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MULTI PRODUCT MARKET EQUILIBRIUM WITH SEQUENTIAL SEARCH*

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Abstract: In this paper I investigate whether, in market equilibrium, one observes price dispersion and search when buyers intend to acquire several products whose price is unknown and exists a positive search cost. Although that seems fruitful, I prove that in market equilibrium it is not observed neither price dispersion nor search and shops act as if they where monopolists. Nevertheless, there is one property of the theory that is in accordance with empirical data, namely the continuous increase in the number and dimension of larger shops.

Keywords: Search, Price Dispersion, Market Equilibrium, Multi-products.

JEL: D8; L1

1. INTRODUCTION

It is an empirical regularity that in the trading of homogeneous goods there is persistent price dispersion and buyers search for the best price. This, however, is not explainable by the classical Arrow-Debreu theoretical framework. It looks straightforward that this empirical regularity is a consequence of the non-verification in true markets of the classical assumption of perfect knowledge, Simon (1955). In spite of this, within a theoretical framework where buyers are homogeneous and intend to acquire one product whose price is unknown, it results in a market equilibrium where there is neither price dispersion nor search. This result is valid

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either when buyers follow the optimal sequential sample strategy, Diamond (1971), or the sub-optimal fixed sample size strategy, Vieira (2004).

The reasons of that theoretical pitfall have involved substantial investigation dating back to Diamond (1971). One investigation path that seems to be fruitful is to consider that buyers search simultaneously several products (Burdett & Malueg, 1981; Carlson & McAfee, 1984; Gatti, 1999; McAfee, 1995). Nevertheless, in this work I prove that this multi-product investigation path is not as fruitful as it seems. In concrete, I prove resorting mathematical formalization that Diamond (1971)'s result stands when the base model is extended to consider the multi-product market equilibrium. That is, *i*) there is no price dispersion; *ii*) buyers do not search and *iii*) shops act as if they where monopolists. Additionally, I prove that in equilibrium all shops sell all the products.

2. ASSUMPTIONS AND DEFINITIONS

Assumption 1. There are two products in the market, product 1 and product 2, being their marginal production cost zero;

Assumption 2. There are N identical buyers that intend to acquire both products and M identical shops;

Assumption 3. Prices affixed at each shop are unknown, being commonly assumed that they are independent extractions from a perfectly known distribution function;

Assumption 4. A buyer must pay the search cost c to know the price of one product affixed at an aleatory selected shop and he/she must pay the search cost $c + \alpha$ to know both product prices, being $c > 0$ and $0 < \alpha < c$;

Assumption 5. Buyers maximize an inverse utility function, $v(P_1,P_2)$, that is strictly decreasing with prices of products 1 and 2, respectively p_1 and p_2;

Assumption 6. The search cost increases the products' acquisition price. Nevertheless, the small magnitude of the search cost allows to assume $v(p_1, p_2) + \frac{dv(p_1, p_2)}{dp_1} c_1 + \frac{dv(p_1, p_2)}{dp_2} c_2$ as a sufficient approximation to $v(p_1 + c_1, p_2 + c_2)$.

Assumption 7. Shops maximize the expected profit.

Definition 1. P_i^- is the smallest price and P_i^+ the highest price amongst all prices affixed at shops for product i.

Definition 2. The market prices distribution function of product i is $F_i(p)$.

Definition 3. A "new" buyer is an individual buyer that did not acquired any of the products in a previous period.

3. MAIN RESULTS

Lemma 1. *If the buyer search for product 1 (product 2) having acquired previously product 2 at price p_2, he/she will buy it when he/she finds a price smaller or equal to a reservation price P_1* (P_2*), unique for each p_2; otherwise, he/she continues searching for product 1. The net expected utility of the search is equal to the utility of acquiring the good at the reservation price.*

Proof. If the buyer intends to acquire product 1, his/her decision problem, knowing the product 1 price affixed at one shop, p_1, and having acquired the product 2 at the price p_2 is modeled by:

$$V(p_1, p_2) = \frac{dv(p_1, p_2)}{dp_1} c + \max\{v(p_1, p_2) \, ; E[V(., p_2)]\} \tag{1}$$

In this expression and all the following, one dot represents a stochastic variable and E represents the expected value of that stochastic variable.

