market power in generation. If Firm 1 were to act as a price taker when $X = 0$, it would produce $\hat{q}$ units of power, where $M(\hat{q}) = C'(L - \hat{q})$. In the case where $q_0 < 0$, $q_0 > \hat{q}$. Since Firm 1's net power purchases are increasing in X, $Q(X) > q_0 > \hat{q}$. Thus, in this case, increasing the size of Firm 1's long futures position induces it to increase the distortion of its output choice (relative to its choice when it acts as a price taker). Intuitively, in this case the firm acts as a monopolist when it has no futures position and the addition of a long futures position exacerbates its incentive to exercise monopoly power.

Different results may occur in the case where $q_0 > 0$. Here, $q_0 < \hat{q}$. In this case, increasing the futures position from $X = 0$ initially causes Q to move closer to the price taking choice of $\hat{q}$. Indeed, there is some crucial $X = \hat{X}$ such that $Q(\hat{X}) = \hat{q}$. As X increases beyond $\hat{X}$, however, Firm 1's choice of Q diverges progressively from $\hat{q}$. Thus, in this case increasing the size of Firm 1's long futures position can either increase or reduce the distortion of its output choice (relative to the price taking choice). Intuitively, in this case the firm acts as a *monopsonist* when it has no futures position; any increase in a long futures position at first attenuates the incentive to exercise monopsony power, and eventually causes the firm to exercise monopoly power instead.

These results have efficiency implications under certain assumptions about the marginal supply price function $M(Q)$. If all other market participants are price takers, then $M(Q)$ is the horizontal difference between the market demand curve and the sum of the marginal cost curves of all remaining power producers. In this case $\hat{q}$ is the efficient level of output for Firm 1. Thus, when $\hat{q} < 0$ (the firm should be a net seller of spot power), increasing $X > 0$ exacerbates market power-related inefficiency because it causes a greater divergence between Firm 1's actual output and its efficient level of output. However, when $\hat{q} > 0$ (the firm should be a net purchaser of spot power), increasing X may actually *reduce* market power-related inefficiency because it may reduce the divergence between actual and optimal output; in essence, the long futures position may counterbalance monopsonistic tendencies. There is always a sufficiently large X, however, such that deadweight losses are larger given this futures position than when $X = 0$.[7]

[7] Similar results obtain when Firm 1 and other owners of generation are Cournot competitors who choose output. It is possible to show that (a) if $X > 0$ and $\hat{q} < 0$, Firm 1 produces a smaller output than when $X = 0$, and (b) although other generators increase output, aggregate output is smaller and the price is higher when $X > 0$. Thus, total surplus is smaller when $X < 0$ and $\hat{q} < 0$ than when $X = 0$.

Welfare comparisons are inherently difficult in this context because manipulation can only occur in a second best world. Result 2 implies that long manipulation cannot occur if no firm has market power. Therefore, manipulation requires some pre-existing deviation from a first best, perfectly competitive world. Determining the welfare effects of manipulation in this second best world therefore requires an analysis of its effects on the activities of all market participants.

The price effects of manipulation depend on the shape of the marginal supply price function $M(Q)$ as well as the size of the futures position X. When the $M(Q)$ curve is very flat, variations in X have little price impact because although such a change causes the firm to change its Q, this change has little effect on prices. Things are quite different when $M(Q)$ is very steep. In this case, increasing X by even a small amount can have a large effect on price. (Of course variations in X have no influence on prices in the limiting case in which the $M(Q)$ curve is vertical.)

The marginal supply price function is typically flat for low levels of load, but becomes very steep as load reaches system capacity. As an example, Figure 3 illustrates the relation between hourly spot prices and load in the PJM market for the 1997-1999 period; note the marked increase in slope as hourly load approaches 48000 MW. For such a supply function, the threat of manipulation is quite modest for lower levels of load, but may become acute when load approaches its maximum. Moreover, demand for power in the very short run (the relevant time horizon in a manipulation analysis) is notoriously inelastic. This implies that price increases do not reduce quantity demanded appreciably. The combination of inelastic supply and inelastic demand conspire to create a very inelastic marginal supply price function $M(Q)$ when load approaches capacity. Given a very steep marginal supply price, even the small distortion in quantity choice can have a huge price impact. Thus, the introduction of derivatives (futures, forward, option) trading on power can have appreciable price effects during high demand periods.

