

A Model of Price Adjustment

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The limitations of equilibrium theory and of the stability analyses which justify it have led to considerable work on the development of a disequilibrium economics.¹ Of the criticisms of stability theory, there are three which have motivated the approach taken in this paper. First, the fundamental question seemingly underlying most stability analyses seems inappropriate. Most papers seem to explore the question of developing an adjustment process which will converge to competitive equilibrium. A more appealing approach is the development of adjustment processes which are designed to reflect some realistic process and then consideration of the long-run position of the market if the process is stable. Second, the economic agents in a disequilibrium process should be aware, at least in part, of the disequilibrium in the economy, and adjust their behavior in response to the altered opportunities which are present. Third, in most markets, all the agents are in the market for their own gain and prices get set by a demander or supplier rather than a nonparticipating auctioneer.

There are many models one might want to construct to reflect price adjustments in differently organized markets. In selecting the particular model presented here great weight has been given to mathematical tractability rather than trying to reflect some specific market (although many aspects are patterned after a retail consumer durable market). The purpose has been to develop a very simple model to permit straightforward analysis while hopefully having a framework which will lend itself to generalization. It is assumed that there are many identical firms and many consumers. Each period each firm sets a price and each consumer visits one firm. The consumer either purchases, according to an underlying demand curve, or concludes that the price is too high and leaves

¹ See, e.g., E. S. Phelps *et al.*, "Microeconomic Foundations of Employment and Inflation Theory," Norton, New York, 1970, and the references given there.

the store, to enter another the following period. Firms are assumed to know the demands they face (including the prices that cause people to walk out of the store) and to maximize profits separately each period. Consumers are uncertain about future prices and must compare the cost of searching further with the expected gain from finding a better price. The key dynamic element in the model is the consumer adjustment of cutoff prices for consumers entering the market for the first time. This adjustment is not analyzed in detail. Rather, plausible assumptions are made about it which are sufficient for the stability analysis.

The model does not converge to competitive equilibrium. In finite time, the price becomes that which maximizes joint profits. This particular price equilibrium rests heavily on several assumptions in the model. However it seems generally true that models of this sort will not converge to competitive equilibrium.

Consumer Behavior

This model will be constructed in discrete time, with the time period being the length of time it takes for a consumer to visit one store. We shall assume that prices change at a comparable rate, so that each period each store sets its price for that period. The consumer learns the price in a store only by entering it. He is aware that other stores may have different prices currently and, more important, may have different prices in the next period when he could reach another store. (The store he is currently shopping in may also have a different price the following period.) The nature of the commodity is such that the consumer purchases a quantity of it only once.² This rules out diversification, i.e., buying a little today and a little tomorrow as protection against making the entire purchase at a high price. It also rules out intertemporal interconnections of demand which would arise with a single budget constraint holding for present and future purchases.

Let us now consider a single consumer in a store at time t . Let us denote by

- x the quantity of the good
- p the price of the good
- z the number of periods the consumer has spent checking prices of the good.

We assume that once the decision is made to purchase in a given period, the quantity purchased depends only on the price that period and is

² Thinking of the good as a durable, the different quantities might represent quality or size differences, as e.g., the dimensions of a television picture.

independent of the number of searches that have been made. Let us call the relationship between quantity and price, given the decision to purchase, the underlying demand curve and denote it by $x(p)$. Let us denote by Q the set of prices which will result in the consumer's purchasing in this period. Then, the actual demand, which we denote by $x^*(p)$ satisfies

$$x^*(p) = \begin{cases} x(p), & p \in Q \\ 0 & p \notin Q. \end{cases} \quad (1)$$

In general, we would expect Q to be fairly complicated. For example, we would expect very low prices to be in Q because the gain from finding a lower price (or even a zero price) would not be worth looking for another period. Somewhat higher prices might not be in Q because of the expectation of doing better in the future. However, even higher prices might be in Q because they signal a rising price trend (and so the desirability of purchasing now). Despite such possibilities, we shall assume that there is a single cutoff price q such that the consumer purchases at any price less than or equal to q :

$$x^*(p) = \begin{cases} x(p) & p \leq q \\ 0 & p > q. \end{cases} \quad (2)$$

Below we will discuss changes in q over time.