Assuming an exogenous reservation price P_1*, not necessarily optimal, it results, by forwarding the expression (1) one period ahead, the net expected utility of the search (net of the search cost):

$$E[V(., p_2) \mid P_1 *] = k\, c + \int_0^{P*} v(x, p_2) f(x) dx + \int_{P*}^{\infty} E[V(., p_2) \mid P_1 *] f(x) dx \tag{2}$$

Being $k = \int_0^{\infty} \frac{dv(x, p_2)}{dx} f(x) dx < 0$

This expression may be simplified, resulting:

$$\int_0^{P*} \left(v(x, p_2) - E[V(., p_2) \mid P *]\right) f(x)\, dx + k\, c = 0 \tag{3}$$

In this expression, $\int_0^{P*}\left(v(x, p_2) - E\left[V(., p_2) \mid P*\right]\right) f(x)\, dx$ is the expected gain of the search and $k\, c$ is the expected cost of the search, both in utility units. In order $P*$ to exist and be unique, at the optimum the expected search gain net of search cost must be a maximum. Deriving expression (3), it results the first condition of optimization:

$$\left(v(P*, p_2) - E\left[V(., p_2) \mid P*\right]\right) f_1(P*) + 0 = 0 \tag{4}$$

$$v(P*, p_2) = E\left[V(., p_2) \mid P*\right],\ f_1(P*) \neq 0, \tag{5}$$

The second condition of optimization is verified by assumption 5:

$$\left.\frac{\partial v(p_1, p_2)}{\partial p_1}\right|_{p_1 = P*} < 0,\ f_1(P*) \neq 0, \tag{6}$$

Expression (5) and (6) guarantee that reservation price exists and is unique for each p_2 and (5) guarantees that the net expected utility of the search is equal to the utility of acquiring the good at the reservation price. QED

Note 1. I will show at lemma 7, that if there is no price dispersion, expression (6) has multiple solutions because $f_1(x)$ is zero almost everywhere. Nevertheless, it will be seen that this exception is not of relevance.

Note 2. As the order of products is arbitrary, this and other following proofs apply to both products.

Lemma 2. *If the buyers search for product 1 (product 2), intending afterwards to search for product 2 (product 1), he/she will buy it when he/she finds a price smaller or equal to a reservation price P_1* (P_2*), otherwise he/she continues searching. The net expected utility of the search is equal to the utility of acquiring both goods at the reservation prices.*

Proof. If the buyer intends to search product 1, the decision problem when he/she knows the product 1 price, p_1, is either i) to acquire the product 1 at that shop and start searching for product 2 or ii) to continue searching for product 1.

By Lemma 1, the i) expected utility is $v(p_1, P_2*)$. Being so, the buyer decision model becomes:

$$V(p_1, .) = k\, c + \max\left\{v(p_1, P_2*)\,;\, E\left[V(.,.)\right]\right\} \tag{7}$$

In algebraic terms this problem is identical to problem (1) with P_2* instead of p_2, being the solution identical as well:

$$v(P_1^*, P_2^*) = E[V(.,.) \mid P_1^*, P_2^*],\ f_1(P_1^*) \neq 0,\ f_2(P_2^*) \neq 0 \tag{8}$$

$$\left.\frac{\partial v(p_1, p_2)}{\partial p_1}\right|_{\substack{p_1=P_1^* \\ p_2=P_2^*}},\ f_1(P_1^*) \neq 0,\ f_2(P_2^*) \neq 0 \tag{9}$$

Expression (8) and (9) guarantee that reservation price exist and is unique for each P_2* and that the net expected utility of the search is equal to the utility of acquiring the good at both reservation prices. QED

Both note 1 and note 2 apply.

