SEEMINGLY RIGID PRICES

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I study the choice of capacity and capacity utilization in competitive environments with demand uncertainty and risk neutral agents. Prices that are paid as a result of executing ex-ante contracts look rigid. When delivery occurs sequentially before the realization of demand is known, spot prices look rigid, the spot markets allocation may be inefficient and a monopoly may improve matters. I derive conditions under which the sequential spot markets allocation is efficient and a condition under which it is possible to view trade in sequential spot markets as the execution of ex-ante contingent contracts.

1. INTRODUCTION

I study the choice of capacity and capacity utilization in competitive environments with demand uncertainty and risk neutral agents. This is done under the assumption that it is too costly to gather all potential buyers and run a Walrasian auction. But there are no costs for using the price system or changing prices. There are two critical assumptions about delivery. Delivery may occur simultaneously after the realization of demand is known or sequentially before the realization of demand is known. I use these competitive environments to explain observations that were interpreted as evidence of price rigidity.

Stigler and Kindahl (1970) studied data about prices of transactions between large firms and their suppliers and conclude that the law of one price is a myth. Using their data, Carlton (1986) found that it is not unusual in some industries for prices to individual buyers to remain unchanged for several years. But more surprisingly, the correlation of price changes across buyers is very low even for what appears to be homogeneous commodities.

Carlton (1986, 1989) argues that the low correlation of price changes across buyers "emphasizes how erroneous it is to focus attention on price as the exclusive mechanism to allocate resources. Non-price rationing is not a fiction, it is a reality of business and may be the efficient response to economic uncertainty and the cost of using the price system." Carlton (1986, page 638).

Here I assume that using the price system is costless and use a variant of the Walrasian-Arrow-Debreu model to account for Carlton's observations. Sellers choose capacity before the realization of demand is known and sell state contingent capacity utilization contracts. Since we do not observe the entire basket of contingent commodities bought by the buyer, the price actually paid by the buyer, when executing the contract, may appear rigid and the correlation between price changes across buyers may be low.

Capacity utilization contracts may explain Carlton's observations about prices paid by large firms but do not explain observations at the retail level about prices paid by individual consumers for mundane commodities like food, clothing and durables. Recently, Bils and Klenow (2002) used BLS data on the monthly frequency of price changes for a large number of consumer goods and services. They find that the median duration of prices is about 5 months. This is less than previous estimates of about a year (see Taylor, 1999, p.1020) but it is still more than one would expect on the basis of the standard Walrasian model. In addition it was observed that even in high inflation periods sellers at the retail level do not change their nominal prices every month. See Lach and Tsiddon (1992) for example. I address this type of observations, using the sequential delivery environment, in the second part of this paper.

2. SIMULTANEOUS DELIVERY CONTRACTS

I consider an economy with two dates ($t = 0,1$) and two goods (X and Y with lower case letters denoting quantities). There is a price-taking firm with a constant returns to scale technology: It can produce X at the cost of λ units of Y per unit of X. Production occurs at $t = 0$.

There are S possible aggregate states of nature (indexed s) where state s occurs with probability Π_s. There are J types of buyers. A type j buyer demands one unit of X at any price less than v_j if he wants to consume and zero otherwise. At t = 1 the state becomes public information and the buyer learns about his desire to consume.

There are n_j type j buyers and in state s a fraction ϕ_{js} of them want to consume. Aggregate demand over all type j buyers in state s at the price p is thus:

(1) $$N_{js}(p) = \phi_{js} n_j \text{ if } v_j \geq p \text{ and zero otherwise.}$$

Aggregate demand over all types in state s is:

(2) $$N_s(p) = \Sigma_j N_{js}(p).$$

In the standard Walrasian auction model the realization of demand is observed before announcing the market clearing price: p_s. Formally,

A standard Walrasian auction equilibrium is a non-negative vector of prices $(p_1,...,p_S)$ and total production (capacity) x such that:

(a) $\Sigma_{s=1}^{S} \Pi_s p_s = \lambda$;

(b) $N_s(p_s) \leq x$ for all s and $p_s = 0$ when the inequality is strict.

Condition (a) ensures that the firm makes zero expected profits. (b) is a market clearing condition.

Later I distinguish between Walrasian and sequential efficiency. To define Walrasian efficiency I consider the problem of a central planner who can observe the state of nature and the reservation price of each buyer. Let I(statement) = 1 when the statement is true and zero otherwise. The central planner's problem may be stated as that of choosing shadow prices p_s and capacity x which solve:

$$(3) \qquad \max \Sigma_s \Pi_s \Sigma_j \phi_{js} n_j v_j I(v_j \geq p_s) - \lambda x$$

$$\text{s.t.} \quad \Sigma_j \phi_{js} n_j I(v_j \geq p_s) \leq x \text{ for all s.}$$

An allocation is Walrasian efficient if it solves (3). The first welfare Theorem says that the standard Walrasian auction prices and the equilibrium choice of x solve (3) and therefore the equilibrium allocation is Walrasian efficient.

I now turn to discuss the possibility of using ex-ante contracts. Here agents are risk neutral and there is no insurance motive for trading in contracts. But it may be cheaper to implement the Walrasian auction allocation in two stages. In the first stage buyers delegate their preferences to a relatively small number of firms and then after the state is revealed, these firms participate in a spot market auction. I use the term delegated auction for this two stages procedure and use the airline industry as an example.

Delegated auctions:

The airline industry must choose and allocate capacity in the face of uncertainty about demand. One possibility is to run an auction at the gate. Alternatively, trade may be done in two stages. In the first stage the airlines sell tickets. Then, close to the time of departure, there is an auction in which airlines participate but individual passengers do not. The two stages alternative may save time if it is easier to run an auction with a smaller number of participants. It may also be a way of transmitting information about prices and allow buyers to make an informed decision about whether or not to take a cab to the airport. I now describe the second alternative in detail.

I start from the case in which the type of the buyer is observed. At $t = 0$, the airlines sell contracts to buyers. A contract (a ticket) is a triplet (μ, α, β): If at $t = 1$ the buyer reports that he wants to fly and the airline chooses to deliver the buyer pays the price μ. If the buyer reports that he does not want to fly he pays α (get a refund for $\mu - \alpha$). If he reports that he wants to fly but there is "overbooking" and the airline does not deliver the buyer gets β (pays $-\beta$).[1] To insure that a buyer who does not want to fly will truthfully report to the airline, we require: $\mu \geq \alpha \geq 0$.