To summarize, this section presents a model of manipulation of a power market by a large long. This analysis produces several implications. First, only firms that can generate power can long manipulate. Firms that (a) generate power, and (b) are long futures manipulate by distorting their output choices. Second, power prices are higher when a generating firm has a long futures position than when it does not. Third, whether prices are higher than they "should be" depends on whether when acting as a price taker the firm would sell or purchase power on the market. Fourth, the market is acutely vulnerable to long manipulation when demand is high and capacity is constrained. Under these circumstances, even small futures positions can have massive price impacts.

Several of these results are unique to the power market. The non-storability of power implies that the traditional speculative corner sometimes observed in markets for storable commodities is not feasible in electricity. The speculative corner requires the manipulator to purchase and sell the deliverable commodity at different prices. This is infeasible for electricity because it must be consumed when it is delivered. The acute vulnerability of the power market to long manipulation during high demand periods is also peculiar to the power market. Hard output and transmission capacity constraints imply that the supply curve for power is extremely steep near capacity, and eventually becomes vertical. The extreme demand inelasticity that characterizes the power market also contributes to a steep net marginal supply function which in turn makes manipulation more likely and profitable. Moreover, output approaches these constraints with some regularity. In contrast, there are no analogous hard supply constraints for most storable commodities; it is almost always possible to enhance supplies at a particular point either by increasing production or shipping supplies from some other location. Supply curves for these commodities are therefore upward sloping, but are unlikely to approach verticality.

4 Short Manipulation of a Power Market

The framework developed in the last section and applied to the case of long futures position ($X > 0$) is also applicable when a firm holds a large short futures position ($X < 0$). This section analyzes manipulation when Firm 1 has a short position of $X < 0$ contracts. This analysis demonstrates that short manipulation can also occur in power markets, and that the same conditions that make long manipulation most profitable also make short manipulation most profitable. This is another difference between manipulation of electricity markets and markets for storable commodities.

The objective function for a firm that has sold X futures positions is identical to (3). In this case, $XM(Q) < 0$ is interpreted as the cost that Firm 1 pays to re-purchase its short futures positions. As before, if $Q > 0$, $-QM(Q)$ is the cost of spot power purchases. If $Q < 0$, $-QM(Q)$ is the firm's revenue from spot market sales and deliveries.

It is readily demonstrated that results 1-3 hold in this case. That is, to manipulate a firm must have generating capacity and market power in generation. Moreover, there is a positive relation between Q and the size of the firm's position. This implies that the firm's spot sales/deliveries are larger (or spot purchases are smaller), the larger the short position.

As when Firm 1 has a long position, there are two distinct cases to consider when the firm has a short position. When $q_0 < 0$ (i.e., the firm is a net seller on the spot market when it has no futures position, as illustrated in Figure 4), the short position induces the firm to increase spot sales/deliveries. Since the firm sells too little in the absence of a futures position in this case, this can be beneficial, although if the short position is sufficiently large the deadweight loss from excessive sales induced by the short futures position can exceed the deadweight loss incurred when the firm has no futures position. Conversely, when $q_0 > 0$ as in Figure 5 the firm is a net buyer on the spot market when it has no futures position, but buys too little. In this case, the short futures position induces it to reduce spot purchases, and may actually induce it to become a seller of spot power. Thus, in this case the futures position exacerbates the distortion that results from the firm's market power.

It is possible to show that a short position may have a very large price impact when the marginal supply price function is very steep and that a short position will have little price impact when this function is flat. This is true because a small distortion in power market purchases or sales has a very large impact on price when the supply function is steep. Thus, a large short can have the greatest influence over price in the same conditions in which the long has the greatest influence over price.

This last result points out another difference between manipulations in the power market and in the markets for storable commodities. In storables markets, the conditions that make short manipulation profitable tend to make long manipulation unprofitable, and vice versa (Pirrong, 1993 Result 4.6). This is again due to the fact that manipulators in storables can buy and sell at different times and different prices. The objective for a short manipulator of a storable is to choose the quantity Q to purchase and then dump on the market (or deliver against futures) in order to maximize the value of his position net of the cost of acquiring these Q units:

$$(X + Q)D(Q) - QMC(Q) \tag{5}$$

In this expression, since $X < 0$ the manipulator wishes to have $D(Q)$ and $MC(Q)$ as small as possible; contrast this with (1), where the long manipulator wants to have a large $MC(Q)$ and a large $D(Q)$. This symmetry implies that if conditions make it easy to drive down $D(Q)$ without raising $MC(Q)$ too much, short manipulation will be profitable and long manipulation unprofitable. The reverse is true if it is easy to drive up $MC(Q)$ without causing $D(Q)$ to fall too much.