Lemma 3. *The reservation price is increasing with the search cost.*

Proof. It is intuitive that the expected utility of the search is decreasing with the search cost. Formally, as in expressions (2) and (7) the search cost in utility units, $k\ c$, is negative and $v(p_1, p_2)$ does not change with the search cost. Then, when search cost c in monetary units increases the expected utility of the search decreases. Therefore, the left-hand side in equalities (5) and (8) decreases, which implies that the reservation price of the searched product increases. QED

Corollary 1. *When the inverse utility function is convex (increasing to scale) the buyer may regret. When the buyer acquires one product and continues searching for the other one, he/she may regret of the acquisition. When, instead of acquiring the product where he/she finds an acceptable price, the buyer waits intending to recall it in the end, he/she may not recall it at all but, instead, restart searching for the first product.*

Proof. When the buyer searches for product 1, by lemma 1 his/her reservation price is conditioned to the price he/she will find for the product 2, as the search cost in utility units depends on it. Being so and as by lemma 2 he/she first decides as if the price of product 2 is P_2*, after he/she resume searching for the product 1, he/she may find a price lower that P_2* that decreases the search cost of product 1. This situation may occur when the inverse utility function is convex (increasing to scale). If cost decrease occurs, by lemma 3 it will decrease the reservation price of product 1 so that the buyer may regret if he/she has already acquire the product 1 or, otherwise, he/she will restart searching for it. QED

Lemma 4. *When there is price dispersion,* P_i^- ¹ P_i^+*, and search cost is positive, then the reservation price* P_i^* *is higher than* P_i^-*. When search cost is zero, the reservation price* P_i^* *is equal to or smaller than* P_i^-*.*

Proof. By absurd reduction, when P_i^* is smaller or equal to P_i^-, the left-hand side of the expression (3) becomes zero. Then the search cost must be zero so that the proposition is truth. In this way, when search cost is positive, P_i^* must be higher than P_i^- and, when search cost is zero, P_i^* must be equal to or smaller than P_i^- (see lemma 7). QED

Lemma 5. *If there is price dispersion, the optimal expected utility of the search is higher than the average (expected) utility less the search cost of the first visit.*

Proof. Rewriting expression (2) for product 1 it becomes:

$$E[V(.,p_2)\,|\,P_1*]F_1(P_1*) = k\;c + \int_0^{\infty} v(x,p_2)\,f(x)dx - \int_{P*}^{\infty} v(x,p_2)\,f(x)dx \tag{10}$$

$$E[V(.,p_2)\,|\,P_1*]F_1(P_1*) = Avg - \int_{P*}^{\infty} v(x,p_2)\,f(x)dx \tag{11}$$

In the right-hand side of this expression, *Avg* is the average utility less the search cost of the first visit. By Lemma 4, $P_i^* > P_i^-$, and assumption 5, the integral in the expression (11) is lower than *Avg*:

$$\int_{P*}^{\infty} v(x,p_2)\,f(x)dx = (Avg - \Delta)\,[1 - F(P_1*)], \text{ with } \Delta > 0 \tag{12}$$

Substituting (12) in (11), it results $E[V(.,p_2)\,|\,P_1*] - Avg = \Delta \dfrac{1 - F_1(P_1*)}{F_1(P_1*)} > 0$. QED

Lemma 6. *When* P_i^- ¹ P_i^+*, the reservation price* P_i^* *is smaller than* P_i^+*.*

Proof. By absurd reduction, when P^* is higher or equal to P_i^+, the buyer acquires the product in the first shop he/she visits, being straightforward to see that the expected inverse utility is equal to the average inverse utility. But by Lemma 5, the expected inverse utility is higher than the average inverse utility which implies P^* must be always smaller than P_i^+. QED

Lemma 7. *If there is no price dispersion,* $P = P_1^- = P_1^+$*, and search cost is positive, then the reservation price* P_1^* *is equal to or higher than P. When search cost is zero, the reservation price* P_1^* *is equal to or smaller than P.*

Proof. When there is no price dispersion, the expected gain from the search is zero. Being so, when there is a positive search cost, it is optimal that the buyer acquires the product in the first shop he/she visits. In this way, the reservation price must assure that the buyer will not find a price higher than the reservation price.