At $t = 1$ all the refund options are exercised and the state of nature is revealed. At this stage airlines trade in a spot market auction at the price p_s.

The airline problem is to choose capacity and choose whether to sell it on the spot market or in advance. In equilibrium the airline is indifferent about the capacity it produces and the way it sells it.

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[1] In the "real world" tickets often have two parameters only (μ, α). In the case of overbooking there is an auction: The airline buys back the number of seats which were "overbooked". This will lead to the same qualitative results as the contracts we assume.

The airline expected profits from producing a unit of capacity at $t = 0$ and selling it on the $t = 1$ spot market are zero:

(4) $$\Sigma_s \Pi_s p_s = \lambda.$$

Since the type is observed the expected revenue from producing a unit and selling a ticket (μ, α, β) at $t = 0$ to a type j buyer is:

(5) $$\Sigma_s \Pi_s\{\phi_{js}[\max(\mu, p_s - \beta)] + (1 - \phi_{js})(p_s + \alpha)\}.$$

The term $\max(\mu, p_s - \beta)$ reflects the choice of the firm: Only if $\mu > p_s - \beta$ it will choose to deliver. The term $(p_s + \alpha)$ is the payoff to the firm when the buyer chooses not to fly: The airline gets α from the buyer and p_s from selling the seat on the spot market.

The expected profits from producing a unit and selling a ticket in advance is zero and therefore airlines let customers choose their tickets subject to the constraint that the expected revenue (5) is equal to λ. The problem of type j buyer is thus to choose $T = (\mu, \alpha, \beta)$ which solves the following problem:

(6) $$\max_T \Sigma_s \Pi_s\phi_{js}\{(v_j - \mu)I(\mu > p_s - \beta) + \beta I(\mu \le p_s - \beta)\} - \Sigma_s \Pi_s(1-\phi_{js})\alpha$$

s.t.

$$\Sigma_s \Pi_s\{\phi_{js}[\max(\mu, p_s - \beta)] + (1 - \phi_{js})(p_s + \alpha)\} = \lambda;$$

$$\mu \ge \alpha \ge 0.$$

The objective in (6) is the expected consumer surplus. Delivery occurs if $\mu > p_s - \beta$ and the buyer wants to fly. Therefore the term $(v_j - \mu)I(\mu > p_s - \beta) + \beta I(\mu \leq p_s - \beta)$ is the consumer surplus when the buyer wants to fly: He gets $v_j - \mu$ if the airline delivers and β otherwise. The last term is the loss which occurs when the buyer does not want to fly and pays α.

I now turn to solve this problem.

Proposition 1: The following is a solution to (6):

$\beta = v_j - \mu$

$\mu = \Sigma_s \Pi_s \phi_{js} \min(p_s, v_j)/\Sigma_s \Pi_s \phi_{js}$

$\alpha = 0$.

Under the proposed solution $\max(\mu, p_s - \beta) = \max(\mu, \mu + p_s - v_j)$ and the ticket will not be delivered if $p_s - v_j > 0$.

Given the choice of β, a buyer who wants to fly pays μ and receives v_j. To elaborate on this interpretation of the contract note that the buyer who wants to fly gets delivery which is valued at v_j if $p_s \leq v_j$ and pays $-\beta = \mu - v_j$ otherwise. The payment of $\mu - v_j$ is equivalent to paying μ and getting v_j. Thus, regardless of the realization of p_s he pays μ and gets v_j. The cost to the airline of guaranteeing v_j to the buyer if he wants to fly is: $\min(p_s, v_j)$. At the proposed solution the expected revenue $\mu\Sigma_s \Pi_s \phi_{js}$ is equal to the expected cost $\Sigma_s \Pi_s \phi_{js} \min(p_s, v_j)$.

I now turn to prove the Proposition.

<u>Proof:</u> We show that the proposed solution maximizes the joint surplus (buyer + firm) and the firm gets only the expected revenue of λ.

The joint surplus (buyer + firm) is:

$$(7)\quad \Sigma_s\ \Pi_s\phi_{js}\{v_j I(\mu > p_s - \beta) + p_s I(\mu \le p_s - \beta)\} + \Sigma_s\ \Pi_s(1 - \phi_{js})p_s - \lambda.$$

The choice $\beta = v_j - \mu$ maximizes (7) because it implies delivery if an only if $v_j > p_s$.

To show that the zero profit condition is binding we substitute (4), $\beta = v_j - \mu$ and $\alpha = 0$ in the constraint to get:

$$(8)\qquad \Sigma_s\ \Pi_s\{\phi_{js}[\mu + \max(0,\ p_s - v_j)] + (1 - \phi_{js})p_s\} = \Sigma_s\ \Pi_s p_s.$$

After some algebra we get $\mu = \Sigma_s\ \Pi_s\phi_{js}\min(p_s,\ v_j)/\Sigma_s\ \Pi_s\phi_{js}$ as the solution to (8). Thus we have shown that the proposed solution maximizes total surplus and the expected revenue of the firm is exactly λ. It must therefore maximize the expected consumer surplus subject to the constraint. □

<u>Corollary:</u> The solution to (6) is not unique. Any μ and α that imply the expected payment:

$$\mu\Sigma_s\ \Pi_s\phi_{js}I(v_j > p_s) + \alpha\Sigma_s\ \Pi_s(1 - \phi_{js}) = \Sigma_s\ \Pi_s\phi_{js}I(v_j > p_s)p_s,$$

and satisfy the constraint $\mu \ge \alpha \ge 0$ is a solution.

I now define equilibrium as follows.

A delegated auction equilibrium is a vector of spot prices $(p_1, \ldots, p_S)$, a vector of contracts $(T_1, \ldots, T_J)$ and total capacity x such that:

(a) $\Sigma_s \Pi_s p_s = \lambda$;

(b) Given the prices $(p_1, \ldots, p_S)$ type j's choice $T_j = (\mu_j, \alpha_j, \beta_j)$ solves (6) for all j;

(c) $x = \max_s\{\Sigma_j \phi_{js} n_j I(\mu_j > p_s - \beta_j)\}$.