We can write the consumer's utility as a function of the price at which he purchases and the number of periods he looks before purchasing, $u(p, z)$. We assume that u is strictly decreasing in each argument. We assume further that the marginal disutility of search increases without limit so that if prices are bounded above there is a finite upper limit to the number of searches any consumer would make. We shall assume that different consumers have different cutoff prices and different utility functions but that all consumers have the same underlying demand. Further, we shall assume that the common underlying demand results in a revenue function which is continuous, strictly quasiconcave, and has its maximum at a finite price p^* . Thus, we are assuming

$$px(p) \text{ increases for } p < p^* \text{ and} \\ \text{decreases for } p > p^*.$$

Since we shall assume zero costs for the firm, this will give the same property to the underlying profit function. Thus, as we shall see, no firm will quote a price above p^* , giving rise to a finite maximum of the number of searches any consumer will make. We shall employ a double superscript $h\tau$ to identify individual consumers, the first index referring

to the type of consumer and the second to the time period when he first entered the market to purchase the commodity. We shall employ a single subscript t to denote the time period in which the variable being considered is relevant. Thus, $q_t^{h\tau}$ is the cutoff price in time t for a consumer of type h who first entered the market at time τ .

Aggregate Demand

We assume that each period a new set of consumers enters the market, each set of consumers identically constituted in terms of consumer types; that is, h runs over the same index for each t . This implies that the utility functions of the same type are the same even though generations differ:

$$u^{h\tau}(p, z) = u^{h\tau+1}(p, z).$$

This does not imply that cutoff prices are necessarily the same, for the different generations have observed prices differently. Below we shall use the concept of similar approaches to cutoff prices of identical types to develop restrictions on the changes in aggregate demand over time.

Let us denote by $N_t^\tau(p)$ the number of consumers of generation τ who are willing to purchase in time t at price p . This is defined by counting the consumers with a cutoff price at least as large as p . From our assumptions above we see that N is nonincreasing and continuous from the left in p . Let us denote aggregate demand at time t by X_t , then

$$X_t(p) = x(p) \sum_{\tau} N_t^\tau(p). \quad (3)$$

Choice of Supplier

Before we can use the model of consumer behavior within a store we must determine which consumers enter each store. Let us assume that there are m stores in this market. Then, we shall assume that each firm faces the demand curve $(1/m) X_t(p)$ in each period. Below, we will also briefly consider the case where the fraction of aggregate demand confronting each firm depends on the firm's price reputation. Let us note some of the restrictions arising from this assumption. We are assuming that individual stores do not appeal to particular types of consumers either because of location, overhead expenditures, or other nonprice elements. Furthermore, we are ignoring the reasonable aspect of search that consumers, having decided not to purchase, will seek out a different store in the following period. If the number of stores is large relative to the number of stores a consumer visits, then the fraction of aggregate demand representing consumers who have been in a given store in the past is small and this aspect of the assumption is not very inaccurate.

Firm Behavior

Given the assumptions that the share of consumers going to each store is independent of history and that there are a large number of firms (and so no one firm considers the future demand by consumers who have walked out of its store), the firm can consider the problem of its best position separately in each period. One would like to parallel the uncertainty on the consumer side by giving firms the problems of estimating the demand curves they face and then of selecting an optimal action in this uncertain setting. A proper formulation of these problems seems very complicated in itself and one that would add to the difficulty of describing the time path of price adjustment. Rather than falling back on rules of thumb to describe firm behavior, it seems preferable to make the extreme assumption that firms know with certainty the demand curves they face each period. This also simplifies the choice of an objective function which can be taken to be profits. Ignoring the consumer share fraction (which being constant, does not affect the choice of price level) we can state the firm's problem as

$$\max_p pX_t(p) = px(p) \sum_{\tau} N_i^{\tau}(p). \quad (4)$$

We have assumed that the firm has no costs. (Constant costs would not affect the stability results given quasiconcavity of the profit function.) By assuming the same costs for all firms, we imply that they all face the same maximization problem and all select the same price. Since N_i^{τ} is continuous from the left, nonincreasing; $px(p)$, quasiconcave, and continuous with maximum at p^* , a finite price, this problem has a solution, which, however, need not be unique. This nonuniqueness would be troublesome for difference equation analysis of this model, but offers no problem for the stability analysis done here. Thus we shall assume that p_t is one of the profit maximizing prices; the statements to be made hold for any choice of p_t . The unique maximum of $px(p)$ at p^* will lead to a unique long-run equilibrium even though the time path may not be unique. Let us note a few preliminary results on profit maximizing price setting.