In contrast, the objective functions faced by a short and a long in the power market do not differ due to the inability to sell at different prices because of non-storability. Thus, the power market is susceptible to both short and long manipulation when supply conditions are tight, and it is relatively invulnerable to each when supply conditions are slack.

5 Transmission Constraints

The foregoing analysis abstracts from transmission constraints. They are readily introduced into the analysis. Two remarks suffice.

First, if the large firm (Firm 1) does not own or control transmission, transmission constraints influence the marginal supply price function. This marginal supply price function is steeper when transmission constraints bind than when they do not. In general, manipulation succeeds by exploiting rigidities in production and transportation technologies, so markets more likely to experience constrained transmission are more susceptible to manipulation. Thus, assumption 1 is superfluous if holders of futures position have no control over transmission.

Second, if the holder of a futures position controls transmission he can make manipulation more profitable. The owner of transmission can influence the marginal supply price function by rationing access to transmission. Rationing access makes this function less elastic, thereby increasing the profitability of manipulation. Thus, firms that control generation and transmission and have obligations to serve load are potentially dangerous manipulators.[8]

[8]Tirole and Joskow (1998a, 1998b) analyze the effect of contracts that confer either financial or physical rights to transmission on the incentive of firms to exercise market power in generation.

6 Preventing and Deterring Manipulation in Power Markets

The foregoing analysis implies that power markets may be vulnerable to manipulation by holders of futures positions, and acutely so when supply conditions are tight. Since manipulation can impose deadweight losses, welfare would be improved if the frequency of manipulation could be reduced at a sufficiently small cost.

There are two basic means of reducing the frequency of manipulation: prevention and deterrence. Prevention entails actions that reduce the market power of those holding futures positions. Deterrence involves the imposition of financial penalties on those who are determined (after the fact) to have manipulated the market. Prevention and deterrence are substitutes. Both are costly. Efficient regulation of the market requires the choice of the lowest-cost mechanism.

Efficient deterrence through the imposition of *ex post* sanctions requires that manipulation can be detected with high probability (Shavell, 1993; Pirrong, 1999). In storable commodity markets, manipulation (especially long manipulation) has peculiar and pronounced effects on prices and quantities that can be detected with high probability. Moreover, these patterns can be reliably distinguished from non-manipulative patterns. Finally, the behavior of a manipulator in the market for a storable commodity is readily distinguished from the behavior of a non-manipulative agent. If these conditions also hold in the power market, deterrence will be a relatively cheap means of reducing the probability of manipulation.

Unfortunately, the characteristics of the power market make it possible that deterrence will not be as efficient or efficacious there as it can be for storable commodities. Prices can spike and vary dramatically in a competitive, unmanipulated market when output approaches capacity. Although manipulation may exacerbate these price movements, it may prove difficult to distinguish reliably manipulative price spikes from non-manipulative ones; conditioning on load being approximately equal to capacity, the extreme variability of prices in competitive conditions reduces the statistical power of any hypothesis test.

A fact-finder could utilize additional information to determine whether a manipulation has occurred. For example, the theory implies that a long manipulator generates less power than he would if he owned no futures position. Therefore, the fact-finder could investigate the futures positions and generation activities of market participants looking for a firm that generated "too little" power. This is problematic, however, inasmuch as determining the quantity of power a firm "should" generate depends on a variety of complex cost and technical considerations. As a simple example, a firm could merely claim that its generating capacity was lower than normal due to a technical malfunction. Determining whether a forced outage was necessary at a particular time is not trivial and could be subject to intense disputes among technicians that judicial or regulatory authorities are ill-suited to referee.