To find a delegated auction equilibrium we pick a standard Walrasian auction equilibrium vector: $(p_1, \ldots, p_S; x)$. We then let agents choose contracts by solving (6). Under the solution proposed in Proposition 1, a buyer will get the seat only if he wants to fly and $v_j > p_s$. This is precisely the allocation rule used in the standard spot market model. Therefore the market clearing condition (c) is satisfied. We have thus shown that for this equilibrium solution,

Proposition 2: The delegated auction allocation is the same as the standard Walrasian auction allocation.

As was said before, we may view the advance purchase of tickets as a practical way of running a spot market auction. I now argue that this delegated auction generates observations that were interpreted as evidence of price rigidity.

We observe the price actually paid by a given passenger over many periods. When buyers do not change preferences (types) often we will observe that the price actually paid by each individual buyer (μ_j) when executing the contract remains constant for a long time. When there is a change in preferences we will observe a change in the actual price paid. But this change need not be correlated with the change experienced by other buyers. We may thus get Carlton's observations in-spite of the fact that there are no costs for using the price system.

It may be useful to describe the delegated auction in terms of trade in contingent commodities. Typically each buyer buys a basket of contingent commodities but if we misspecify the commodity space and assume that the airlines sell one good only, we may erroneously conclude that the law of one price is violated. I now illustrate this point by an example.

Example 1: There are three types and two states of nature. A type 1 buyer wants to consume in both states and his reservation price is $v_1 = 10$. A type 2 buyer wants to consume only when $s = 2$ and his reservation price is $v_2 = 7$. A type 3 buyer wants to consume only when $s = 1$ and his reservation price is $v_3 = 4$. There are the same numbers of agents from each type. The cost of production is $\lambda = 5$ per unit of capacity.

A standard Walrasian equilibrium vector for this case is: $p_1 = 3$, $p_2 = 7$, $x = 2$.

A delegated auction equilibrium specifies, in addition, the tickets sold to each type. We can have an equilibrium with $\alpha_j = \beta_j = 0$, $\mu_1 = 5$, $\mu_2 = 7$ and $\mu_3 = 3$.

In this example, the type 2 buyer has bought flight in state 2 for 7 units of the numeiraire commodity. The type 3 buyer has bought flight in state 1 for 3 units. The type 1 buyer has bought a basket of two commodities for a total of 10 units. His actual payment may be 3 in state 1 and 7 in state 2. But because of risk neutrality this is equivalent to paying 5 in both states.[2] If we misspecify the commodity space and assume that the airlines sell one good instead of two, we may erroneously conclude that the law of one price is violated.

Carlton's data are about long-term relationship between large firms (typically in the fortune 500) and their suppliers. In a long term relationship the type is revealed and therefore our underline assumption may be quite realistic. In an Appendix which is available upon request I use the Corollary to show that the above analysis may apply even if the type is not revealed because the free parameter (α) can be used to get a separating equilibrium without loss of efficiency.

I now turn to discuss the sequential delivery environment. It was already shown in Eden (1994, 2001) that in this environment we can get seemingly rigid prices even in spot markets transactions. I will therefore focus here on the issue of efficiency.

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[2] In general our environment requires many commodities. There are S aggregate state and there are many individual histories which are possible for any given aggregate state. In an Arrow Debreu world there will therefore be many commodities and a typical basket of these commodities will be described as a ticket with many parameters. Here we used risk neutrality and symmetry to reduce the number of parameters to three.

3. SEQUENTIAL SPOT MARKETS

The uncertain and sequential trade (UST) model is based on ideas in Prescott (1975) and Butters (1977). In a review article of the Phelps volume, Prescott considers an example in which sellers of motel rooms set prices before they know how many buyers will arrive and derive an equilibrium price distribution. He assumes that cheaper rooms are sold first and therefore in equilibrium sellers face a tradeoff between price and the probability of making a sale. In the UST approach taken by Eden (1990) an equilibrium distribution of prices is obtained even though sellers are allowed to change their prices during trade and have no monopoly power. Prices in this model appear to be rigid because sellers have no incentive to change their prices during trade. Dana (1998) studies a Prescott type model with heterogeneous agents and show that the resulting allocation may not be Walrasian efficient. He blame the assumed price rigidity for the inefficiency. Here I study this problem in a UST framework in which prices are flexible and extend the analysis in previous UST models to the case in which buyers are heterogeneous.

Markets

The UST model assumes a sequence of Walrasian markets, where each batch of demand opens a new market. A seller may choose not to sell his entire supply in the market that opens because he is betting on the event that additional demand will arrive and open the next, higher-price market.

As in the previous section capacity choices are made at t = 0. Then at t = 1, buyers learn about their desire to consume. The $\Sigma_{j=1}^{J} \phi_{js} n_j$ buyers who want to consume form a line by a lottery that treats all buyers who want to consume symmetrically. After the line is formed, buyers arrive at the market place one by one according to their place in the line and choose whether to buy at the cheapest available offer. Figure 1 illustrates the sequence of events.

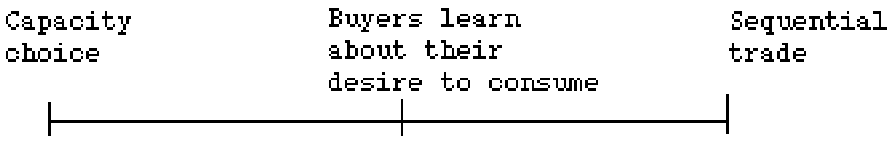

Figure 1

From the firm's point of view demand arrives in batches. The first batch with Δ_1 buyers arrives with certainty. After the buyers in the first batch complete trade a second batch of Δ_2 buyers may arrive. In general, there can be two possible events after buyers in batch i complete trade: Either trade ends or an additional batch of Δ_{i+1} buyers arrive. Figure 2 illustrates the sequential trade process.

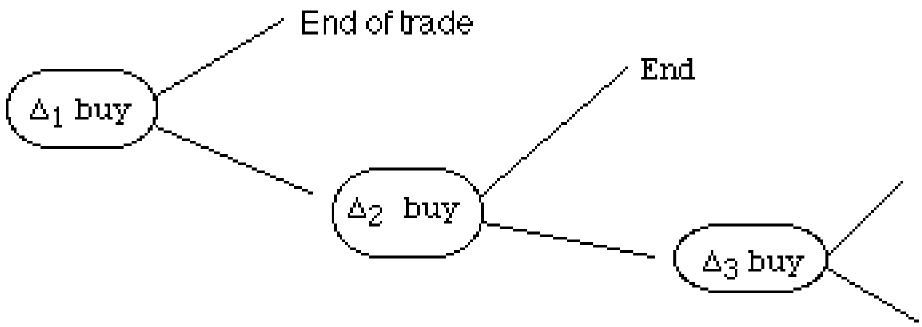

Figure 2

The firm can sell at the price P_i to buyers in batch i if they arrive. It makes a contingent plan to sell x_i units at the price P_i to batch i if it arrives, subject to:

(9) $$\Sigma_i x_i = x,$$

where x is the total amount it chooses to produce.

