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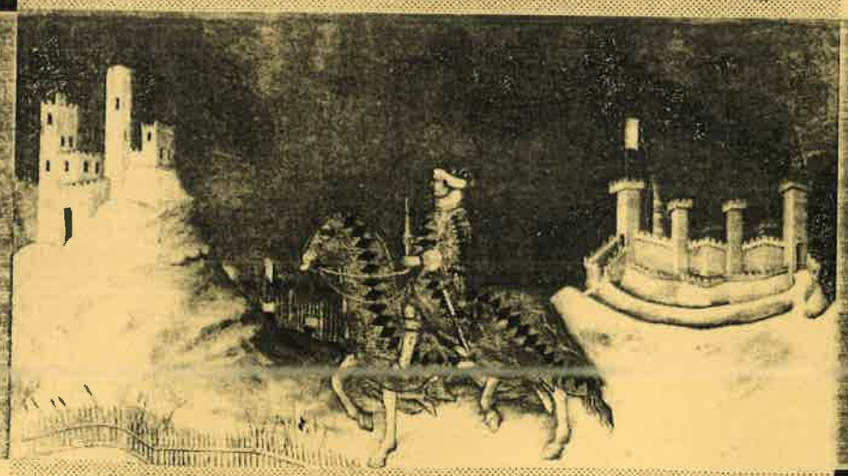
MASSIMO A. DE FRANCESCO

PRICE AND CAPACITY DETERMINATION UNDER UNCERTAIN DEMAND AND CUSTOMER MARKETS



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Massimo A. De Francesco

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Siena, marzo 1995

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Introduction *

It has long been recognized that the prices of industrial products are remarkably stable in the face of short-term fluctuations in demand. Theories of price determination in terms of full cost (R.L. Hall and C.J. Hitch, 1939) or normal cost (P.W. Andrews,1949) are among the earliest attempts to explain this price rigidity. However, these theories have often been criticized, among other things, for not providing a satisfactory determination of the mark-up. For instance, it has been observed that «[the various price formulas along full cost pricing] rely on a predetermined output volume that is left implicit and that none of the full-costers were able to explain» (P. Mongin, 1990-1991, p.236). On the other hand, the earliest proponents of these theories have offered an insight that might prove fruitful in searching for the mark-up, namely that price stability in itself is not inconsistent with free competition. For instance, Hall and Hitch concluded that the threat of entry is of key importance in preventing established firms from agreeing on prices above full cost:

> «If prices are in the neighbourhood of full cost, they are not raised by actual or tacit agreement because it is thought that, while this would pay in the short run, it would lead to an undermining of the firms by new entrants in the long run»(Hall and Hitch (1939, p.116)).

A similar idea of a competitive, although rigid, price will be developed below. The paper addresses the determination of productive capacity and price in an industry which faces a fluctuating demand in the short term. We shall assume that, while the price of output is not affected by short-term changes in capacity utilization, the price choice is made competitively by established firms and prospective entrants. Why competition takes place within

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this framework of price stability is not an issue that will be addressed here.[1]

The paper is organized as follows. Section 1 provides the building block for the analysis of price and capacity decisions of firms. This section is concerned with the organization of the market for a certain product. It is argued there that product homogeneity does not prevent the development of "customer relations" such that each firm is "assured" of the custom of a certain group of buyers. The size of this custom is shown to depend on the productive capacity of the firm, given the capacities of the other firms. Based on this result, we then turn to the issue of price and capacity determination. This analysis proceeds in two stages. In section 2 we assume that a unique price prevails in the output market and consider what level of capacity the industry tends to build up, at that price, as a result of competition among the firms through capacity creation. In section 3 we consider whether - starting from an arbitrary market price and the associated level of total capacity - the firm has an incentive to deviate from the market price. A particular industry configuration is then identified, which will tend to prevail in the long term. This configuration is characterized by a capacity sufficiently large to meet the most favourable levels of total demand which may occur and by a price such that expected costs for that capacity are just covered.

I - Customer markets

The model presented here addresses the two related issues of price and capacity determination for a one-commodity industry, with exogenously given input prices. Two major elements of the model

[1] A clue to the answer may be that producers benefit from price stability. Indeed, it is to be expected that the independent capacity decisions of firms in a certain industry will inevitably give rise to frequent imbalances between total capacity and demand. It has been argued that the associated fluctuations in profits are less under stable prices than under flexible prices (G.B. Richardson, 1965, 1967).

are irreversibility of investment and variability of demand. Irreversibility often arises because some of the capital employed is specific to the process of production of a particular commodity. Besides precluding a continuous adaptation of industry capacity to a fluctuating demand, specificity eliminates any incentive for the seller to dispose on the secondary market of the equipment temporarily idle. Because potential buyers of this capital goods face the same product demand conditions, such an operation is expected to bring no gain compared to accepting a temporary underutilization of capacity. Moreover, and perhaps because of specificity, there may not exist a developed secondary market on which one can expect to realize the true value of the capital sold. These two circumstances imply that capacity is chosen by the firm for a certain time horizon, involving periods of underutilization.

The product under consideration is assumed to be perfectly standardized across producers. A first question concerns the distribution of buyers among the different firms. We shall argue below that, in spite of product homogeneity, there is a clear case for stable relations to get established between buyers and sellers. Markets displaying this feature are here labelled "customer markets", borrowing Okun's expression. The notion of customer markets we propose is characterized by each buyer being committed to the seller he is currently purchasing from as long as there is no *strict* improvement to be achieved by diverting his custom to some other seller. Two important corollaries of this assumption must be noted. First, entry can only be successful if the potential entrant is able to offer to potential customers better conditions than they are facing at their current sellers. Second, once the custom of a buyer has been lost, it will not be regained by merely meeting the conditions offered by the competitor.

The notion of customer markets just discussed stands in sharp contrast with the view that has been held since the emergence of the theory of monopolistic competition. In fact, Chamberlin was quite explicit in regarding product differentiation as a prerequisite

for the market of a certain "product" to take the form of a network of related markets. In his words,

«[...] when products are differentiated, buyers are given a basis for preference, and will therefore be paired with sellers, not in a random fashion (as under pure competition), but according to these preferences. Under pure competition [a market structure «involving (1) a relatively large number of buyers and sellers of (2) a perfectly homogeneous product» (p.16)], the market of each seller is perfectly merged with those of his rivals; now it is to be recognized that each is in some measure isolated, so that the whole is not a single large market of many sellers, but a network of related markets, one for each seller.»(Chamberlin, 1962, p.69)

By contrast, our characterization of customer markets draws instead on the notion of goodwill advanced several decades ago by P.W. Andrews [P.W. Andrews (1949), H.R. Edwards (1951, 1953)] and further developed by G.B. Richardson (1960, 1965, 1967). Much textual evidence might be given for this claim. For instance, we may note that, exposing Andrews' theory of normal cost, Edwards states explicitly that even when «the products of a group of manufacturers are standardized in every relevant empirical respect[...] the general market is separated into the particular markets of the individual manufacturers in terms of stable goodwill relations»(Edwards, 1952, p.58). (Actually, this is a view that, according to Andrews (1951, p.151, goes back to Marshall.[2]) Reversibility of goodwill was also emphasized, as the factor which would prevent established firms from charging more than the normal cost («markets, once lost, may very well not come back for some considerable time, even if the price is lowered again» (Andrews, 1949, p.154).