So-called "economic withholding" of capacity is more easily identified under certain market structures. In particular, in power pools such as PJM, NEPool, or the California market, generators submit bids that indicate the price at which they are willing to operate their generating units. If a generator's bid is marginal or inframarginal, the firm is obligated to sell power at the market clearing price (i.e., the price at which the quantity of generation supplied by the bidders equals the quantity demanded at that price.) A long manipulator can withhold capacity by submitting a bid to supply power from a plant at a price in excess of its marginal generating cost. For example, Bowring *et al* (2000) show that on 7 June, 1999, a particular generating unit in PJM was bid to operate at $850/MWh despite the fact that it operated on other occasions when the spot price of power was substantially below $850/MWh.[9] This sort of evidence can make it easier to identify a manipulator, but even given this information it may be difficult to identify the economic impact of such actions. For example, it was clear that PJM capacity was inadequate to meet demand on 7 June, 1999. Thus, prices would likely have "spiked" in any event. It is difficult to determine how much smaller the spike would have been if this particular generator had not bid this unit at a price well above marginal cost. This makes it difficult to determine whether (a) prices were in fact artificially high due to manipulation, and (b) whether the actions of this particular party caused the price to become artificial. Since under current US law it is necessary to prove both price artificiality and causation (i.e., proof of the ability to cause an artificial price) to prove a manipulation case, even evidence on economic withholding of capacity may be insufficient to form the basis for a manipulation case.

Prevention of manipulation through structural means may be more practical than deterrence in power markets. Specifically, vertical "disintegration" may reduce the frequency of long power market manipulations. Recall that

[9] Variations in fuel cost cannot explain this operating pattern.

a firm must own generating capacity to manipulate the market. A power marketer that must serve load, but which owns no generating capacity, cannot manipulate the market even if it is allowed to accumulate a large long futures position (perhaps as a hedge). Although a firm that owns generation can execute a long manipulation if it owns a long futures position, it would have little justification for holding such a position if it does not have a load service obligation. Such a firm would sell power futures if it were a hedger. Therefore, a combination of (a) vertical disintegration in which owners of generation have no load service obligations, and (b) position limits that constrain the ability of (disintegrated) owners of generation to accumulate large *long* futures positions, can sharply reduce the vulnerability of the market to long manipulation.

There are two potential difficulties with this approach to reducing long manipulation. First, vertical integration may offer benefits. If so, vertical dis-integration will be a costly remedy to long manipulation. For example, integration between load serving and generating entities can improve communication and information flow, which in turn can lead to improved operation and investment decisions. Similarly, integration can reduce the potential for opportunistic holdup, although this problem is mitigated to the extent that there is a well-functioning spot market for power with several buyers and sellers.

Second, although vertical disintegration and restrictions on the ability of generators to hold large long positions reduces the market's vulnerability to long manipulation, it does not address the problem of short manipulation. Recall that an owner of generation who is short futures has an incentive to increase output (beyond the level it would produce in the absence of a futures position) to depress the futures price.

This second problem may not be too worrisome in a disintegrated market. Disintegrated owners of generation (i.e., generating firms with $L = 0$) are always net sellers of power. Recall that holding short futures positions actually induces these firms to sell more power than they would absent any futures position. If generators exercise market power by restricting output, "short manipulation" may actually improve welfare. However, the difficulty of making welfare comparisons in the context of power market manipulation makes definitive statements impossible. Nonetheless, whereas generators' holding of long futures positions exacerbates tendencies to restrict output, their holding of short futures positions does not. This suggests that although distinegration and restrictions on generators holding large futures positions does little to reduce short manipulation, this disadvantage is likely to be more than off-set by the fact that these policies will reduce substantially the market's vulnerability to long manipulation.

The foregoing suggests that the unique nature of manipulation in electricity markets may require unique measures to reduce its frequency. Penalizing manipulators after the fact is quite efficacious in markets for storable commodities; the difficulty of distinguishing manipulative price movements from non-manipulative ones undermines the efficacy of *ex post* deterrence in the power markets. Conversely, preventative measures are likely to be costly and cumbersome in markets for storable commodities; the combination of dis-integration and position limits on generators is a powerful means of preventing long manipulations in the power market. Unless the costs of disintegration are excessive, it is arguably the preferred means of reducing the frequency of manipulations in power.

7 Summary and Conclusions

Non-storability distinguishes electricity from virtually all other commodities. This unique feature of power causes the economics of manipulation of the power market to differ from the economics of the market for any storable commodity (such as, soybeans). In particular, whereas speculative corners are feasible in storables markets, a pure speculative corner is not feasible in power. A power manipulator must both produce power. Non-storability also implies that power markets are vulnerable to manipulation by large shorts and large longs, whereas storables markets are typically vulnerable to only one type of manipulation (usually long manipulation). The unique nature of power also implies that the best regulatory response to manipulation is likely to be different in power markets.

Manipulation is a potentially serious concern in power markets when supply conditions are tight, as during a summer heat wave in North America. Manipulators exploit frictions in production and transportation, and such frictions are acute when demand conditions place strains on generation and transmission systems. Manipulation can exacerbate the large price movements that can occur under such conditions. There is much less danger of manipulation during normal periods when capacity and transmission constraints are not binding.