It helps to think in terms of markets that open sequentially. The first batch of buyers opens the first market. If the second batch of buyers arrives, it opens the second market and so on. The price in market i is P_i, the quantity supplied to market i is x_i and the quantity demanded in market i is Δ_i. In equilibrium markets that open are cleared:

(10) $$\Delta_i = x_i.$$

Trade occurs sequentially but does not take real time. The only information that the sellers receive during the trading process is about the number of batches that arrive: at stage i of the trading process sellers know that i batches already arrived.

What determines the size of each batch Δ_i and the probability that market i will open? I start from the relative simple case in which all potential buyers have the same reservation price.

<u>The reservation price is the same across buyers</u>

I assume $v_j = v$ for all j and that aggregate demand $N_s = N_s(v)$ is increasing in the state: $N_1 < N_2 < ... < N_S$. For notational purposes I set $N_0 = 0$. The minimum demand is $\Delta_1 = N_1$. After the first N_1 buyers have completed trade there may be two possibilities: either s = 1 and there are no more buyers or s > 1. If s > 1, then $N_s - N_1$ buyers could not buy in market 1. The minimum residual demand is:
$\Delta_2 = \min_s\{N_s - N_1\} = N_2 - N_1$. The probability that s > 1 is $q_2 = 1 - \Pi_1$ and this is the probability that market 2 will open. After transactions in market 1 are completed, there may be again two possibilities: either no additional buyers arrive or, if s > 2, some additional buyers do arrive. The probability that s > 2, is $q_3 = 1 - \Pi_1 - \Pi_2$ and this is the probability that market 3 will open. The minimum residual demand if s > 2 is: $\Delta_3 = \min_s\{N_s - N_2\} = N_3 - N_2$. Proceeding in this way we define q_s and Δ_s for all s = 1, ...,S.

A UST spot markets equilibrium is a vector $(P_1,...,P_S; x_1,...,x_S)$ such that: (a) $P_i = \lambda/q_i = \lambda/\Sigma_{s=i}^{S}\Pi_s$ and
(b) $x_i = \Delta_i = N_i - N_{i-1}$ if $P_i \leq v$ and zero otherwise.

Because of constant returns to scale equilibrium prices are determined by supply considerations only. At these prices ($P_i = \lambda/q_i$) sellers are indifferent about how much they supply to each market and therefore they are willing to satisfy demand.

To solve for the equilibrium quantities we substitute the equilibrium condition (a) in (b) to get: $x_i = \Delta_i$ if $\lambda \leq vq_i$. This says that capacity will be created to satisfy the demand of batches that arrive with a high enough probability so that the cost per unit λ is less than the expected value vq_i.

The social planner's problem in this environment is to choose capacity and allocate it across the potential markets to maximize expected surplus. That is:

$$\text{(11)} \qquad \max_{x_i} \; v\Sigma_i \, q_i x_i - \lambda\Sigma_i \, x_i \; ; \text{ s.t. } x_i \leq \Delta_i.$$

An allocation that solves (11) is sequential efficient. The solution to (11) is: $x_i = \Delta_i$ if $vq_i \geq \lambda$ and zero otherwise. This coincides with the equilibrium outcome and therefore the UST spot markets allocation is sequential efficient in our special case.

Note that the solution to (11) is not the same as the solution to (3) because in the sequential case the planner cannot make his choice contingent on s.

To elaborate on the difference between (3) and (11) and the distinction between Walrasian and sequential efficiency, it may be useful to write (11) in an alternative way. Let p_{is} denotes the shadow price applies to batch i in state of nature s. We can write the planner's problem (3) as that of choosing p_{is} to solve the following problem:

$$\text{(12)} \qquad \max_{p_{is}} \; v\Sigma_{s=1}^{S} \, \Pi_s \Sigma_{i=1}^{s} \, \Delta_i I(v > p_{is}) - \lambda\Sigma_{i=1}^{S} \, \Delta_i I(v > p_{is}).$$

In a sequential trade environment the planner has to choose how much to supply to each batch before he knows the state. He therefore solves (12) under the constraint:

(13) $$p_{is} = p_i \text{ for all } s \text{ and } i.$$

This constraint will bind in general because when s is small the solution to the unconstraint problem is $p_{is} = 0$. I therefore distinguish between Walrasian efficiency (a solution to [12]) and sequential efficiency (a solution to [12] subject to the constraint in [13]).

Note that prices may appear rigid in the sequential environment because they do not respond to the realization of demand (the state s). Nevertheless it can be shown that sellers do not have an incentive to change prices during trade.

I now turn to another special case in which v_j may vary across types but the consumption probabilities do not.

<u>Consumption probabilities are the same across types:</u>

I assume that $\phi_{js} = \phi_s$ for all j and s and $0 = \phi_0 < \phi_1 < \phi_2 < ...< \phi_S = 1$. The reservation price v_j may vary across types. I use

(14) $$x_{ji} = 1 \text{ if } v_j \geq p_i \text{ and zero otherwise,}$$

to denote the demand per type j buyer in market i. It is assumed that

$p_i \leq p_{i+1}$ and therefore $x_{ji} = 0$ implies $x_{ji+1} = 0$. I now calculate the demand in each market given the prices p_i. To simplify, I assume that there exists a type, say type 1, with a sufficiently high reservation price such that: $x_{1i} = 1$ for all i.