[2] The following passage from *Industry and Trade* [quoted by Richardson (1960, p.63, n.1)] seems to lend support to Andrews' claim: «A producer, a wholesale dealer or a shopkeeper, who has built up a strong connection among purchasers of his goods, has a valuable property. He does not generally expect to get better prices from his clients than from others. But he expects to sell more easily to them because they know and trust him...»[Marshall, 1923, p.182]. The "other" buyers here referred to are to be understood as purchasing the same product as the firm under consideration is offering to its customers, so that this firm is prevented from receiving "better prices". The existence of customer relations, therefore, is here seen by Marshall as perfectly compatible with firms offering identical products.

For now we simply take as an assumption, to be justified later, the prevalence of customer markets as characterized above. The question to be addressed next is the determination of market shares, when productive capacities are given and all firms are charging the same price for their output. To deal with this issue we must first characterize industry demand. The specification adopted here captures the assumed demand variability in a simple way. Each buyer's demand (a time-rate, as we are working in continuous time) is assumed to be a continuous random variable with a time-invariant probability distribution. The market price is for simplicity assumed not to affect the quantity demanded at a certain point in time, at least within the range of prices being considered. Moreover, any portion of demand which is not met at any point in time is assumed to be lost (demand cannot be fulfilled with delay). The probability distribution of individual demand ($f(u)$) is taken to be the same for all the buyers. Actual demand itself (u) is taken to be the same for all the buyers at each point in time. It is assumed

$$\begin{aligned} f(u) &\geq 0 \qquad \text{for } u_m \leq u \leq u_M, \\ f(u) &= 0 \qquad \text{for } u < u_m \ , \ u > u_M, \end{aligned} \tag{1}$$

so that u_m and u_M represent the minimum and maximum level of individual demand, respectively. Assuming that there are B buyers, total demand is $U = Bu$ and ranges in the interval $\left[(U_m = Bu_m,\ U_M = Bu_M)\right]$ with probability distribution $\varphi(U) = (1/B) f(U/B)$.[3]

[3] Let x be a continuous random variable with probability distribution $f(x)$, and let $z = \phi(x)$ be a function of x with inverse $x = \phi^{-1}(z)$ differentiable with derivative $\dfrac{d\phi^{-1}(z)}{dz} \neq 0$ and continuous; then, it is known that z has probability distribution $\varphi(z) = \left|\dfrac{d\phi^{-1}(z)}{dz}\right| f\left[\phi^{-1}(z)\right]$(cf. A.M.Mood et al., 1974, p.200).

Let $\overline{Y}$ denote total industry capacity, defined as the time rate of output obtained under full utilization of the existing equipment. With $\overline{Y} < U_M$, the size of each firm's custom follows straightforwardly from the condition that buyers receive the same treatment at any firm. Indeed, with firms charging the same price, this condition obtains when firms are equally able to meet the demand of their customers, which in turn requires that total demand is allocated to firms in proportion to their capacities. More formally, let $\overline{Y}_i$ denote firm i's capacity, B_i the number of its customers, and $U_i = B_i u$ the demand addressed to the firm at a certain point in time. With $\overline{Y} < U_M$, U will sometimes exceed $\overline{Y}$. At any such date, for whatever allocation of buyers it will be $U_i > \overline{Y}_i$ for at least a fraction of firms. Suppose a very simple rationing scheme, according to which a customer's demand is either entirely unsatisfied or satisfied, with probabilities

$$\rho_i = \left(U_i - \overline{Y}_i\right) / U_i = 1 - \left(\overline{Y}_i / B_i u\right). \qquad (2)$$

and $1 - \rho_i = \overline{Y}_i / B_i u$, respectively.[4] (Alternatively, we might as well assume a uniform rationing scheme, in which case ρ_i would be the fraction of each buyer's demand that remains unsatisfied at firm i.) Equation (2) shows that ρ_i - henceforth, the risk of rationing - is directly related to the ratio between demand and the firm's capacity. There will be a uniform risk of rationing across the firms when for all firms we have

$$U_i = \lambda_i U, \qquad \text{where } \lambda_i = \overline{Y}_i / \overline{Y}, \qquad (3)$$

[4] To be accurate, if B_i is an integer - that is, if there are no buyers dividing their demand among more sellers - the probability of having one's demand *entirely* satisfied at a certain date is given by $\ddot{B}_i u / B_i u = \ddot{B}_i / B_i$, where $\ddot{B}_i$ is such that $\ddot{B}_i u \le \overline{Y}_i$ and $\left(\ddot{B}_i + 1\right)u > \overline{Y}_i$. This will generally somewhat less than $\overline{Y}_i / B_i u$.

which in turn involves each firm having attached $B_i = \lambda_i B$ customers.[5]

This condition must also hold if $\overline{Y} = U_M$, in such a case to ensure that all firms are able to meet the highest demand made by their customers. On the other hand, equation (3) need not hold if $\overline{Y} > U_M$. In such a case, for buyers to always receive equal treatment from whatever seller, what is required is that each firm's capacity is not less than the highest demand made by its customers. Clearly, other demand allocations exist, beyond that associated with (3), which meet this condition. How to choose within this set is a matter that we shall briefly discuss later.

When equation (3) holds (as it must, according to the argument set forth above, when $\overline{Y} \le U_M$) the probability distribution of demand for firm i will be given by

$$\psi(U_i) = (1/\lambda_i)\varphi(U_i/\lambda_i). \qquad (4)$$

With total demand allocated to firms in proportion to their capacities, there will be a uniform expected rate of capacity utilization. The proof is simple. Expected output for firm i is given by

$$E(Y_i) = \int_{U_m}^{\overline{Y}_i} U_i \frac{1}{\lambda_i}\varphi\left(\frac{U_i}{\lambda_i}\right)dU_i + \overline{Y}_i \int_{\overline{Y}_i}^{U_M} \frac{1}{\lambda_i}\varphi\left(\frac{U_i}{\lambda_i}\right)dU_i,$$

which, through variable substitution, can be written as

$$E(Y_i) = \lambda_i \int_{U_m}^{\overline{Y}} U\varphi(U)dU + \lambda_i \overline{Y} \int_{\overline{Y}}^{U_M} \varphi(U)dU = \lambda_i \left[\int_{U_m}^{\overline{Y}} U\varphi(U)dU + \overline{Y} \int_{\overline{Y}}^{U_M} \varphi(U)dU\right]. \qquad (5)$$

[5] Unless λ_i is an integer for each firm, absolute uniformity in the risk of rationing requires that some buyers divide their demand among more sellers. Assuming, as we shall do in the following, absolute uniformity implies that the inconvenience involved in not always relying on a unique seller is sufficiently small to be more than offset from the advantage of reducing one's own risk of rationing.

