A MODEL OF MONOPOLISTIC COMPETITION WITH TECHNOLOGICAL ASYMMETRIES

(Preliminary Version)

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Abstract: This paper introduces asymmetric preferences and technologies in the Dixit-Stiglitz model of monopolistic competition. It departs from the mainstream models based on representative agents proposing a self-organizing industry populated by bounded rational firms and consumers that take decisions of production and consumption in an independent way. The supply side is a set of producers with asymmetric product and process technologies, and the demand side has consumers with heterogeneous tastes. Some simulations are presented to illustrate the ability of the model to mimic some stylized facts of industrial organization.

Key words: industrial dynamics, monopolistic competition, bounded rationality, economy of scale, product differentiation.

J.E.L.: D20; D43; D58; L11

* Acknowledgements: I am grateful to Duncan Foley for comments on previous drafts. I also thank CAPES (a Brazilian federal fellowship agency of Ministry of Education) for the support to my Ph.D. course at The New School for Social Research. The usual caveats apply.

1. INTRODUCTION

This paper analyses the properties of industries characterized by heterogeneous firms and consumers. The empirical phenomena addressed by the model have been examined by several researches from different points of view. For example, Baldwin (1995), Dunne *et al* (1988), Caves (1998), and Geroski (1995) discuss the industry turnovers, the firm size distributions, and the entry and exit rates. The economics of innovation suggests heterogeneity in technological capabilities at firm level as an important determinant of industrial structures (Dosi, 1988; Freeman, 1994). In the industry life cycles approach, the industrial structure evolves over time and the technological asymmetries between latecomers and incumbents play a decisive role in the industrial dynamics. Entry and exit are also shown to vary as a result of technological heterogeneity (Klepper, 1997). In the literature of the population ecology of organizations, the empirical works also takes the technological capabilities as determinants of the variation in the number of firms and their rate of surviving (Hannan and Freeman, 1989; Carroll and Hannan, 1995; Carroll, 1997).

The model that follows is in accordance with these empirical studies when defines the industrial structure as an emergent phenomena of a set of heterogeneous firms. Thus, some general characteristics of industries are: (i) firms have heterogeneous technological capabilities, (ii) the probability of survive depends on the individual characteristic and also on the relative capabilities of other competitors and imitators, (iii) and the industrial structure is an outcome that reflects structural asymmetries, (v) the skewed distributions of firms are indicators of these different capabilities (Sutton, 1998; Dosi *et al*.,1995).

The model also rejects the assumption that firms and consumers have high levels of foresight and knowledge, thus it is supposed that economic agents follows simple routines ("rules of thumb") to take decisions in a complex environment. The agents are supposed to be bounded rational, which is in accordance with theoretical propositions of Nelson and Winter (1982), Simon (1978 and 1987), Dosi (1988), among many others. This approach is in contrast to more mainstream economic models of competition, which accept full rationality as a fundamental modeling assumption.

The model departs from the conventional approach in three senses. First, the industry is a set of individual and heterogeneous firms that perform simultaneous and independent exchanges. Because firms have limited information on the consumer preferences and technologies, there is no instantaneous equilibrium and the industry reaches a steady state in an evolutionary fashion.

Second, the supply and the demand sides are modeled as bounded rational individual agents with different endowments (e.g. information, preferences, technology, income, capital). Hence, it diverges from the traditional industrial organization models where firms know the demand, and can choose the price that maximizes profit and produce the exact amount demanded by consumers, which reallocate their expenditure instantaneously.

The third departure is related to how production and demand interact. First, firms purchase inputs, produce, and set prices. The production is followed by expenditure decisions: consumers get prices and set their demands. The demand is determined independently of production decisions, and not simultaneously. Consequently, excess demand or excess supply can occur.

On the supply side, changes in firm size and price adjustments replace the instantaneous equilibrium. The excess supply raises inventories and decreases the amount of working capital for the next period of production. Since unsold production cannot be converted into capital, firms cannot buy the same amount of labor in the next period. Thus overproductions mean that firms have lower levels of production and higher inventories in the next period of production, which may bring their prices down. When there is excess demand, firms supply just the amount of goods available and consumers do not spend all their income. The adaptive behaviors of firms and consumers lead to processes of technological selections, and changes in firm sizes, costs, prices, and levels of consumption and expenditure.

The subsequent topics describe the model in detail. The second topic establishes the main reference to the present model in the literature: the Dixit-Stiglitz model of monopolistic competition. The third part presents the behavior of the firms in complex industrial environment. The fourth topic presents some illustrative simulations.