LEMMA 1. $p_t \leq p^*$.

Proof. For $p > p^*$, $p^*x(p^*) > px(p)$ and

$$N_i^{\tau}(p^*) \geq N_i^{\tau}(p) \quad \text{for all } \tau.$$

Let us define \bar{p}_t as the greatest price which still results in all consumers buying:

$$\bar{p}_t = \min_{h,\tau} q_t^{h\tau}. \quad (5)$$

From this definition we see that for

$$p < \bar{p}_t, N_t^\tau(p) = N_t^\tau(\bar{p}_t).$$

We can use \bar{p}_t for further restrictions on price setting.

LEMMA 2. For $\bar{p}_t \geq p^*$, $p_t = p^*$

Proof. By Lemma 1, $p_t \leq p^*$. For $p < p^*$ $p^*x(p^*) > px(p)$ and

$$N_t^\tau(p) = N_t^\tau(p^*) \quad \text{for all } \tau.$$

LEMMA 3. For $\bar{p}_t \leq p^*$, $p_t \geq \bar{p}_t$

Proof. By quasiconcavity, for $p < \bar{p}_t$, $px(p) < \bar{p}_t x(\bar{p}_t)$. By the definition of \bar{p}_t , $N_t^\tau(p) = N_t^\tau(\bar{p}_t)$ for all τ .

Changes in Cutoff Price

We have considered consumer and firm behavior within a single period. To develop a complete model, we must describe the change in parameters between successive periods. The supply side of the market and the underlying demand by each consumer are unchanged over time. The number of consumers and their cutoff prices change over time, however, as new consumers enter the market for the first time, as consumers make purchases and leave the market, and as consumers who have not purchased revise their cutoff prices in the light of the observed price and the increase in the marginal disutility of further search. A natural approach to this question would be to develop a theory of price awareness for individuals not in the market and a theory of expectation adjustment in response to observed prices. I did not want to face the formidable task of developing such a theory for these purposes and have chosen instead to look for reasonable restrictions on cutoff price changes for demanders remaining in the market and on the differences in cutoff prices between successive generations entering the market for the first time. These restrictions alone would not be sufficient to determine the full path of price adjustment, but will be sufficient to show convergence to equilibrium.

There are two separate questions which must be faced in determining cutoff prices. One is the change in cutoff prices for consumers remaining in the market. A second is the determination of cutoff prices for consumers

in the market for the first time. It seems reasonable to assume that a consumer who does not purchase in one period raises his cutoff price for the next period. One reason for this is the price observed when the consumer does not buy, which was sufficiently high to make him feel it was worth waiting. A price which a consumer rejects will lead to a revision of price expectations. This revision seems likely to increase the price at which the consumer is willing to make a purchase without further searching.³ A second reason for a rise in cutoff price from an unsuccessful attempt to purchase is the assumed increasing marginal disutility of search. Even if the consumer's price expectations are unchanged by the observed price, the increased cost of searching should make him willing to settle at a somewhat higher price than he was willing to settle for previously. Furthermore, we assume that there is a minimal response. Thus, we assume that a consumer continuing in the market in period $t + 1$ has a cutoff price which satisfies

$$q_{t+1}^{h\tau} > q_t^{h\tau} + \eta \quad \text{for } \eta > 0 \text{ and independent of } h, \tau, \text{ and } t. \quad (6)$$

Generational Differences

The pattern of cutoff prices for a consumer in the market is a relatively well-defined problem i.e., incorporating additional information into a well-defined maximization problem. The question of the initial cutoff price for a new entrant into the market is far less well-defined. More specifically, we are interested in the differences between successive generations of new entrants. One approach might be to assume that successive generations enter with the same set of cutoff prices for different types. Consumers of this type presumably receive no information on the price in this market. (It is natural to think of them as tourists, having no local information.) A second type of consumer (resident) receives some information on the price level in this market, even though he is not directly observing the price by trying to purchase. It would be interesting to develop models with both types of consumers and, I suspect, would result in a different structure of equilibrium from the one which will develop here with just resident types. (Surprisingly, it seems that the presence of tourists may lower the price for residents.)