We see here that, given total capacity (and hence the expression in square bracket), expected output for the firm is proportional to the ratio between its own capacity and total capacity. From (5) there follows

$$\frac{E(Y_i)}{\overline{Y}_i} = \frac{E(Y_i)}{\lambda_i \overline{Y}} = \frac{1}{\overline{Y}} \int_{U_m}^{\overline{Y}} U\varphi(U)dU + \int_{\overline{Y}}^{U_M} \varphi(U)dU = \frac{E(Y)}{\overline{Y}}, \qquad (6)$$

that is, a uniform expected rate of capacity utilization.

Notice the relevance of these results for the analysis of competition. As long as $\overline{Y} < U_M$, by increasing its capacity a firm will raise its expected output *at the expense* of rivals. This is quite apparent from (3), seen from the point of view of rivals: the *level* of demand addressed to any such firm at a certain date - and hence, the size of its custom - declines as its share of total capacity declines. The reason is straighforward. By increasing capacity a firm will in the first place benefit its current customers, for the risk of rationing they incur at times of high demand will be reduced. But this means that, if the initial allocation of total demand were the equilibrium one, these customers will now be better off than the other buyers. Any such buyer has thus an incentive to turn his custom to the firm whose capacity has risen, and, in what follows, we assume enough information for a uniform risk of rationing tending to prevail across firms.

By now it should also be clear that, if $\overline{Y} \geq U_M$ (in which case no rationing does ever occur at any seller), the firm would be unable to increase its market share by merely enlarging its capacity. Since in that case a buyer would gain nothing from turning his custom to the firm whose capacity has risen, he would, under customer markets, remain loyal to his current seller.

Finally, turn back to our assumption of customer markets. Its reasonableness is easily assessed when compared with the polar situation in which, at each time, buyers pick sellers at random. Such a random pairing results in increased variability of demand at the firm's level, which involves several costs. First, even if at a certain

extent as to lower its expected utilization to $E(U)/U_M$. To be specific, suppose productive capacity has remained unchanged at the firm under concern, although this is not strictly necessary for the argument being made. (In particular, the firm might increase its capacity at the same time that it raises the price.) One can easily check that the customers retained by the firm - whose demand would now be entirely met at any time - would be in a *better* position than other buyers. Indeed, the condition of the former would have improved as if the industry configuration had moved from $\left(p_{(\tau-1)} < p^*, \overline{Y}_{(\tau-1)} = \overline{Y}_{|E(\Pi)=0}\right)$ to $\left(p = p^*, \overline{Y} = U_M\right)$, whereas the condition of the latter would have worsen as if the industry configuration had changed to $\left(p_{(\tau-1)}, \overline{Y} < \overline{Y}_{|E(\Pi)=0}\right)$.[16] Therefore, the reduction in market share for the firm under concern cannot go so far, which means that the firm's expected profit will rise above zero.

Based on this result, one can imagine a variety of paths along which the industry configuration will tend towards $\left(p = p^*, \overline{Y} = U_M\right)$. For instance, all established firms might raise their price to p^*. They will thus gain positive profits as long as $\overline{Y} < U_M$, which in turn will invite new entrants until $\overline{Y}$ becomes equal to U_M.

IV- Some final remarks

In this paper we have developed a theoretical framework for the analysis of price and capacity determination, starting from the assumption that the price of output remains stable in the face of short-term fluctuations in capacity utilization. Free entry has been shown as reasonably tending to eliminate pure profits, in the sense that price and expected unit cost are brought into equality with each other. More specifically, under the particular assumptions adopted as to the demand conditions, the industry configuration $(p, \overline{Y})$ has been seen as tending to (p^*, U_M). The price tends thus to

16 Because of the increased custom of the other firms, the risk of rationing faced here at times of high demand has increased. Therefore, at these firms things are as if there had been a decrease in total capacity with all firms still charging the initial price.

the expected unit cost associated to an amount of total capacity equal to the highest demand. This expected unit cost can be referred to as the "normal cost of production", being the unit cost a firm must expect to sustain, on average over time, due to the fluctuations of demand.

Of course, the quantitative predictions obtained - the exact levels of total capacity and expected unit cost - depend on assumptions that might be questioned on grounds of realism. For instance, demand was taken as completely price-insensitive, whereas in many cases it is better to allow for a certain sensitivity. Moreover, no delays in delivery were allowed for. In this regard, it may be expected that, once the possibility of meeting demand with delay is introduced into the model, a normal industry configuration is likely to entail a level of capacity somewhat less than the highest demand. Indeed, it seems reasonable that buyers to some extent prefer a lenghtening in delivery terms at a time of high demand rather than paying the high expected costs incurred by firms if they were required to meet the highest demand without any delay.

One must distinguish, however, assumptions which have been made for the sake of simplicity from the basic premises of the model, namely the notion of customer markets and the dependence of market shares on productive capacities. These two circumstances have actually played a prominent role in the analysis of the competitive process. Think, for instance, of reversibility of goodwill. This turns out to be a sort of discipline device, which prevents established firms from charging more than the normal cost. Indeed, new firms will otherwise be invited in the market, for they will be able to cover expected costs even later, when their price will presumably be matched by established firms. Demand allocation in proportion to productive capacities has also proved central to the competitive process. Furthermore, it must be noted that allowing for delays in delivery does not weaken the necessity of such a condition in order for buyers to receive equal treatment from whatever firm in a situation in which prices have settled at a uniform level.

relationship depends, among other things, upon the relationship between $E(Y)$ and $\overline{Y}$:

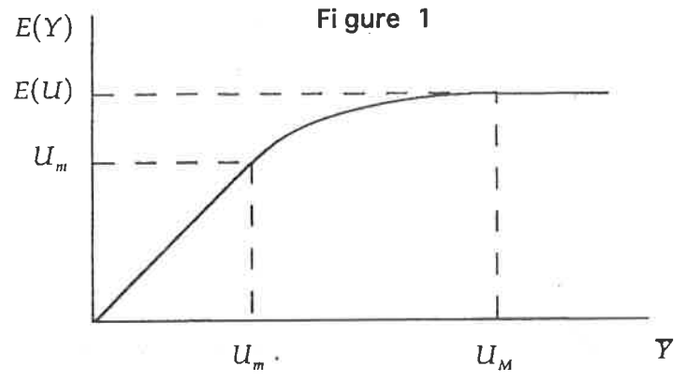
$$E(Y) = \int_{U_m}^{\overline{Y}} U\varphi(U)dU + \overline{Y}\int_{\overline{Y}}^{U_M} \varphi(U)dU. \qquad (10)$$

Differentiation of (10) gives

$$\partial E(Y) / \partial \overline{Y} = \int_{\overline{Y}}^{U_M} \varphi(U)dU, \qquad (11)$$

In plain terms, the rate of change of expected output is equal to the probability of full utilization of existing capacity, which is nothing but the probability that demand exceeds capacity. From equation (10) we can see that $E(Y)=\overline{Y}$ for $\overline{Y} \le U_m$, whereas $E(Y)=E(U)$ for $\overline{Y} \ge U_M$. For $U_m < \overline{Y} < U_M$, $E(Y)$ increases at a diminishing rate as $\overline{Y}$ increases, as shown by equation (11). This gives rise to a curve like that in figure 1.[6]

Figure 1



We can now turn to the behaviour of $E(\Pi)$. $E(\Pi)$ is equal to expected "quasi-rents", $E(QR)=(p-wg)E(Y)$, minus capital costs, $CC=\mu\overline{Y}$. The $E(QR)$ curve (figure 2) has obviously the same shape as the $E(Y)$ curve. If $p-wg>\mu$, the straight section of the $E(QR)$ curve lies above

6 The $E(Y)$ curve has been drawn under the assumption that $f(u)>0$ for any $u_m < u < u_M$, which is more than was assumed above (cf. (1)). Allowing for the possibility of straight sections of the $E(Y)$ curve for some $\overline{Y} \in (U_m, U_M)$ would not affect the results, however.

the CC curve. This being so, $E(\Pi)$ (the vertical distance between the $E(QR)$ and $\mu\overline{Y}$ curves) first increases with total capacity and then decreases, to fall below zero on the left of the intersection point of the two curves. Let $\overline{Y}^{\circ}$ denote the level of capacity such that $E(\Pi)$ is maximized. $\overline{Y}^{\circ}$ is found by imposing $\partial E(\Pi)/\partial\overline{Y}=0$, which gives

$$(p-wg)\int_{\overline{Y}}^{U_M}\varphi(U)dU=\mu. \qquad (12)$$

The left-hand side of (12) is the rate of change of $E(QR)$, whereas the right-hand side is the rate of change of capital costs: of course, as long as the former exceeds the latter, $E(\Pi)$ increases with increases in $\overline{Y}$.

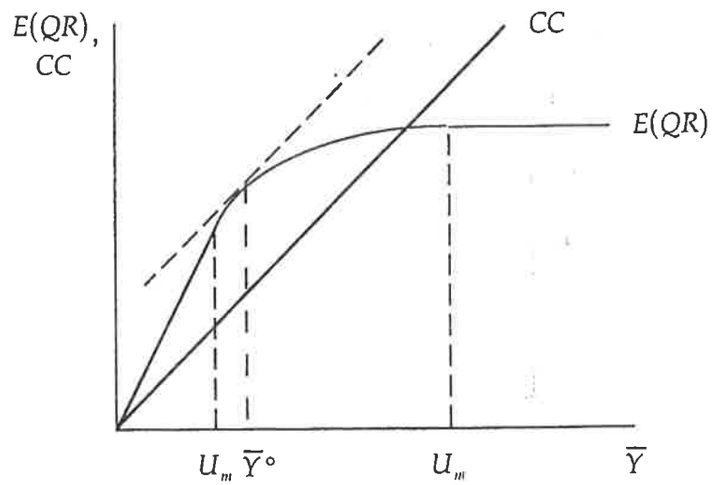


Figure 2

It has been argued [Nickell (1978), Malinvaud (1987, 1989)][7] that it is actually a condition such as (12) that determines total capacity. Such a result has been achieved by taking the probability distribution of demand for the "representative firm" as given independently of the capacity it may choose. However, as (3') or (4)

7 For a more through discussion of Malinvaud's model cf. M.A. De Francesco (1991).

determination, thereby completing the analysis of capacity determination itself. In pursuing this task we proceed as follows. First, the market price is assumed to have remained unchanged for a period of time sufficiently long so as to give rise to the associated level of total capacity. Firms (possibly a prospective entrant) are next given the opportunity to deviate from the current price, so that we see whether the assumed price is likely to persist in the future.

A buyer is reasonably willing to pay something more if this involves a lower risk of rationing at times of high demand. In this respect, we shall here assume that, with a market price $p\in[wg+\mu,\ p^*]$, the buyer will always perceive his position as improving when p increases and $\overline{Y}=\overline{Y}_{|E(\Pi)=0}$ correspondingly increases. This assumption, which I readily aknowledge may be very far from reality, is only made for analytical simplicity.[11] Under such an assumption, it turns out that, within the set of $(p,\overline{Y})$ vectors satisfying (17), the well-being of buyers is maximized at $(p=p^*,\overline{Y}=U_M)$. We are going to argue that other industry configurations can hardly persist.

In what follows the price decision is assumed to be made independently and simultaneously by the firms for discrete intervals of time. To start with, suppose that firms have long been charging a price $p_{(\tau-1)}\geq p^*$ so that, by (17), total capacity can be taken to be $\overline{Y}_{(\tau-1)}=U_M$ at the end of period $\tau-1$. We then allow for price competition among the firms. Consider the decision problem facing a potential entrant. He might contemplate charging less than $p_{(\tau-1)}$ to make his way in the market. The perceived consequences

11 Let $\varphi(U)$ be such that there is a small probability of demand taking on values in a certain interval $[\hat{U},U_M]$, with $\hat{U}$ not too far from U_M. With total capacity equal to $\hat{U}$, demand will be almost entirely satisfied, on average over time. On the other hand, increasing total capacity up to U_M may well require a not negligible price increase, under the $E(\Pi)=0$ condition. Therefore, it seems reasonable that to the buyers the slight improvement in terms of satisfaction of demand is worth less than the required price increase.

depend, of course, on how established firms are believed to react. In this respect it is assumed, in the first place, that one period of time must elapse before any reaction is made. The potential entrant may thus be confident that at τ the established firms are still quoting $p_{(\tau-1)}$. As for the subsequent reaction, the potential entrant is assumed to believe that his present undercutting of the market price will subsequently be matched.