2. Demand with Asymmetric Differentiated Products

In the standard specification of the Dixit-Stiglitz model of monopolistic competition every consumer shares a utility function U that represents a composite index of the consumption of goods. In the industry there is N firms f or varieties, and U is defined by as constant elasticity of substitution (CES) demand function:

$$U = (\sum A_f Q_f^{\rho})^{1/\rho}, \text{ for } f = 1 \ldots N,\ 0 < \rho < 1, \text{ and } A_f = 1 \tag{1}$$

The utility function above is rather conventional and makes all products "homogeneously differentiated" when the coefficients A_f are set 1. Varian (1992: 19-20, and 112) observes that $A_f = 1$ is a quite convenient way to deal with otherwise intricate situations. Krugman (1979, 1980, and 1991) and Fujita, Krugman and Venables (1999) are examples on how useful the assumption of "symmetric differentiated products" is in modeling industries with economies of scale and heterogeneous products.[1]

The demand side of the model proposed here diverge from this conventional approach supposing that products may be "asymmetrically differentiated", which means $A_f \neq 1$. Let us say that these specific A_f's are responsible for the product quality. Thus, given the income Y and a set of prices P_f, the consumers maximize its utility:

$$U = (\sum A_f Q_f^{\rho})^{1/\rho} \text{ for } f = 1 \ldots N,\ 0 < \rho < 1, \text{ and } A_f > 0$$

$$\text{Max } U = (\sum A_f Q_f^{\rho})^{1/\rho} \text{ s.t. } Y = (\sum P_f Q_f) \tag{2}$$

The maximization problem says that the equality of marginal rates of substitution to price ratios for any pair of goods i and j is:

$$Q_i = Q_j\,[(P_i/A_i) / (P_j/A_j)]^{1/(\rho-1)} \tag{3}$$

Substituting the equation 3 into the constraint Y (equation 2), we have the demand function for the variety Q_j:

[1] Fujita and Thisse (1996), Neary (2001) and Tirole (1988) point out the limitations of CES demand function. Tirole (1988, p. 100) says: "However, for applications to industrial organization, it [the CES] may have some drawbacks. As it does not make explicit the characteristics over which firms are competing, it sometimes gives limited intuition concerning the plausibility of preferences. Or else, it may be very specific, as in the case of the CES utility function given above. The latter utility function treats all the differentiated products in a symmetric way".

$$Q_j = Y\ [P_j^{\ 1/(\rho-1)}\ A_j^{\ 1/(1-\rho)}]\ /\ [\sum P_f^{\ \rho/(\rho-1)}\ A_f^{\ 1/\ (1-\rho)}] \qquad (4)$$

Such as in Fujita *et al* (1999, Chapter 4), if $\rho = [(\sigma - 1) / \sigma]$ or $\sigma = [1 / (1- \rho)]$, and σ represents the elasticity of substitution between any two varieties, the equation above can be written as:

$$Q_j = Y\ (P_j^{-\sigma}\ A_j^{\sigma})\ /\ [\sum P_f^{\ (1-\sigma)}\ A_f^{\sigma}] \qquad (5)$$

The only difference between the demand equation 5 and the conventional ones is the coefficient $A_f \neq 1$. Hence, the quantities demanded of all varieties may differ even if their prices are the same. Thus, the higher the A_f, the better is the quality of product f, and the greater the demand of firm f.[2]

3. LIMITS FOR CONVENTIONAL PROFIT MAXIMIZATION PROCEDURES

One could argue that equation 5 could be plugged into a profit-maximizing firm in order to get the equilibrium price and output, such as in Krugman (1980) and Fujita *et al* (1999). By conventional maximization procedures, the equilibrium price and output of any firm would be:

$$P_f^* = C_f\ W\ [\sigma / (\sigma - 1)] \qquad (6)$$

$$Q_f^* = F_f\ (\sigma - 1) / C_f \qquad (7)$$

The technical coefficients F_f and C_f stand for fixed and marginal costs, respectively. The elasticity of substitution σ and the nominal wage (W) are given and known by the firm. Thus, profit maximization implies that all firms would have the same equilibrium price and output if

[2] It must be noted that the quality of each product (A_f) is a subjective characteristic. It represents consumer taste, a variable that it is not known by firms, at least when the product is introduced into the market. It recalls an "Akerlof type market": a market with quality uncertainty (Akerlof, 1970).