When combined with limits on long derivatives positions held by owners of generation, vertical disintegration in the power industry can sharply reduce, and perhaps eliminate, the long manipulative threat in power markets. Vertical disintegration is a key component of utility restructuring in most jurisdictions. Disintegration may also be necessary to ensure the development of liquid and efficient markets for managing power risks. Without effective disintegration, the threat of manipulation may impede the development of liquid markets for power futures, forwards, and options.

References

[1] Bowring, J., W. Flynn, R. Gramlich, M. McLaughlin, D. Picarelli, and S. Stoft. "Monitoring the PJM Energy Market: Summer, 1999." Working paper, PJM Market Monitoring Unit.

[2] Joskow, P., and J. Tirole. 1998a. "Transmission Rights and Market Power on Electric Power Networks I: Financial Rights." Working paper, MIT.

[3] Joskow, P., and J. Tirole. 1998a. "Transmission Rights and Market Power on Electric Power Networks II: Physical Rights." Working paper, MIT.

[4] Pirrong, S. C. 1993. "Manipulation of the Commodity Futures Market Delivery Process." 66 *Journal of Business* 335.

[5] Pirrong, S. C. 1995. "Mixed Manipulation Strategies in Commodity Futures Markets." 15 *Journal of Futures Markets* 13.

[6] Pirrong, S. C. 1999a. "Manipulation of Cash-Settled Futures Contracts." Working paper, John M. Olin School of Business.

[7] Pirrong, S. C. 1999b. "Efficient Deterrence of Manipulation in Futures Markets." Working paper, John M. Olin School of Business.

[8] Shavell, S. 1993. "The Optimal Structure of Law Enforcement." 36 *Journal of Law and Economics* 255.