The price considered for entry is taken to be equal to p^* if $p_{(\tau-1)} > p^*$, and slightly less than p^* if $p_{(\tau-1)} = p^*$. Expected utilization for the entrant will exceed $E(U)/U_M$ as long as his lower price is not matched by established firms. Indeed, no informed buyer would miss the opportunity to save money which is allowed by any spare capacity available at the cheapest seller. Total capacity of established firms being equal to U_M, a buyer could always resort to them (in particular, to his usual seller) whenever he found a capacity shortage at the new entrant. To fix ideas, one can imagine the new entrant as raising as many stable customers as he can assure continuous full satisfaction of their demand. Denoting by B_i the number of such stable customers, it will then be $B_i u_M = \overline{Y}_i$, where $\overline{Y}_i$ denotes the new entrant's capacity. Therefore, B_i accounts for an expected utilization equal to $E(U)/U_M$.[12] Whenever $u < u_M$, the margin of capacity still available after demand by stable customers has been met will be taken advantage of by "occasional" buyers.

Therefore, entry looks promising, as far as the near future is concerned. Turning now to the longer-term prospects, under the

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[12] Let $\tilde{U}_i$ denote the demand by the B_i buyers who have permanently turned their custom to the new entrant. This demand can be written as $\tilde{U}_i = B_i u = \left(\overline{Y}_i / U_M\right)U$, as $B_i = \overline{Y}_i / u_M$ and $u = U/B$. If there were no other buyers ever addressing their demand to the new entrant, output for the new entrant would always be equal to the demand coming from this stable clientele, that is, $Y_i = \tilde{U}_i = \left(\overline{Y}_i / U_M\right)U$. Expected output would be equal to $E(Y_i) = E\left(\tilde{U}_i\right) = \left(\overline{Y}_i / U_M\right)E(U)$ and expected utilization would thus be equal to $E(Y_i)/\overline{Y}_i = E(U)/U_M$.

$\overline{Y}_{|E(\Pi)=0} < U_M$), total capacity increases as p increases. For $p = p^*$, the industry builds up a level of capacity equal to U_M. Then one can ask: what would happen for $p > p^*$? At such prices $\overline{Y}_{|E(\Pi)=0} > U_M$. However, although $E\left(\Pi_{|\overline{Y}=U_M}\right) > 0$, $\overline{Y}$ would not increase above U_M. In fact, when $\overline{Y} = U_M$, a potential entrant has no hope of attracting buyers away from established firms, for he is unable to offer better prospects in terms of risk of rationing when such a risk has already disappeared from the industry. An important result has thus emerged: competition through capacity creation alone leads to the disappearance of pure profits only in so far as $p \le p^*$. To sum up, given p, total capacity is determined by either of the following two conditions:

$$\begin{aligned} &\overline{Y} = \overline{Y}_{|E(\Pi)=0} \quad \text{if } p \le p^*, \\ &\overline{Y} = U_M \quad \text{if } p \ge p^*. \end{aligned} \tag{17}$$

Before closing this section, we want to briefly discuss the issue of industry structure - the number and size of firms. From the model developed so far one might be led to argue that the only sustainable structure is one with an infinitely large number of infinitely small firms. The argument would be a dynamic extension of the one set forth to illustrate proposition (ii) on p.15. Suppose that, at a certain date, $\overline{Y} = \overline{Y}_{|E(\Pi)=0}$. Now consider a firm that is about to replace its equipment and can therefore reduce its capacity without incurring the costs arising from investment irreversibility. Given the productive capacities of the other firms, a reduction of capacity by this firm would make total capacity diminish and hence $E(\Pi)$ increase above zero (see figure 2). Therefore, there seems to be an incentive for each firm to reduce (to some extent) capacity when replacing the equipment. The subsequent appearance of profits in the industry would then invite new firms to enter the market, which again would make total capacity increase towards $\overline{Y}_{|E(\Pi)=0}$. These two forces seem thus to suggest that, in the very long

term, there is a tendency for each firm's size to become negligible and for the number of firms to increase indefinitely.

At this point, however, one might wonder whether important forces have been overlooked, which would prevent this counterfactual tendency from taking place. The first thing which perhaps may come to mind is technical indivisibility, and hence the existence of a minimum size of equipment. Obviously, the process described above could not proceed any further once that minimum size was achieved.

But one might wish to go even further than is allowed by only taking into account indivisibility. For instance, one might wish to explain the fact that in real-world industries there are often firms of various size. In this regard, one point must be preliminarily noted. Suppose that, at a certain point in time, there are quite a large number of firms, with a total capacity equal to $\overline{Y}_{|E(\Pi)=0}$. Then, the profit supposedly to be made by a firm which reduces its capacity would be very small, since even a large reduction would have a little impact on total capacity, thus involving only a slight increase in expected utilization. Even small costs involved in a downward adjustment of capacity may then be enough for the change in question to become unprofitable. We are thus led to conclude that, in the presence of such adjustment costs, the number and size of firms at a certain date have much to do with history, that is, with how the different firms have performed in the competitive process which has occurred up to that time. This means that it is very important, among other things, whether past opportunities for profitable expansion were seized by new entrants or already established firms.

III - Price and capacity determination

So far we have seen how industry capacity depends, given the demand conditions, on the price one assumes to prevail in the output market. The stage is now set to address the issue of price

(i) At $\hat{\overline{Y}}$, if any, it must be $(p-wg)\int_{\overline{Y}}^{U_M}\varphi(U)dU<\mu$. Therefore, $\hat{\overline{Y}}>\overline{Y}^{\circ}$.[9]

(ii) At $\hat{\overline{Y}}$, if any, $E(\Pi)$ - the numerator on the right-hand side of (16) - must be greater than zero for any finite F, while tending to zero as F becomes infinitely large. The existence of profits at equilibrium is easily understood. Suppose firm i expects $\sum_{j\neq i}\overline{Y}_j<\overline{Y}_{|E(\Pi)=0}$. It will then choose a capacity that is lower than that which would make total capacity amount to $\overline{Y}_{|E(\Pi)=0}$. Indeed, $E(\Pi)$ will thus be greater than zero (see figure 2), which in turn involves, by uniformity of expected utilization, positive expected profits for all firms, firm i included.

From (i) and (ii) it follows that $\hat{\overline{Y}}$ must be searched in the range $\left(\overline{Y}^{\circ},\overline{Y}_{|E(\Pi)=0}\right)$, with $\overline{Y}_{|E(\Pi)=0}\leq U_M$ as $p\leq p^*$. Therefore, it was justified to rely on $E(Y_i)/\overline{Y}_i$ being uniform across the different firms.