they had the same process and product technologies. However, if firms had products with different qualities and technologies, the equation 5 would say that equilibrium Q_f^* might not be the same for all firms ($Q_f^* \neq Q_f$). For example, the quantities demanded of varieties i and j would be:

$$Q_i = Y\,(P_i^{-\sigma} A_i^{\sigma}) / [\sum P_f^{(1-\sigma)} A_f^{\sigma}] \tag{8}$$

$$Q_j = Y\,(P_j^{-\sigma} A_j^{\sigma}) / [\sum P_f^{(1-\sigma)} A_f^{\sigma}] \tag{9}$$

The quantities demanded for these two varieties would be the same ($Q_f^* = Q_i = Q_j$) only when $A_f^* = A_i = A_j$, and firms know and choose the best technologies ($F^* = F_i = F_j$, and $C^* = C_i = C_j$), which makes $P_f^* = P_i = P_j$. When product qualities differ and/or firms have incomplete information (or access) to the best on technology, it seems quite difficult for a firm to solve the profit maximization by conventional procedures.

To avoid restrictive assumptions, such as complete information and unlimited and instantaneous computational capabilities, in the following section it is proposed a simple way to establish the equilibrium output and price in an industry. The main assumptions are: (1) there is no perfect information, (2) firms are bounded rational agents with asymmetric technological capabilities, and (3) consumers have different tastes and change their allocation of income in an adaptive way.

4. Firm Behavior

In the simple version of the model, each industry has a maximum number of potential firms or technologies. Each firm has (1) a specific amount of capital K_f, (2) a fixed cost F_f and labor productivity C_f (process technology), (3) produces one variety with differentiated quality A_f (product technology), and (4) all firms have some increasing returns of scale. Each firm operates a single technique – the best it knows, and there is no way to relocate capital to the production of other varieties or even imitate technologies.

4.1. PRICE AND ECONOMIES OF SCALE

The starting point of the supply side is the market of inputs: each firm has an amount of capital (K_f) and buys a certain quantity of labor (L_f), which is the only input of the industry. The total amount of labor available for firms depends on the nominal wages (W), which is an exogenous variable. To keep the model simple, firms are supposed to invest all their capital, no matter the level of inventories or even the previous level of demand. In short, firms do not save and do not have a speculative behavior. Therefore, each firm hires a number of workers proportional to their monetary capital:

$$L_f = (K_f / W) \qquad (10)$$

Assuming that the only input is labor and the wage is given, the quantity supplied by each firm is:

$$Qs_f = [(L_f - F_f) / C_f] + V_f \qquad (11)$$

The technological function above allows economies of scale at the firm level. When consumers buy a large amount of a specific product, only the firm producing that specific variety can supply it. Given the potential economies of scale, some firms can move into a "virtuous cycle": decreasing prices, increasing demand, and high capital growth. On the other hand, if consumers do not buy some minimum amount of goods, the firm shrinks, costs of production increase, and further decreases in demand may occur. Hence, in a "vicious cycle", some firms may be excluded from the market because of their noncompetitive technologies or/and lower product quality.

Total production of firm Qs_f is the sum of current production plus some eventual stock of unsold goods (V_f). When $F_f > 0$, there is economies of scale: the quantity produced increases, the fixed cost per unit decreases, and the average cost falls. When $F_f > L_f$, firm does not have the minimum amount of input required to operate its technology. In this case, the firm fails and its technique is eliminated.[3]

Firms set prices following a simple routine of rationality: a fixed markup over unitary costs. Given its total supply and cost of production, the price is just the unitary cost multiplied by a exogenous markup (Mk_f), which is supposed to be fixed, and its bottom-line can be even given by some exogenous variable (e.g. interest rate):

$$P_f = Mk_f \, (K_f / Qs_f), \text{ where } Mk_f > 1 \tag{12}$$

To set their prices, firms do not search for extra information, compare their prices with those of other products, or even estimate the elasticity of demand. They just set prices using only the information available in each period of production: the capital invested K, the quantity produced Qs, and its markup Mk. This pricing rule reduces the amount of information to an extreme low level and allows firms to compute prices requiring limited computational capabilities. Firms can thus change prices in the short-term, without bearing high costs of information and decision-making.[4]

4.2. A First Measure of Equilibrium: the excess of demand

The pricing routine says that if all firms sell the whole production, their total sale $\sum(P_f \, Qd_f)$ would be total capital multiplied by their markup ($\sum Mk_f \, K_f$). The demand is exogenous (Y) and sets the maximum sale of the industry, therefore:

$$Y \geq \sum P_f \, Qs_f = \sum Mk_f \, K_f, \text{ and} \tag{13}$$

$$Y \geq \sum P_f \, Qd_f, \text{ where } Qd_f \leq Qs_f, \tag{14}$$

[3] The economies of scale help to explain why firms would invest all capital available. Postponed investment would reduce production and raise mill price, and might cut back demand and increases stock in a cumulative way. Such process could push firms into the "vicious cycle". In order to avoid such risk, firms would try to keep the production at the maximum level.