Figure 1

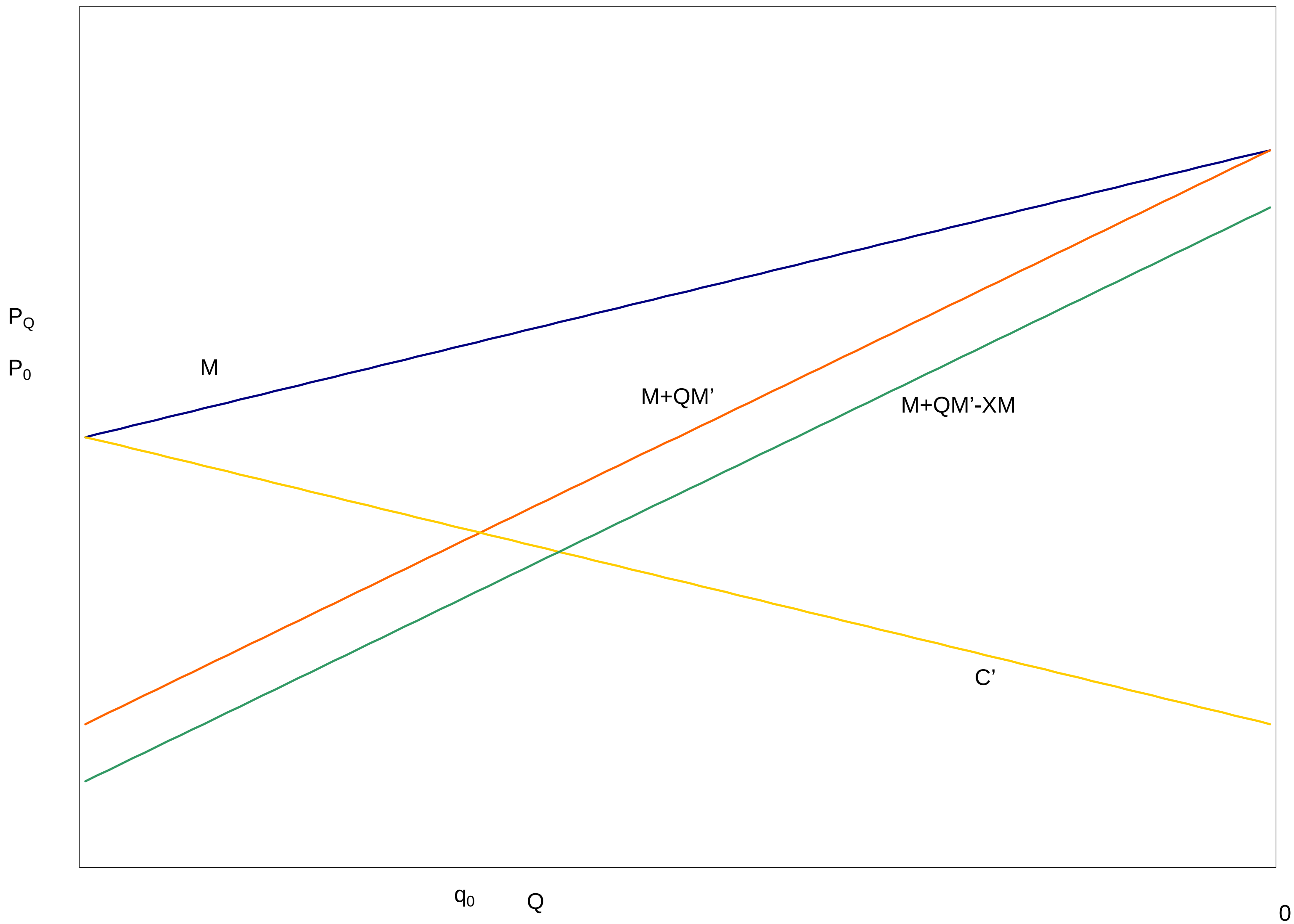


Figure 2