(iii) There always exists a unique $\hat{\overline{Y}}$. (Proof in Appendix, **A.1.**) Therefore, there always exist a unique equilibrium in capacity strategies, represented by the choice of the unique $\hat{\overline{Y}}/F$ by each firm.

(iv) $\hat{\overline{Y}}$ is increasing in F. (Proof in Appendix, **A.2.**)[10]

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9 That one cannot have $\overline{Y}\leq\overline{Y}^{\circ}$ at equilibrium, can be understood as follows. One can check that at any such levels of total capacity $\partial E(\Pi_i)/\partial\overline{Y}_i>0$. This implies that if firm i expects $\sum_{j\neq i}\overline{Y}_j\leq\overline{Y}^{\circ}$ its capacity choice will be such that $\overline{Y}=\overline{Y}_i+\sum_{j\neq i}\overline{Y}_j>\overline{Y}^{\circ}$.

10 This result can be understood more intuitively as follows. From $\frac{\partial E(\Pi_i)}{\partial\overline{Y}_i}=\left[(p-wg)\left(E(Y)/\overline{Y}\right)-\mu\right]+(p-wg)\overline{Y}_i\left[\partial\left(E(Y)/\overline{Y}\right)/\partial\overline{Y}\right]$, the change in $E(\Pi_i)$ brought about by a change in $\overline{Y}_i$ can be viewed as the sum of two terms. On the one hand, as $\overline{Y}_i$ increases there would be a proportional increase in $E(\Pi_i)$ if one neglected the associated reduction in $E(Y)/\overline{Y}$. On

(v) $E(\Pi)_{|\overline{Y}=\hat{\overline{Y}}}$ is decreasing in F. This follows straightforwardly from properties (i) - implying that $E(\Pi)$ decreases with increases in $\hat{\overline{Y}}$ - and (iv).

(vi) $\hat{\overline{Y}}$ is increasing in p, and decreasing in w and μ. (Proof in Appendix, **A.3.**)

Free entry

We turn now to the case of free entry, by far the relevant one for most industries. It may be worth to recall that the prospects of entry are here evaluated under the assumption that the entrant quotes the same price as established firms. Suppose $\overline{Y} < U_M$ and $E(\Pi) > 0$ at some date. Entry is then encouraged. Indeed, the prospect of reducing the risk of rationing will make buyers switch their custom to a new entrant until his expected utilization will have risen to the level prevailing elsewhere. But this means that for a new entrant expected profit is positive when it is so for established firms, as can be seen from equation (8). Under free entry total capacity tends thus to be such that $E(\Pi) = 0$, provided, as we shall see below, $\overline{Y}_{|E(\Pi)=0} \leq U_M$.

It is now easy to see how total capacity is affected by changes in output price. A higher p shifts the $E(QR)$ curve upwards in figure 2, thus increasing $\overline{Y}_{|E(\Pi)=0}$. Therefore, as long as $p < p^*$ (so that

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the other hand, the reduction in $E(Y)/\overline{Y}$ leads to a decrease in expected output, and hence in expected quasi-rents, on the initial capacity - a reduction which is the greater as the firm's capacity is the higher. Now, let $\hat{\overline{Y}}'$ be the Nash-equilibrium level of total capacity with F' firms, so that $\partial E(\Pi_i)/\partial \overline{Y}_i = 0$ when each firm's capacity is $\overline{Y}_i = \hat{\overline{Y}}'/F'$. It is then easy to understand that, with $F'' > F'$ firms, it must be $\hat{\overline{Y}}'' > \hat{\overline{Y}}'$. Indeed, let total capacity be unchanged at $\hat{\overline{Y}}'$, and evenly distributed among the firms (as required in equilibrium). Then, $\partial E(\Pi_i)/\partial \overline{Y}_i > 0$ (the only change in the equation above being the decrease of $\overline{Y}_i$), and the same would be true, *a fortiori*, if total capacity fell below $\hat{\overline{Y}}'$.

make clear, the demand prospects facing the firm do depend on its relative capacity. When this is taken account of, it can be shown that capacity creation by prospective entrants lead to the disappearance of pure profits, provided the (for now, given) market price lies within a certain range. Before seeing the implications of entry, however, let us consider a setting with a fixed number of firms.

A fixed number of firms

A simple game structure is here developed for the case in which the capacity decision is made simultaneously by firms and once and for all until the end of the equipment lifetime. A Nash equilibrium is a combination of capacity choices such that each firm maximizes its expected profit given the capacity choice of the other firms. Let p^* be the price such that expected profit is zero at a level of total capacity equal to the highest demand. This price is found by imposing $E(\Pi)_{|\overline{Y}=U_M} = 0$, which by Equation (9) gives

$$p^* = wg + \mu \frac{U_M}{E(U)}. \tag{13}$$

Things are made simpler if in the following the given market price is assumed to be $p \leq p^*$. As we shall see later, this implies that, at equilibrium, $\overline{Y} < U_M$, so that $E(Y_i)/\overline{Y}_i$ can be taken as uniform across firms. By substituting (6) into (8), $E(\Pi_i)$ can thus be written as

$$E(\Pi_i) = \left\{ (p - wg) \left[\frac{1}{\overline{Y}} \int_{U_m}^{\overline{Y}} U\varphi(U)dU + \int_{\overline{Y}}^{U_M} \varphi(U)dU \right] - \mu \right\} \overline{Y}_i \tag{14}$$

Let F be the fixed number of firms. One can check that, given $\sum_{j \neq i} \overline{Y}_j$, $E(\Pi_i)$ is a continuous and twice-differentiable function of $\overline{Y}_i$, with $\partial E(\Pi_i)/\partial \overline{Y}_i$ given by

$$\frac{\partial E(\Pi_i)}{\partial \overline{Y}_i}=\left\{(p-wg)\left[\frac{1}{\overline{Y}}\int_{U_m}^{\overline{Y}} U\varphi(U)dU+\int_{\overline{Y}}^{U_M}\varphi(U)dU\right]-\mu\right\}$$

$$-(p-wg)\frac{\overline{Y}_i}{\overline{Y}}\left(\frac{\int_{U_m}^{\overline{Y}} U\varphi(U)dU}{\overline{Y}}\right)$$

and $\partial^2 E(\Pi_i)/\partial \overline{Y}_i^2<0$ for $\overline{Y}>U_m$.[8] Therefore, provided it is profitable for firm i to install, given $\overline{Y}_{-i}$, any capacity at all, $E(\Pi_i)$ is maximized at $\overline{Y}_i$ such that $\partial E(\Pi_i)/\partial \overline{Y}_i=0$, a condition that gives

$$\frac{\overline{Y}_i}{\overline{Y}}=\frac{(p-wg)\left[\int_{U_m}^{\overline{Y}} U\varphi(U)dU+\overline{Y}\int_{\overline{Y}}^{U_M}\varphi(U)dU\right]-\mu\overline{Y}}{(p-wg)\int_{U_m}^{\overline{Y}} U\varphi(U)dU}. \qquad (15)$$