The minimum number of buyers who want to consume is $\phi_1\Sigma_{j=1}^{J} n_j$ and the demand of this first batch is: $\Delta_1 = \phi_1\Sigma_{j=1}^{J} n_j x_{j1}$. After the first batch have completed trade a second batch will arrive if not all buyers who wanted to buy in market 1 made it. That is, if: $(\phi_S - \phi_1)\Sigma_{j=1}^{J} n_j x_{j1} > \Delta_1$. This event occurs with probability $q_2 = 1 - \Pi_1$. The minimum residual demand at the price p_2 is: $\Delta_2 = (\phi_2 - \phi_1)\Sigma_{j=1}^{J} n_j x_{j2}$ units and this is the demand in the second market if it opens. In general, market i opens with probability $q_i = \Sigma_{s=i}^{S} \Pi_s$ and the demand in market i if it opens is:

$$\Delta_i = (\phi_i - \phi_{i-1})\Sigma_{j=1}^{J} n_j x_{ji}. \tag{15}$$

A UST spot markets equilibrium is a vector $\{x_{ji}, p_i, \Delta_i\}$ such that:

(a) $p_i = \lambda/q_i$;

(b) $x_{ji} = 1$ if $v_j \geq p_i$ and zero otherwise;

(c) $\Delta_i = (\phi_i - \phi_{i-1})\Sigma_{j=1}^{J} n_j x_{ji}$.

Substituting equilibrium condition (a) in (b) leads to the equilibrium allocation rule:

$$x_{ji} = 1 \text{ if } v_j \geq \lambda/q_i. \tag{16}$$

The planner's problem in this environment is:

$$(17) \qquad \max_{x_{ji} \in \{0\ 1\}} \Sigma_{i=1}^{S} q_i(\phi_i - \phi_{i-1})\Sigma_{j=1}^{J} n_j v_j x_{ji} - \lambda\Sigma_{i=1}^{S} \Delta_i$$

$$\text{s.t. } \Delta_i = (\phi_i - \phi_{i-1})\Sigma_{j=1}^{J} n_j x_{ji}.$$

If the planner chooses $x_{ji} = 1$ he will get $q_i(\phi_i - \phi_{i-1})n_j v_j$ at the cost of $\lambda(\phi_i - \phi_{i-1})n_j v_j$. He will therefore make this choice only if (16) is satisfied. We have thus shown that the equilibrium allocation (16) solves the planner's problem (17) and is therefore sequential efficient. We can now combine the results of the two special cases as follows.

<u>Proposition 3:</u> When the reservation price is the same across types ($v_j = v$ for all j) or the consumption probabilities are the same across types ($\phi_{js} = \phi_s$ for all j and s) the UST spot markets allocation is efficient in the sequential sense.

I now turn to the more general case.

<u>The reservation prices and the consumption probabilities vary across types:</u>

I describe an algorithm for computing the market structure (q_i, Δ_i) for an arbitrarily chosen price vector: $P_1 \leq ... \leq P_S$. This is done by computing the residual demand at each stage of trade. The next batch will arrive if there is strictly positive residual demand (buyers who wanted to buy in previous markets but could not). The number of buyers in the next batch is the minimum size of the residual demand. To illustrate the working of the algorithm, I start with a version of example 1.

Example 2: There are two types of buyers and two states of nature. The number of buyers from each type is n. A type 1 buyer demands one unit if the price is less than 10 ($p \le 10$) and zero otherwise. A type 2 buyer demands 1 unit if $p \le 7$ and $s = 2$ and demands zero otherwise. The cost of production is: $\lambda = 5$.

Total demand at the price p in state of nature s, $N_s(p)$, is:

$$N_1(p) = N_2(p) = 0 \quad \text{if } p > 10;$$

(18) $$N_1(p) = N_2(p) = n \quad \text{if } 7 < p \le 10;$$

$$N_1(p) = n \text{ and } N_2(p) = 2n \quad \text{if } p \le 7.$$

The minimum demand and hence the number of buyers in the first market is:

(19) $$\Delta_1(P_1) = n \quad \text{for } P_1 \le 10 \text{ and zero otherwise.}$$

Market 2 will open if there are buyers who wanted to buy at the first market but could not. In our example this will occur in state 2 when $P_1 \le 7$. The probability that market 2 will open is therefore:

(20) $q_2(P_1) = {}^1\!/_2$ for $P_1 \le 7$ and zero otherwise.

When $P_1 \le 7$ and $s = 2$, $({}^1\!/_2)n$ buyers from each type make a buy in market 1 and the number of unsatisfied customers is $({}^1\!/_2)n$ of each type. When $P_2 \le 7$, all the unsatisfied buyers want to buy in market 2 and therefore:

(21) $$\Delta_2(P_1, P_2) = n \text{ for } P_1 < P_2 \le 7.$$

When $7 < P_2 \le 10$ only type 1 buyers want to buy in market 2 and therefore:

(22) $$\Delta_2(P_1, P_2) = ({}^1\!/_2)n \quad \text{for } P_1 \le 7 \text{ and } 7 < P_2 \le 10.$$

When $P_2 > 10$ none of the unsatisfied buyers want to buy in market 2 and therefore:

(23) $$\Delta_2(P_1, P_2) = 0 \quad \text{for } P_1 \le 7 \text{ and } P_2 > 10.$$

Since the second market opens in this example with probability ${}^1\!/_2$, equilibrium prices are:

(24) $$P_1 = \lambda = 5 \text{ and } P_2 = 2\lambda = 10.$$

For the prices (24) the number of buyers in the second batch is $({}^1\!/_2)n$ (according to [22]) and production is therefore (1.5)n units at the cost of (7.5)n. The surplus in state 1 is: $(v_1 - 7.5)n = (2.5)n$. The surplus in state 2 is: $(v_1 + (^1/_2)v_2 - 7.5)n = 6n$. The average surplus over the two states is (4.25)n.

A monopoly will choose $P_1 = 10$ and produce one unit making a profit of 5n. Thus a monopoly may improve matters.

The general case:

Market 1 will open when $\Sigma_j\ \phi_{js} > 0$, with probability $q_1 = \Sigma_{s=1}^{S}\ \Pi_s I(\Sigma_j\ \phi_{js} > 0)$. To simplify, I assume $q_1 = 1$.