To develop a dynamic model, we need to ask how consumers of each type entering the market for the first time in period $t + 1$ differ from those who entered for the first time in period t . In terms of our notation,

³ This argument is not completely compelling. A consumer with a low dislike for searching may be heartened by finding a price close to his cutoff price in the early stages of searching and feel that this enhances his chances of finding even lower prices and so may lower his cutoff price. This case seems possible but unusual.

how does q_{t+1}^{ht+1} differ from q_t^{ht} ? The prime difference in experience between these individuals is the occurrence of p_t . It is natural, then, to relate the difference between q_{t+1}^{ht+1} and q_t^{ht} to p_t and q_t^{ht} . A natural reaction would be to relate sign differences in the former to sign differences in the latter. This approach, however, is not completely appealing because of the presence of the cost of searching. If the price were expected to be at a given level next period (ignoring the remaining future), this would justify a cutoff price in excess of that price today, in response to the searching-cost saving from purchasing today rather than tomorrow. In the face of a price tomorrow of p , expected with certainty, the ideal cutoff price for today q^* would satisfy

$$u^h(q^{*h}, 1) = u^h(p, 2). \quad (7)$$

Considering the continuous functional relationship between q^* and p defined by this equation, the presence of search costs implies

$$q^{*h}(p) > p. \quad (8)$$

We shall now assume that the cutoff price for generation $t + 1$ lies in the interval defined by the cutoff price for generation t and the ideal cutoff price which p_t would have justified. Thus we have one of the following two cases

$$q^{*h}(p_t) \leq q_{t+1}^{ht+1} \leq q_t^{ht} \quad (9)$$

or

$$q_t^{ht} \leq q_{t+1}^{ht+1} \leq q^{*h}(p_t).$$

This restriction seems more appealing than one based on q_t^{ht} and p_t , although it is far from satisfactory. We shall further assume that the difference in cutoffs between successive generations does not become vanishingly small relative to the difference between cutoff and ideal cutoff. For some ϵ , $0 < \epsilon < 1$

$$|q_{t+1}^{ht+1} - q_t^{ht}| \geq \epsilon \min\{1, |q^{*h}(p_t) - q_t^{ht}|\} \quad (10)$$

for all h and t .

With these restrictions on cutoff price adjustment, we have restrictions on the movement of the minimum cutoff price for all the consumers in the market.

LEMMA 4. $p_t \geq \bar{p}_t$ implies $\bar{p}_{t+1} > \bar{p}_t$.

Proof. For all consumers in the market in $t + 1$ who were in the market previously, we have, by (6),

$$q_{t+1}^{hr} > q_t^{hr} \geq \bar{p}_t \quad \text{since } \bar{p}_t \text{ is the minimum of cutoff prices.}$$

For consumers in the market for the first time, we have, by (9),

$$q_{t+1}^{ht+1} \geq \min(q^{*h}(p_t), q_t^{ht}).$$

Since $q^{*h}(p_t) > p_t \geq \bar{p}_t$, we need only be concerned with a consumer type for which $q_t^{ht} = \bar{p}_t$. Then, by (10), $q_{t+1}^{ht+1} > q_t^{ht}$. Therefore all cutoff prices, and thus their minimum, are greater than \bar{p}_t .

LEMMA 5. $\bar{p}_t \geq p_t$ implies $\bar{p}_{t+1} \geq p_t$.

Proof. $p_t \leq \bar{p}_t$ implies that all consumers in the market at time t make their purchases. For consumers in the market for the first time in $t + 1$, $q_{t+1}^{ht+1} \geq \min(q^{*h}(p_t), q_t^{ht})$. By hypothesis, $q_t^{ht} \geq p_t$. From (8), $q^{*h}(p_t) > p_t$.

Stability

The assumptions made above are sufficiently strong to lead to convergence of p_t to p^* in finite time.