Each firm thus accounts for the same share of total capacity in equilibrium (simmetry of Nash equilibrium). At a Nash equilibrium it must therefore be

$$\frac{1}{F}=\frac{(p-wg)\left[\int_{U_m}^{\overline{Y}} U\varphi(U)dU+\overline{Y}\int_{\overline{Y}}^{U_M}\varphi(U)dU\right]-\mu\overline{Y}}{(p-wg)\int_{U_m}^{\overline{Y}} U\varphi(U)dU} \qquad (16)$$

Let $\hat{\overline{Y}}$ denote any solution to (16). $\hat{\overline{Y}}$ thus represents total capacity at a Nash equilibrium. Here we are interested in the case $F>1$. (Obviously, with $F=1$, (16) reduces to (12), and hence $\hat{\overline{Y}}=\overline{Y}^{\circ}$.) The following properties are established:

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8 $\partial^2 E(\Pi_i)/\partial \overline{Y}_i^2=-(p-wg)\left\{\frac{2}{\overline{Y}^2}\left(1-\frac{\overline{Y}_i}{\overline{Y}}\right)\int_{''}^{\overline{Y}} U\varphi(U)dU+\frac{\overline{Y}_i}{\overline{Y}}\varphi(\overline{Y})\right\}$.

beliefs assumed above they are favourable or not, on the whole, depending on whether it was $p_{(\tau-1)}>p^*$ or $p_{(\tau-1)}=p^*$, respectively.

Consider first the case $p_{(\tau-1)}>p^*$. It can be seen that, as soon as the market price falls to the price p^* quoted by the new entrant, expected profit for the latter falls to zero thereafter, so that entry is profitable on the whole. On the one hand, it is true that, given the capacity of the established firms, entry makes total capacity increase above U_M, and significantly so if the capacity added by a new entrant is not negligible and/or several firms have entered the market at time τ. As a result, for the industry as a whole expected utilization becomes less than $E(U)/U_M$ and hence $E(\Pi)$ falls below zero. On the other hand, it must be recalled that a buyer is assumed to be committed to his current seller when other sellers offer no strictly better conditions. Therefore, it is only the entrant's occasional buyers who are expected to quit.[13] As for the stable customers the entrant has built up (accounting for an expected utilization equal to $E(U)/U_M$), there is no advantage for them to quit, as they can still rely on their demand being always met. As a result, expected profit for the entrant becomes zero rather than negative. Thus, the penalty for the excess of industry capacity resulting from entry falls entirely on established firms, which will then be forced to reduce their capacity.

Consider now the case $p_{(\tau-1)}=p^*$. By the same reasoning it is clear that, as soon as the price differential has disappeared, expected profit for the entrant becomes negative - the price being less than p^* and expected utilization being equal to $E(U)/U_M$. This should advice a potential entrant to stay out.[14]

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13 It is implicitly assumed that there is an inconvenience, however small (cf.n.5, p.7, above) in not relying continuously on a unique seller over time.

14 One may wonder, however, whether a potential entrant might not contemplate undercutting repeatedly the market price. This would allow full utilization of his capacity and hence yield positive profits even in later periods (as long as the market price has not fallen to $wg+\mu$, in which case losses would be incurred even at full capacity). Such an option is discarded if it is feared that his repeated undercutting of the market price will sooner or later be emulated. Once each seller tries to underbid competitors, no one can be confident that his attempts will be persistently successful.

We shall now discuss heuristically the reasonableness of the prospective entrant's belief that the price considered for entry will subsequently be matched. One alternative for established firms is to remain passive. This would probably invite new entrants in the subsequent periods, for the same lack of reaction might then be viewed as likely to persist in the next future. Further entry would thus take place, and an increasing fraction of demand would be met by new entrants. More realistically, established firms will come to realize what is going on well before being entirely or largely displaced.

On the opposite, established firms might contemplate retaliation. Consider the case $p_{(\tau-1)} > p^*$. Established firms may have agreed to punish the entrant, by charging some price less than p^* for so many periods as to make entry unprofitable on the whole. Lack of space here prevents us from tackling this issue adequately. It seems to be the case, however, that a reaction strong enough to leave no profits to the entrant would make established firms themselves worse-off than if they simply matched the entrant's price. If this is true, the incumbents are probably afraid of making agreements like that.[15]

So far, we have seen how the market price would fall if it were initially higher than p^*. Let us now start with an industry configuration $\left(p_{(\tau-1)} < p^*, \overline{Y}_{(\tau-1)} = \overline{Y}_{|E(\Pi)=0}\right)$. It must be recalled that, with $p \in [wg + \mu, p^*]$, buyers are assumed as perceiving an improvement in their condition when $\left(p, \overline{Y} = \overline{Y}_{|E(\Pi)=0}\right)$ increases. A firm might then consider raising its price, for instance, just to p^*. We want to show that this move will be strictly profitable even if competitors leave their price unchanged. Indeed, consider the situation in which expected profit remains equal to zero for the firm under concern. For this to be so, the market share of this firm should fall to such an

15. Suppose the actions prescribed by the agreement are part of a perfect equilibrium. Each firm will thus find to be in its own interest to conform to the prescriptions if other firms are expected to conform. The agreement thus creates an individual incentive to act in a way that, we claim, will make all firms worse-off than if the entrant's price had been matched.

time total demand did not exceed total capacity, each buyer would risk finding a capacity shortage at the randomly chosen seller, with the subsequent inconvenience of having to look elsewhere immediately after in order for his demand to be satisfied. Second, investment becomes more risky, so that, with risk-averse firms, expected costs are higher than if each seller could instead rely on a stable body of customers. Third, it is reasonable that, in the face of higher fluctuations in their current production, firms make more frequent recourse to overtime work and, perhaps, engage more heavily in "labour hoarding", which again leads to higher expected costs.

Given this inefficiency of random pairing, it is quite easy to imagine how this mode, should it ever exist, would evolve towards the system of customer markets. Of course, each seller would prefer raising a stable body of customers, for his expected unit costs would then be lowered. What is most important, this may be achieved by simply announcing that regular customers will be given the precedence whenever demand will press on capacity. As Richardson put it, «Sellers will be able in time of shortage to give preferential treatment to particular buyers, and they may use this power to induce loyalty from their customers in normal times»(Richardson, 1960, p.64).