The number of type j buyers who want to buy in the first market at the price P_1 in state s is:

(25) $$N_{js}^1(P_1) = \phi_{js}n_j \text{ if } v_j \geq P_1 \text{ and zero otherwise.}$$

Total demand in the first market at the price P_1 is therefore:

(26) $$N_s^1(P_1) = \Sigma_j\ N_{js}^1(P_1).$$

The number of buyers in the first batch is the minimum demand at the price P_1 over all states:

(27) $$\Delta_1(P_1) = \min_+\{N_1^1(P_1),\ldots,N_S^1(P_1)\},$$

where I use the operator $\min_+$ to select the smallest strictly positive number if such a number exists and zero otherwise.[3]

Market 2 will open in state s if after the completion of trade in the first market there is residual demand in this state: $N^1_s(P_1) > \Delta_1(P_1)$. The probability that market 2 will open is thus:

$$q_2(P_1) = \Sigma^S_{s=1}\ \Pi_s I[N^1_s(P_1) > \Delta_1(P_1)]. \tag{28}$$

If $q_2(P_1) = 0$, we set $q_i = 0$ and $\Delta_i = 0$ for $i > 1$. If $q_2(P_1) > 0$, we calculate the size of the second batch. The fraction of satisfied buyers out of all buyers who wanted to buy is:

$$\psi^1_s(P_1) = \Delta_1(P_1)/N^1_s(P_1) \text{ if } N^1_s(P_1) > 0 \text{ and zero otherwise.} \tag{29}$$

It is assumed that the fraction of satisfied buyers is the same for all types who wanted to buy in market 1. The number of unsatisfied type j buyers is $[1 - \psi^1_s(P_1)]\phi_{js}n_j$ and the number of unsatisfied type j buyers who want to buy at the price P_2 is:

$$N^2_{js}(P_1, P_2) = [1 - \psi^1_s(P_1)]\phi_{js}n_j \quad \text{if } v_j \geq P_2 \text{ and zero otherwise.} \tag{30}$$

The total residual demand at the price P_2 is:

$$N^2_s(P_1, P_2) = \Sigma_j\ N^2_{js}(P_1, P_2). \tag{31}$$

[3] For example: $\min_+(1,2,0) = 1$ and $\min_+(0,0,0) = 0$.

We can now compute the number of buyers in batch 2 by taking the minimum residual demand at the price P_1 over all states:

(32) $$\Delta_2(P_1, P_2) = \min_+\{N_1^2(P_1, P_2),\ldots,N_S^2(P_1, P_2)\}.$$

Market 3 will open if after completion of trade in market 2 there is strictly positive residual demand. This occurs with probability:

(33) $$q_3(P_1, P_2) = \Sigma_{s=1}^{S} \Pi_s I[N_s^2(P_1, P_2) > \Delta_2(P_1, P_2)].$$

In general, the probability that market i will open depends only on prices in markets with indices less than i and is denoted by: $q_i(P_1, \ldots, P_{i-1})$. The probability $q_i(P_1, \ldots, P_{i-1})$ is zero if $q_{i-1}(P_1, \ldots, P_{i-2})$ is zero. When $q_i(P_1, \ldots, P_{i-1}) > 0$, the number of buyers in batch i, $\Delta_i(P_1, \ldots, P_i)$, depends on the prices in all the first i markets. If $q_i(P_1, \ldots, P_{i-1}) = 0$ then $\Delta_i(P_1, \ldots, P_i) = 0$.[4] For convenience it is assumed that $q_1 = 1$.

Because of constant returns to scale the supply to market i does not depend on the supply to other markets: It depends only on the probability that market i will open and the price in this market. The firm takes prices $(P_1, \ldots, P_i)$ as given and chooses the quantity x_i to solve:

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[4] Note that market i may open and $\Delta_i(P_1, \ldots, P_i)$ may equal zero because the price P_i is too high. Note also that by construction, the number of markets that open is less than or equal to the number of states (S).

(34) $$\max\ [q_i(P_1,\ \ldots,\ P_{i-1})]P_i x_i - \lambda x_i.$$

The firm will choose any interior solution, $0 < x_i < \infty$, if:

(35) $$[q_i(P_1,\ \ldots,\ P_{i-1})]P_i = \lambda.$$

Given the functions $q_i(P_1, \ldots, P_{i-1})$ and $\Delta_i(P_1, \ldots, P_i)$ I define equilibrium as follows.

<u>A UST spot markets equilibrium</u> is a vector of prices and quantities $(P_1, \ldots, P_S;\ x_1, \ldots, x_S)$ that satisfy:

(a) $P_1 \leq P_2 \leq \ldots \leq P_S$;

(b) $[q_i(P_1, \ldots, P_{i-1})]P_i = \lambda$ if $q_i(P_1, \ldots, P_{i-1}) > 0$;

(c) $x_i = \Delta_i(P_1, \ldots, P_i)$.

Since the probability that market i opens depends only on prices in lower indexed markets, we can solve for the unique UST equilibrium in the following way. Since $q_1 = 1$, we set $P_1 = \lambda$ and compute $N_s^1(\lambda)$ and $\Delta_1(\lambda)$. We then compute the probability that market 2 will open: $q_2(\lambda) = \Sigma_{s=1}^{S} \Pi_s I[N_s^1(\lambda) > \Delta_1(\lambda)]$. If $q_2(\lambda) = 0$ then $q_i = \Delta_i = 0$ for all $i > 1$ and we are done. Otherwise, we choose: $P_2 = \lambda/q_2(\lambda)$ and compute $N_s^2[\lambda, \lambda/q(\lambda)]$, $\Delta_2[\lambda, \lambda/q(\lambda)]$. We then compute the probability that market 3 will open:
$q_3[\lambda, \lambda/q(\lambda)] = \Sigma_{s=1}^{S} \Pi_s I\{N_s^2[\lambda, \lambda/q(\lambda)] > \Delta_2[\lambda, \lambda/q(\lambda)]\}$. If $q_3[\lambda, \lambda/q(\lambda)] = 0$, we are done. Otherwise, we choose:
$P_3 = \lambda/q_3[\lambda, \lambda/q(\lambda)]$ and so on. Thus,

Proposition 4: There exists a unique UST spot markets equilibrium.

I now use the functions $q_i(P_1,...,P_{i-1})$ and $\Delta_i(P_1, ...,P_i)$ to discuss the choice of a monopoly and the choice of a social planner.

Monopoly: A monopolist who must satisfy demand sequentially, will choose the prices ($P_1 \leq P_2 ... \leq P_S$) to maximize the expected profits:

(36) $\Sigma_{i=1}^{S} [q_i(P_1,...,P_{i-1})][\Delta_i(P_1, ...,P_i)]P_i - \lambda\Sigma_{i=1}^{S} \Delta_i(P_1, ...,P_i)$.