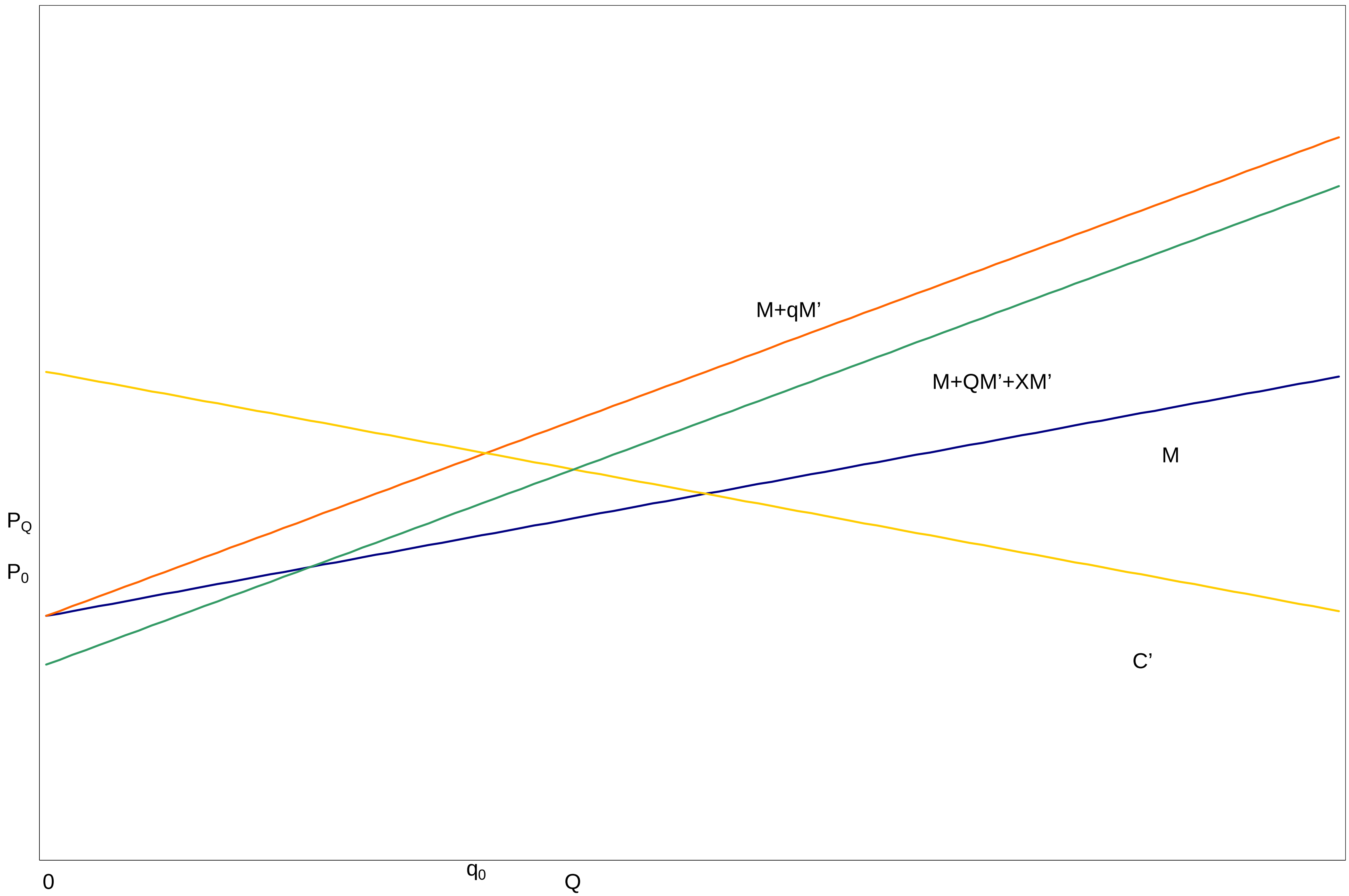
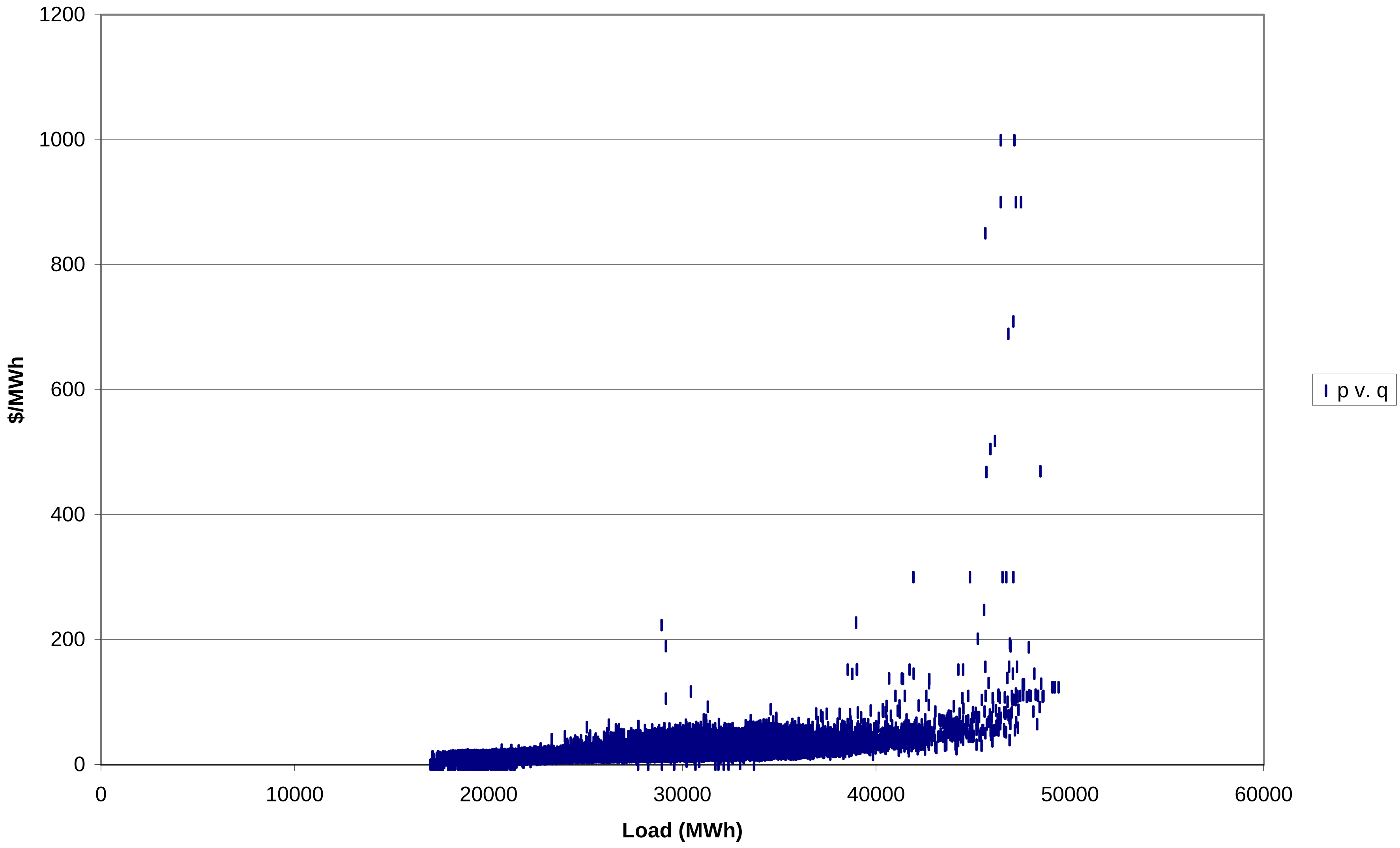