When search cost is zero, the buyer is indifferent between acquiring the product in the first shop he/she visits or to continue searching. In this way there remains uncertainty if the buyer acquires the product in the first shop he/she visits, $P^* = P$, or if he/she continues searching forever, $P^* < P$.

It is not of relevance that the reservation price be multiple because it only means that the buyer must acquire the product in the first shop he/she visits ($P_1^* > P$) or that it is "algebraically" possible that the search continues forever ($P_1^* < P$). QED

Lemma 8. *If the buyer searches simultaneously for product 1 and product 2, visiting shops that sell both products, he/she will buy both products when he/she finds a sum of prices smaller than a reservation price* P_{1+2}^* *and individual prices are smaller than the reservation price* P_1^* *and* P_2^**, respectively. Otherwise, the buyer acquire only the product i when* P_i £ P_i^**, continuing searching for the other product.* P_{1+2}^* *is smaller than* $P_1^* + P_2^*$ *but higher than* P_1^* *and* P_2^**.*

Proof. It is obvious that P_{1+2}^* is not greater than $P_1^* + P_2^*$, as the buyer may search the products separately. When buyer search simultaneously both products, after knowing both product prices affixed at one shop, he/she may i) acquire both products; ii) acquire one product and continuing searching for the other product or ii) do not acquire any product at all. Assuming that the buyer allocate the search cost part c to product 1 and the search cost part α to product 2:

$$V(p_1,p_2)=k_1\ c+k_2\ a+\max\begin{Bmatrix} v(p_1,p_2)\,; \\ v(p_1,P_2*);v(P_1*,p_2)\,;(\text{Lemma 2}) \\ E[V(.,.)] \end{Bmatrix} \qquad (13)$$

With $k_1=\dfrac{dv(p_1,p_2)}{dp_1}\,;k_2=\dfrac{dv(p_1,p_2)}{dp_2}$

It may be interpret without loss that to search simultaneously both products is identical to search product 1 "with left hand", with cost search c, and to search product 2 "with right hand", with cost search α. Having this in mind it is straightforward to extend lemma 2 to both products:

$$E[V(.,.)]=v(P_1*,X_2*) \qquad (14)$$

The buyer acquires both product when $p_i \le P_i*$ and $p_1 + p_2 \le P_1* + X_2*$.

From assumption 4, $0 < \alpha < c$, and lemma 3, the reservation price when product 2 is searched simultaneously with product 1, X_2*, is lower than the reservation price when product 2 is searched alone, $0 < X_2* < P_2*$. Naming $P_{1+2}*$ as the combined reservation price, it results:

$$P_{1+2}* = P_1* + X_2* < P_1* + P_2* \qquad (15)$$

The allocation of the combined search cost between product 1 and product 2 is "algebraic" so buyer will adopt the allocation that corresponds to the highest expected utility. In this way, the expected utility will not be smaller than the case considered which implies that $P_{1+2}*$ is always smaller than $P_1* + P_2*$ and higher than P_1* or P_2*. QED

Lemma 9. *If the buyer searches both products simultaneously by visiting only shops that sell both products, his net expected inverse utility will be higher than if he/she searches in shops that are specialized in one of the products.*

Proof. It results straightforward from lemma 8 that the net expected inverse utility when buyer searches simultaneously both products is higher than the net expected utility if the buyer searches one product at each time, $V(P_1*,X_2*)>V(P_1*,P_2*)$. But only when the buyer visits shops that sell both products he/she may search simultaneously the products. Being so, when he/she visits shops of that type his/her net expected utility is higher. QED

Lemma 10. *Assuming only "new" buyers, the expected profit function of shops that sell both products is higher than shops that are specialized in one of the products. In this way, in equilibrium all shops sell both products.*