Social planner: We start by computing the average valuations of buyers in batch i.

The fraction of type j buyers in all the buyers who want to buy in market i is:

(37) $$\alpha_{js}^{i}(P_1,...,P_i) = N_{js}^{i}(P_1,...,P_i)/N_{s}^{i}(P_1,...,P_i),$$

if $N_{s}^{i}(P_1,...,P_i) > 0$ and zero otherwise.

It is assumed that this is also the fraction of type j buyers who actually buy in market i. The average valuation of the buyers in batch i is therefore:

(38) $$V_i(P_1,...,P_i) = \Sigma_s \Pi_s \Sigma_j v_j\alpha_{js}^{i}(P_1,...,P_i).$$

The social planner chooses prices ($P_1 \leq P_2 ... \leq P_S$) to maximize the expected consumer surplus:

$$(39) \qquad \Sigma_{i=1}^{S} [q_i(P_1,...,P_{i-1})][\Delta_i(P_1, ...,P_i)][V_i(P_1, ...,P_i)]$$

$$- \lambda\Sigma_{i=1}^{S} \Delta_i(P_1, ...,P_i).$$

An allocation is sequential efficient if it solves (39). We already showed by example 2 that the UST allocation may not be efficient in the sequential sense and a monopoly may improve matters. In example 2 the UST competitive firm produces more than the monopoly. I now show by example that excess production is not the only reason for the inefficiency.

Example 3: As in example 2 there are two types and two states. But unlike example 2, type 1 buyers want to consume a unit if $p \le v_1 = 9$. Type 2 buyers want to consume a unit if $p \le v_2 = 7$ and $s = 2$.

The cost of production is 5 and therefore the UST prices remain the same as in the previous example: $P_1 = 5$ and $P_2 = 10$. As in the previous example, market 2 will open in state 2 but since $\Delta_2(5, 10) = 0$ it will not be active. In a UST equilibrium only n units are produced and allocated to market 1. The surplus is: $(9 - 5)n = 4n$ in state 1 and $[(1/2)(9 + 7) - 5]n = 3n$ in state 2. The average surplus is: $(3.5)n$.

A monopoly will choose $P_1 = 9$ guaranteeing a profit (surplus) of 4n.

In example 3 the monopoly and the competitive firm produce the same amount but the monopoly does a better job in allocating capacity to the buyers who value it the most.

Example 4: I now add to example 2, n type 3 agents who want to consume a unit if $p \leq 4$ and $s = 1$.

Adding the type 3 buyers will not change the UST equilibrium and the monopoly choice: production in the UST equilibrium is (1.5)n units and the monopoly will produce n units. But it will change the planner's choice. Now the planner can do better by producing two units and pricing them at $p \leq 4$.

When s = 1, type 1 and type 3 buyers will buy the good and the surplus will be (10 + 4 - 10)n = 4n. When s = 2, type 1 and type 2 will buy the good and the surplus will be (10 + 7 - 10)n = 7n. The average surplus is (5.5)n which is higher than the monopoly's profits.

In this example the UST firm is producing too little relative to the sequential efficient level: (1.5)n instead of 2n.

Examples 2 - 4 show:

Proposition 5: (a) The UST output may be either too high or too low relative to the sequential efficient level of output (b) The UST allocation may be inefficient in the sequential sense even if the amount produced coincide with the social optimum and (c) A monopoly may improve matters.

As was said before, Dana (1998) showed that the allocation in a Prescott type model may not be Walrasian efficient and attributes this result to the presence of price rigidity. Here there is no price rigidity. Furthermore, here I show that the allocation obtained in the UST model is not sequential efficient. Thus I apply a weaker efficiency criterion that takes into account the constraints that arise from sequential delivery.

4. SEQUENTIAL DELIVERY CONTRACTS

To better understand the reason for the market failure in the UST model I now allow for ex-ante contracts contingent on the type and the order of arrival.

As before, agents learn about their type at $t = 0$ and at $t = 1$ they learn about their desire to consume. But unlike the previous section, here buyers who want to consume form J separate lines: One line per type.

Contracts contingent on the type and the order of arrival are signed at $t = 0$ and are executed at $t = 1$. A type j buyer can enter a contract with the firm to buy a unit at the price p_i if he arrives in batch i. This contract is a commitment on both sides: The firm is committed to sell and the buyer is committed to buy if the buyer arrives in the specified batch.

To simplify, I assume: $0 = \phi_{j0} \le \phi_{j1} \le \phi_{j2} \le \ldots \le \phi_{jS}$ for all j. The $\phi_{js}n_j$ type j buyers who want to consume form a line and arrive at the market-place according to their place in the line. A type j buyer will enter a contract to buy at the price p_i if $v_j \ge p_i$. As before, I use: $x_{ji} = 1$ if $v_j \ge p_i$ and zero otherwise, to denote the demand per type j buyer in market i. It is assumed that $p_i \le p_{i+1}$ and therefore $x_{ji} = 0$ implies $x_{ji+1} = 0$. I also assume that there exists a type, say type 1, with a sufficiently high reservation price such that: $x_{1i} = 1$ for all i. Furthermore, it is assumed that for type 1 the number of buyers who want to consume is strictly increasing in the state:

$0 < \phi_{11} < \phi_{12} < \ldots < \phi_{1S}$.

The minimum number of type j buyers who are committed to buy in market 1 is $\Delta_{j1} = \phi_{j1} n_j x_{j1}$. After contracts in market 1 are executed there are $(\phi_{jS} - \phi_{j1}) n_j x_{j1}$ type j buyers who wanted to buy in market 1 but did not make it. A second batch of type j will arrive if $(\phi_{jS} - \phi_{j1}) n_j x_{j1} > \Delta_{j1}$. The minimum residual type j demand at the price p_2 is: $\Delta_{j2} = (\phi_{j2} - \phi_{j1}) n_j x_{j2}$ units and this is the size of the second batch of type j buyers. In general, market 2 opens with probability $q_i = \Sigma_{s=i}^{S} \Pi_s$ and the demand of type j buyers in market i if it opens is:

$$\Delta_{ji} = (\phi_{ji} - \phi_{ji-1}) n_j x_{ji}. \tag{40}$$

A firm that supplies a unit to market i will get the expected revenue $q_i p_i$ at the cost of λ. The firm will therefore supply any amount to market i if: $p_i = \lambda/q_i$.