Figure 3



1200
1000
800
600
400
200
0
$/MWh
0
10000
20000
30000
40000
50000
60000
Load (MWh)
p v. q

Figure 4

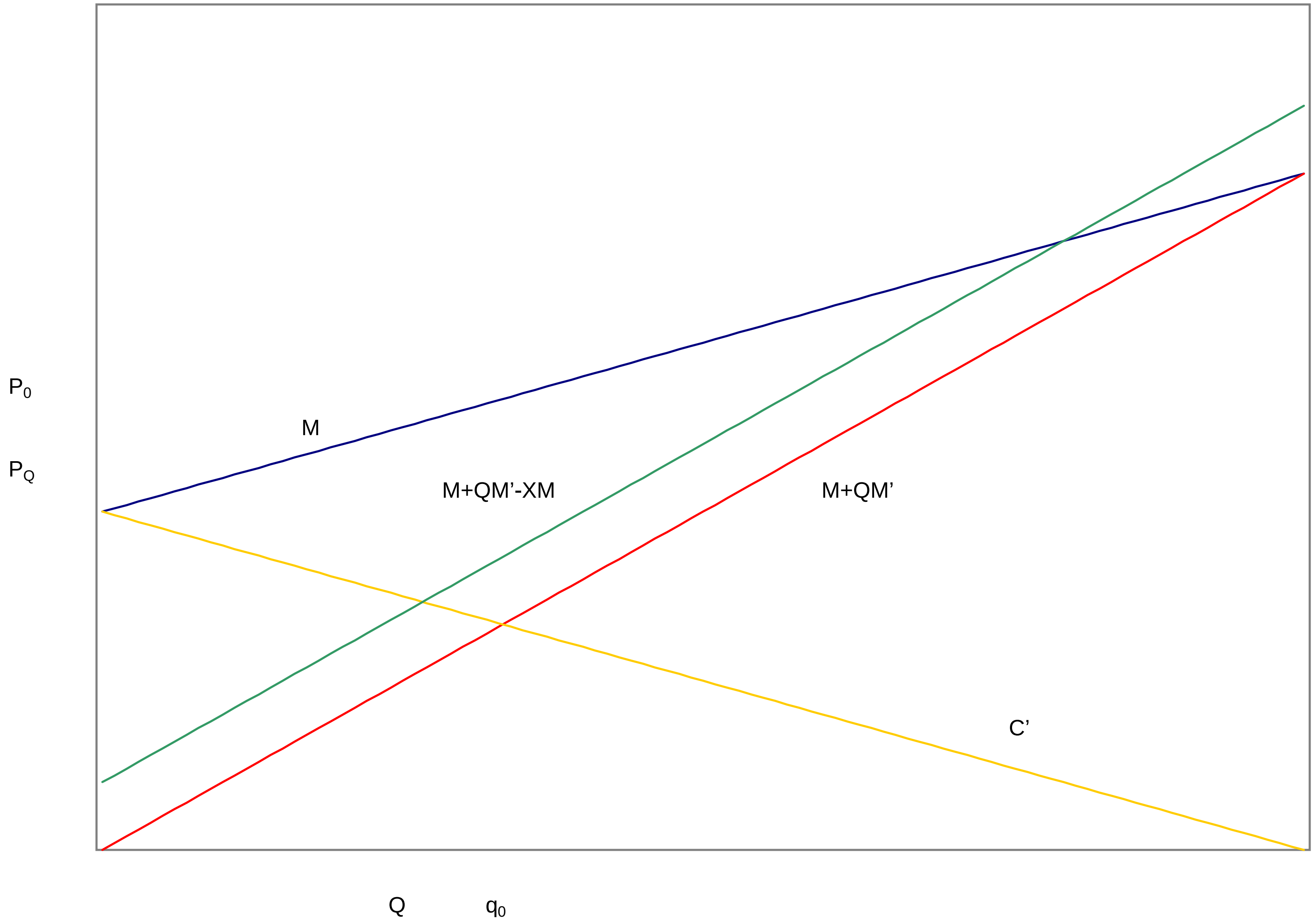


Figure 5