Proof. By lemma 9, when it is publicly known which are the shops that sell only one product, no "new" buyer will visit them, so their expected profit is zero. When that is unknown, on average, *N*/*M* buyers visit each shop. Assuming the more favorable case (unknown) for shops specialized in one product, their expected profit function is:

$$E[p_1(p_1,.)\,|\,1] = \frac{N}{M} q_1(p_1,.)\,p_1, \quad \forall\, p_1 \le P_1{*} \tag{16}$$

In this case, the expected profit function of shops that sell both products is:

$$E[p_{1+2}(p_1, p_2)] = \frac{N}{M}[q_1(p_1, p_2)p_1 + q_2(p_1, p_2)p_2], \quad \forall p_1 \le P_1{*}, p_2 \le P_2{*}, p_1 + p_2 \le P_{1+2}{*} \tag{17}$$

Shops will affix prices that maximize their expected profit. By lemma 6, when shops act as monopolist they affix prices not lower than P_i*. Being so, shops specialized in one product affix the reservation price, being the expected profit $\frac{N}{M} q_1(P_1*,.)P_1*$ while other shops set $p_1 + p_2 = P_{1+2}*, p_1 \le P_1*, p_2 \le P_2*$, being the expected profit $\frac{N}{M}\max\left(q_1(p_1, p_2)p_1 + q_2(p_1, p_2)p_2\right)$ that, by lemma 8, is higher than $\frac{N}{M} q_1(P_1*,.)P_1*$.

From this result and from assumption 7, in equilibrium, all shops sell both products. QED

Lemma 11. *The buyer acquires both goods at the first shop where he/she asks prices.*

Proof. From lemma 10, shops sell both products and, from lemma 9, buyers search both products simultaneously. As shops maximize the expected profit when they affix prices $p_1 \le P_1*, p_2 \le P_2*, p_1 + p_2 = P_{1+2}*$, the buyer acquires both products at the first shop he/she visits. QED

Corollary 2. *All buyers that search are of the "new" type.*

Proof. As buyer acquires both products at the first shop he/she visits, there will be no buyer that acquires a product and continues searching for the other product. QED.

***Theorem* 1.** *In multi-product market equilibrium, i) every shop sells both products and ii) there is no price dispersion. When search cost is positive, iii) buyers acquire both products at the first shop they visit and iv) shops act as if they where monopolists. When search cost is zero, v) buyers visit an indeterminate number of shops and vi) shops contest a la Bertrand.*

Proof. By lemma 10 and corollary 2, every shop sells both products and affixes the same combined price for the bundle, $p_1 + p_2 = P_{1+2}*$. Being so, and by lemma 11, buyers acquire both products at the first shop they visit. If, by reduction to absurd, there is price dispersion, by lemma 9 no shop will set prices higher than P_1* or P_2* which is impossible because it violates lemma 6. If there is no price dispersion, lemma 9 is compatible with lemma 7. Being so and by lemma 7, when search cost is positive, in market equilibrium there is no price dispersion and shops act as if they where monopolist. Using the same lemma 7, it results that when search cost is zero, buyers visit an indeterminate number of shops so that the market is in "perfect competition" equilibrium. QED

4. EXTENSION TO *L* PRODUCTS

It is straightforward to extend assumptions, corollaries and theorem to the market with L products, $L > 2$, being all truth.

5. CONCLUSION

Although it seems fruitful to consider that buyers search simultaneously several products in the justification why in the trading of homogeneous goods there is persistent price dispersion and buyers search for the best price, I prove in this paper that it is not as fruitful as it seems. That is because the result of Diamond (1971) that there is neither price dispersion nor search stands when one considers several products market equilibrium.

Nevertheless, there is one property of the theory that is in accordance with empirical data: buyers expected utility is higher when they visit shops that sell all products and those shops have a higher expected profit. This theoretical result is in accordance with the continuous increase in the number and dimension of larger shops commonly observed.

Intuitively, it seems to me that to assume small magnitude search cost (assumption 6) does not change my main conclusion. That is because it is certain (lemma 3) that higher search costs will not increase search intensity (that is already zero for low search cost).

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