<u>A sequential delivery contracts equilibrium</u> is a vector $\{x_{ji}, p_i, \Delta_{ji}\}$ such that:

(a) $p_i = \lambda/q_i$;

(b) $x_{ji} = 1$ if $v_j \geq p_i$ and zero otherwise;

(c) $\Delta_{ji} = (\phi_{ji} - \phi_{ji-1}) n_j x_{ji}$.

Substituting equilibrium condition (a) in (b) leads to the equilibrium allocation rule:

$$x_{ji} = 1 \text{ if } v_j \geq \lambda/q_i. \tag{41}$$

The planner's problem in this environment is:

(42) $$\max_{x_{ji}\in\{0\ 1\}} \Sigma_{j=1}^{J}\Sigma_{i=1}^{S} q_i(\phi_{ji} - \phi_{ji-1})n_j v_j x_{ji} - \lambda\Sigma_{i=1}^{S}\Sigma_{j=1}^{J} \Delta_{ji}$$

$$\text{s.t. } \Delta_{ji} = (\phi_{ji} - \phi_{ji-1})n_j x_{ji}.$$

If the planner chooses $x_{ji} = 1$ he will get $q_i(\phi_{ji} - \phi_{ji-1})n_j v_j$ at the cost of $\lambda(\phi_{ji} - \phi_{ji-1})n_j v_j$. He will therefore make this choice only if (43) is satisfied. We have thus shown that:

Proposition 6: The sequential delivery contracts equilibrium allocation (41) solves the planner's problem (42).

To illustrate I now reconsider example 2. In this example, there are two states of nature. Type 1 buyers always want to consume: $\phi_{11} = \phi_{12} = 1$. Type 2 buyers want to consume only in state 2: $\phi_{21} = 0$ and $\phi_{22} = 1$. Equilibrium prices are given by:
$p_1 = \lambda = 5$ and $p_2 = \lambda/q_2 = 2\lambda = 10$. Since $v_1 = 10$ and $v_2 = 7$, at these prices: $x_{11} = 1$ and $x_{22} = 0$. We can now apply (42) and calculate the demand per type in each market. This leads to: $\Delta_{11} = nx_{11} = n$; $\Delta_{12} = 0$; $\Delta_{21} = 0$; $\Delta_{22} = nx_{22} = 0$. Thus, when ex-ante contracts are allowed and it is possible to distinguish among types only type 1 buyers will enter into a commitment to buy. The amount produced is n and the total surplus is 5n.

In the absence of ex-ante contracts there is only one line and some type 2 buyers get serviced in state 2. We may therefore think of the inefficiency as the result of incomplete markets: We need SJ markets and in the UST spot market model there are only S markets.

I now turn to discuss the special case in which the consumption probabilities are the same across types ($\phi_{js} = \phi_s$ for all j).

Consumption probabilities are the same across types:

When ex-ante contracts are allowed we have J lines. In state s, line j consists of $\phi_{js}n_j$ buyers. When $x_{ji} = 1$, the percentage of line j buyers who make a buy in market i is: $(\phi_{ji} - \phi_{ji-1})/\phi_{js}$. To check this note that: $(\phi_{js}n_j)(\phi_j - \phi_{ji-1})/\phi_{js} = (\phi_j - \phi_{ji-1})n_j$.

Now in the UST spot markets mechanism there is one line with $\Sigma_{j=1}^{J} \phi_{js}n_j$ buyers. When $x_{ji} = 1$, the fraction of buyers that make a buy in market i is:

$(\Sigma_{j=1}^{J} \phi_{ji}n_j - \Sigma_{j=1}^{J} \phi_{ji-1}n_j)/\Sigma_{j=1}^{J} \phi_{js}n_j = \Sigma_{j=1}^{J} (\phi_{ji} - \phi_{ji-1})n_j/\Sigma_{j=1}^{J} \phi_{js}n_j$. This is a weighted average of the type specific fractions $(\phi_{ji} - \phi_{ji-1})/\phi_{js}$.

In the special case $\phi_{js} = \phi_s$ for all j the fraction of type j buyers that execute its contract in market i is

$(\phi_i - \phi_{i-1})\Sigma_{j=1}^{J} n_j/\phi_s\Sigma_{j=1}^{J} n_j = (\phi_i - \phi_{i-1})/\phi_s$ and this is exactly the fraction of type j agents which buy in market i when spot markets trade is done according to the UST model. Thus,

Proposition 7: When the consumption probabilities are the same across types ($\phi_{js} = \phi_s$ for all j), the UST spot markets trade can be viewed as the execution of sequential delivery contracts signed at t = 0.

This Proposition generalizes the claim in Eden (1990) to the case in which the reservation prices differ across types.

CONCLUDING REMARKS

Prices that do not behave according to the standard Walrasian model can arise even in the absence of costs for changing prices and do not always imply market failure.

In our airline example, delivery occurs simultaneously to all buyers. The airline can conduct an auction at the gate just before departure but it may be better to conduct a delegated auction in which the airlines collect information through travel agents that sell tickets to potential passengers. This delegated auction may achieve the same outcome as an auction at the gate but leads to observations about prices (paid at the execution stage of the contract) that were interpreted as evidence for price rigidity.

In a sequential delivery environment buyers get delivery when they arrive and do not wait until the uncertainty about demand is resolved. This may occur when it is too costly to gather all buyers at the same time and place. Since delivery occurs before the state is known we should apply a weaker less demanding efficiency criterion for this case.

It was shown that (a) the UST spot markets allocation is sequential efficient if the reservation prices or (and) the consumption probabilities are the same across types; (b) the amount produced by UST sellers may be either too low or too high relative to the social efficient level; (c) a monopoly may improve matters.

I also studied the relationship between the UST spot markets model and the Arrow-Debreu model. It was shown that in a sequential delivery environment ex-ante trade in contracts contingent on the type and the order of arrival (SJ commodities) leads to an efficient outcome. Since in the UST spot market model there are only S commodities, this suggests that the reason for the inefficiency in the UST spot markets model is in the incompleteness of markets. It is also shown that when the consumption probabilities are the same across types, it is enough to allow for contracts which are contingent only on the order of arrival (S commodities) and the UST spot markets allocation may be viewed as the execution of ex-ante contingent contracts.

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