THEOREM. *There exists a time t' such that $p_t = p^*$ for all $t \geq t'$.*

Proof. If at any time t , $\bar{p}_t \geq p^*$, then, by Lemma 2, $p_t = p^*$. By Lemma 5, $\bar{p}_{t+1} \geq p^*$, implying that the price would be p^* for all future time. Thus, if the theorem is false, $\bar{p}_t < p^*$ for all t . By Lemmas 1 and 4 it would then follow that $p_t \geq \bar{p}_t$ and $\bar{p}_{t+1} > \bar{p}_t$. Thus the sequence $\{\bar{p}_t\}$ would be increasing and bounded above. It would, therefore, converge to \hat{p} , say, with $\hat{p} \leq p^*$. Let us define $r = \min_{h, \theta}(q^{*h}(p) - p)$ for $\hat{p} - \epsilon \leq p \leq \hat{p}$, where ϵ is the value for the minimal response in q^h in (10). By assumption, $r > 0$. Then there would exist a time \hat{t} such that

$$\hat{p} - \bar{p}_{\hat{t}} \leq \min\{\eta/2, \epsilon/2 \min(1, r)\},$$

where η is the value in (6).

For all consumers in the market at \hat{t} and $\hat{t} + 1$, we would have

$$q_{\hat{t}+1}^{hr} > q_{\hat{t}}^{hr} + \eta \geq \bar{p}_{\hat{t}} + \eta > \hat{p}.$$

Now let us consider consumers in the market for the first time. By Lemma 3, we would have $p_t \geq \bar{p}_t$ and thus $q^{*h}(p_t) \geq p_t + r \geq \bar{p}_t + r$.

For those consumer types with $q_i^{h\hat{t}} \geq q^{*h}(p_i)$, we have $q_{i+1}^{h\hat{t}+1} \geq q^{*h}(p_i) \geq \bar{p}_i + r > \hat{p}$. For those consumer types with $q_i^{h\hat{t}} < q^{*h}(p_i)$, we have

$$\begin{aligned} q_{i+1}^{h\hat{t}+1} &\geq q_i^{h\hat{t}} + \epsilon \min\{1, q^{*h}(p_i) - q_i^{h\hat{t}}\} \\ &= \min\{q_i^{h\hat{t}} + \epsilon, q_i^{h\hat{t}} + \epsilon(q^{*h}(p_i) - q_i^{h\hat{t}})\} \\ &\geq \min\{\bar{p}_i + \epsilon, (1 - \epsilon)\bar{p}_i + \epsilon(p_i + r)\} \\ &\geq \min\{\bar{p}_i + \epsilon, \bar{p}_i + \epsilon r\} \\ &> \hat{p}. \end{aligned}$$

Thus all consumers in the market in $\hat{t} + 1$ have a higher cutoff price than \hat{p} , which is a contradiction. Therefore, the price p^* is reached in finite time.

Equilibrium Analysis

Given convergence to a constant price position, it is easy to see that the joint profit maximizing price p^* will be the equilibrium price. In a steady state, consumers expect the price next period to equal the long-run value. They, therefore, have a cutoff price this period slightly above the long-run price, since it is worth a small sum to make the purchase this period rather than next period. Thus, in the neighborhood of the long-run price, the actual demand facing a firm is the same as the underlying demand. With constant shares of consumers each period, the firm is interested only in short-run profits. Thus the equilibrium position will be one of profit maximization of the underlying demand curve. With changing shares of consumers, this strong conclusion will not follow; however, it does not seem that consideration of future market shares would be sufficient to result in the competitive price. Let us briefly consider a model with changing shares and examine possible long-run equilibrium positions.

Varying Shares of Consumers

The assumption that the fraction of consumers entering any store is constant is both unrealistic and important for the above results. Without developing a dynamic model with varying shares to examine stability, let us consider equilibrium positions, assuming a steady state is reached. We must alter the above analysis to introduce determination of firm shares and to develop rules for firm decision making in this new setting. (We shall ignore the change needed in consumer analysis to incorporate the presence of different prices at different stores in any period.)