II - Capacity determination

We assume that industry output is produced, under constant returns to scale, by means of fixed proportions of labour and a fixed capital good. The efficiency of the capital good remains unchanged over its physical lifetime. We have argued above that risk aversion and costly adaptability of the labour input in the short term may help explain the emergence of customer markets. In what follows, however, things will be made simpler by assuming risk-neutral firms as well as a costless adjustment of labour. Let p denote the nominal price of output, w the nominal wage rate, δ the

(instantaneous) nominal interest rate, k and g the given capital-capacity and labour-output ratios, respectively, p_k the price of one unit of the fixed capital good, T its physical lifetime, K_i firm i's capital stock, and Y_i its time rate of output. Firm i's pure profit (from now on, "profit") per unit of time can then be written as

$$\Pi_i = pY_i - wgY_i - \frac{\delta e^{\delta T}}{e^{\delta T}-1}p_k K_i = (p-wg)Y_i - \frac{\delta e^{\delta T}}{e^{\delta T}-1}p_k k\overline{Y}_i$$
$$= \left[(p-wg)\frac{Y_i}{\overline{Y}_i} - \frac{\delta e^{\delta T}}{e^{\delta T}-1}p_k k\right]\overline{Y}_i, \qquad (7)$$

where $(p-wg)$ is what can be called "quasi-rents" per unit of output and $\left[\delta e^{\delta T}/\left(e^{\delta T}-1\right)\right]p_k k$ is the capital cost (interests plus amortization) incurred in the unit of time per unit of productive capacity. Y_i being the only random variable in (7), expected profit can then be written as

$$E(\Pi_i) = \left[(p-wg)\frac{E(Y_i)}{\overline{Y}_i} - \mu\right]\overline{Y}_i, \qquad (8)$$

where $\mu = \left[\delta e^{\delta T}/\left(e^{\delta T}-1\right)\right]p_k k$.

As we saw above, the expected rate of capacity utilization $E(Y_i)/\overline{Y}_i$ (henceforth, "expected utilization") tends to be the same for all firms as long as $\overline{Y} \le U_M$. This implies the uniformity of $E(\Pi_i)/\overline{Y}_i$ (the expression in square bracket). By summation of (8) across firms, expected profit for the industry as a whole can be written as

$$E(\Pi) = \left[(p-wg)\frac{E(Y)}{\overline{Y}} - \mu\right]\overline{Y}, \qquad (9)$$

or, equivalently,

$$E(\Pi) = (p-wg)E(Y) - \mu\overline{Y}, \qquad (9')$$

where $E(\Pi) = \sum E(\Pi_i)$, $Y = \sum Y_i$, and $\overline{Y} = \sum \overline{Y}_i$. When addressing the determination of industry capacity given output price, a preliminary step is to find out how $E(\Pi)$ changes with $\overline{Y}$. Such a

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APPENDIX

A.1. Proof of proposition (iii). Let $h(\overline{Y},p,w,\mu)$ denote the right-hand side of (16), so that $\hat{\overline{Y}}$ is such that $1/F = h(\overline{Y},p,w,\mu)$. We already know (see p.18) that any solution to (16) must belong to the interval $\left(\overline{Y}^{\circ},\overline{Y}_{|E(\Pi)=0}\right)$. Now, it can be easily seen that $h(\overline{Y}^{\circ},p,w,\mu)=1>1/F$, whereas $h\left(\overline{Y}_{|E(\Pi)=0},p,w,\mu\right)=0<1/F$. Along with continuity of $h(\overline{Y},...)$, this ensures the existence of $\hat{\overline{Y}}$. As for uniqueness, differentiation of $h(\overline{Y},p,w,\mu)$ with respect to $\overline{Y}$ gives

$$\frac{\partial h(\overline{Y},p,w,\mu)}{\partial \overline{Y}} = \left\{\left[(p-wg)\left(\int_{\overline{Y}}^{U_M}\varphi(U)dU\right)-\mu\right]\int_{U_m}^{\overline{Y}}U\varphi(U)dU\right.$$

$$\left.-\overline{Y}\varphi(\overline{Y})\left[(p-wg)\left(\int_{U_m}^{\overline{Y}}U\varphi(U)dU+\overline{Y}\int_{\overline{Y}}^{U_M}\varphi(U)dU\right)-\mu\overline{Y}\right]\right\}\div\left[(p-wg)\left(\int_{U_m}^{\overline{Y}}U\varphi(U)dU\right)^2\right]$$

With $\overline{Y}\in\left(\overline{Y}^{\circ},\overline{Y}_{|E(\Pi)=0}\right)$, the expression in the first square bracket in the numerator is negative, whereas the expression in the second square bracket is positive. Therefore, in that range $h(\overline{Y},p,w,\mu)$ is always decreasing in $\overline{Y}$, which ensures the uniqueness of $\hat{\overline{Y}}$ (see figure 3).

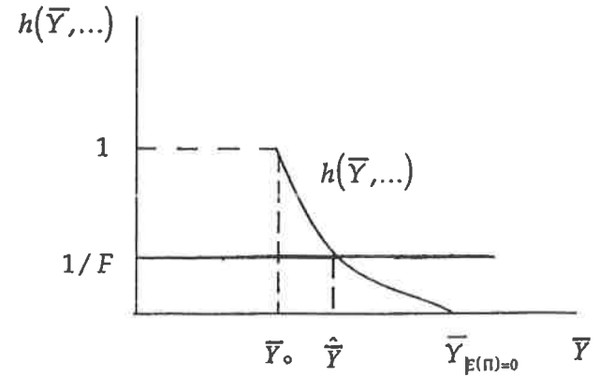

Figure 3

A.2. Proof of proposition (iv). From the property that $\partial h(\overline{Y},p,w,\mu)/\partial\overline{Y}<0$ for $\overline{Y}\in\left(\overline{Y}^{\circ},\overline{Y}_{|E(\Pi)=0}\right)$, it follows straightforwardly that $\partial\hat{\overline{Y}}/\partial F>0$ (in figure 3, the $1/F$ line shifts downwards as F increases).

A.3. Proof of propositions (vi): By differentiation of $h(\overline{Y},p,w,\mu)$ with respect to p, it is obtained

$$\frac{\partial h(\overline{Y},p,w,\mu)}{\partial p}=\frac{\mu\overline{Y}}{(p-wg)^2\int_{U_m}^{\overline{Y}}U\varphi(U)dU}>0.$$

Therefore, in figure 3 the $h(\overline{Y},p,w,\mu)$ curve shifts upwards as p increases, so that $\partial\hat{\overline{Y}}/\partial p>0$. By analogous procedure, one can easily check that $\partial\hat{\overline{Y}}/\partial w<0$ and $\partial\hat{\overline{Y}}/\partial\mu<0$.

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