Let us denote by $\alpha_t = (\alpha_t^1, \dots, \alpha_t^m)$ the vector of shares of consumers

entering each of the m stores and by $\beta_t = (\beta_t^1, \dots, \beta_t^m)$ the prices set by each of the stores. It seems appropriate to have firm shares determined by price histories

$$\alpha_t^j = \psi^j(\beta_{t-1}, \beta_{t-2}, \dots), \quad j = 1, 2, \dots, m. \quad (11)$$

We might simplify this if we assume that the shares at time $t - 1$ summarize the impact of past prices on share development. Then we would have

$$\alpha_t^j = \phi^j(\alpha_{t-1}, \beta_{t-1}), \quad j = 1, 2, \dots, m. \quad (12)$$

In keeping with the spirit of the above model we would want each firm to set its price in ignorance of the prices being set concurrently by other firms and with interest only in its own current profit and future share. If the firm is maximizing an additive function of current profits and expected future position we would have an objective function

$$\alpha_t^j \beta_t^j X_t(\beta_t^j) + V_t^j(\alpha_{t+1}^j), \quad (13)$$

where V is some expectation operator reflecting the evaluation in the future of starting $t + 1$ with share α_{t+1}^j and the probability of the different values of α_{t+1}^j given the choice of β_t^j and the subjective probabilities of other prices in the market. The dependence of V_t on β_t implies that prices are not chosen simply to maximize short-run profits. Since V should be decreasing in β , prices will tend to be less than they would be with single-period profit maximization in that period and the long-run price will be less than p^* . The greater the dependence of V on β in the long-run equilibrium position, the lower will the long-run price tend to be. Given a long-run equilibrium it does not seem possible that the competitive (zero) price will rule. In this extreme model of no costs a one period gain in profits above the zero level is worth a considerable drop in future shares, since there are no profits to be made in the future at the competitive price. More generally, if market shares depend smoothly on prices (rather than the sharp loss of all business in the standard competitive model), we would expect equilibrium to occur between the competitive and profit maximizing prices.

Demand Functions

The assumption of quasiconcavity of revenue functions played a key role in the uniqueness of long-run equilibrium. If there is a price p^1 such that $p^1 x(p^1) > p x(p)$ for $p \leq p^1 + \max_h q^{*h}(p^1)$, $p \neq p^1$, then the price p^1 is a possible long-run equilibrium. Thus without quasiconcavity there can be multiple equilibria, the initial set of cutoff prices determining

the relevant one. Also the choice of a particular price p_t at a time when there are several profit maximizing prices can determine the long-run equilibrium. With some rules for choosing p_t among prices giving equal profits one can get cycling among local maxima of $px(p)$ which are near to each other (relative to $q^*(p)$). It is not clear whether there can be cycles involving prices that are not local maxima. Cycling can also occur in the case of differing demand curves among individuals even when it is assumed that each of the individual revenue functions are strictly quasi-concave. Thus it seems that a more general model will require additional assumptions to obtain stability.

Entry

The model presented above assumed a fixed set of firms. Since there was a tendency for the appearance of pure profits, it is natural to inquire about the entry of additional firms. It seems more realistic to include a fixed cost of setting up a firm in addition to the variable costs, which happened to be zero above. If the annual profits exceed the interest on fixed setup costs, it is natural for additional entrepreneurs to consider setting up a firm. The new element needed for a theory is the behavior of market shares when an additional firm appears. Let us first consider the model with fixed shares. It is natural to divide the consumers among $n + 1$ stores rather than the previous n ; and to divide them evenly if there are no advantages of location. The presence of an additional firm does nothing, then, to change the pricing analysis done above. The possibility of an additional firm when industry profits are high should have no effect on the behavior of individual firms. Thus the price analysis is unchanged and profits per firm are decreased. Presumably this process continues until firms are just making normal return on the cost of setting up a firm. This outcome is very similar to that of monopolistic competition. Additional firms enter the market until there are no pure profits, but prices remain above marginal costs because of the downward slope of the demand curve caused in this case by the advantage of the product once a consumer is in a store.

The case of variable shares is naturally more complicated. In a model where new stores start with small shares and can only build them up over time and with lower prices, there will be less incentive for entry than in the model with fixed shares. Thus historical position gives a firm an element of goodwill to which one can impute part of the profits. The more difficult for additional rivals to reach a break-even position, the more valued the historical position. The process of equilibrium is nevertheless well-defined provided one describes the subjective probabilities of potential entrepreneurs toward future market conditions.

Concluding Remarks

The mark of having been chosen more for mathematical tractability than for realism appears clearly on many of the assumptions in this paper. The directions in which the model needs to be generalized are fairly obvious. The basic question of stability which was asked in the paper is intrinsically less interesting than comparative static and welfare questions. Hopefully, it will be possible to consider these questions both for the long-run equilibrium position and for the single period positions during the adjustment process.

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