[4] Because firms invest all capital in hiring labor and maintain markup fixed, the typical behavior of firms is to maximize capital growth. They do not take advantage of consumers by raising markups when there is excess demand, which would mean profit maximization in the short term. Of course other pricing rules could replace the one proposed here.

When $Qd_f > Qs_f$, there is an excess of demand, firms do not deliver the amount of goods demanded by consumers, and inventory is $V_f = 0$. In this case, consumers do not spend all the income allocated to the consumption of good f, and some income is not spent ($S_f > 0$). Thus, consumers may not spend all their income and are forced to save (expenditure is postponed).

When $Qd_f < Qs_f$, there is an excess of supply, firms deliver the amount of goods demanded by consumers ($S_f = 0$) and there is some amount of unsold goods ($V_f > 0$). Only when all income is spent the demand side is in equilibrium. Therefore, there are three cases:

When $Qd_f > Qs_f$, $Sf = Pf\,(Qdf - Qsf)$ and $Vf = 0$; (15)

When $Qd_f < Qs_f$, $Sf = 0$ and $Vf = (Qs_f - Qd_f)$; (16)

When $Qd_f = Qs_f$, $Sf = 0$ and $Vf = 0$; (17)

4.3. A Second Measure of Equilibrium: the profit rate

The demand equilibrium does not mean that the industry is in equilibrium, since it does not inform if the supply side is also in equilibrium. The supply side is in equilibrium only when the capital of each firm in a period t is equal to the capital in the period t + 1. That means the capital growth rate of all firms is $(K_{f\,(t)} / K_{f\,(t+1)}) = 1$.

At the end of each period t, firms distribute a percentage γ of the capital invested by the shareholders ($K_{f\,(t)}$). The capital available for the next period of production (t + 1) is the revenue at period t ($P_f\,Qd_f$) minus the income transferred to shareholders:

$$K_{f\,(t+1)} = P_{f\,(t)}\,Qd_{f\,(t)} - \gamma\,K_{f\,(t)} \tag{18}$$

When a firm f reaches its steady state, its capital at the beginning of the period of production has to be equal to the capital at the end of that period of production:

$$K_f = (P_f\,Qd_f) - \gamma K_f$$

$$K_f = P_f\,Qd_f / (1 + \gamma) \tag{19}$$

Substituting the price equation 12 into the equation 19, it is possible to assert that in steady state the inventory is positive when $Mk_f > (1 + \gamma)$, which is quite realistic assumption:

$$K_f = (Mk_f\, K_f / Qs_f)\, [Qd_f / (1 + \gamma)]$$

$$Qs_f / Qd_f = Mk_f / (1 + \gamma)$$

$$Qd_f = Qs_f\, (1 + \gamma) / Mk_f \tag{20}$$

It is also possible to compute the profit rate of firms in steady state substituting the equations 12 and 20 into a standard profit equation:

$$\pi_f = (P_f\, Qd_f) – (W\, L_f) = (P_f\, Qd_f) – K_f \tag{21}$$

$$\pi_f = [Mk_f\, K_f / Qs_f][Qs_f\, (1 + \gamma) / Mk_f] - K_f$$

$$\pi_f = \gamma\, K_f, \text{ or } (\pi_f / K_f) = \gamma \tag{22}$$

Therefore, when shareholders receive some income ($0 < \gamma < Mk_f – 1$), the profit rate is positive and equal to the distribution of dividends. Now, let us suppose that all production is sold ($Qd_f = Qs_f$). In this case, the profit is:

$$\pi_f = (Mk_f – 1)\, K_f$$

$$(\pi_f / K_f) = (Mk_f – 1) \tag{23}$$

The profit rate of equation 23 is thus the maximum profit rate, which is higher than that of equilibrium profit rate of equation 22. However only at the transitional phase firms may reach it, at the steady state all firms have to have their profit rate equalized to γ, which is an indirect measure of the capital growth rate ($K_{f\,(t)} / K_{f\,(t+1)} = 1$). Thus any deviation from γ can be seen as a measure of disequilibria of the supply side.

5. TECHNOLOGY, FINANCE, AND ENTRY

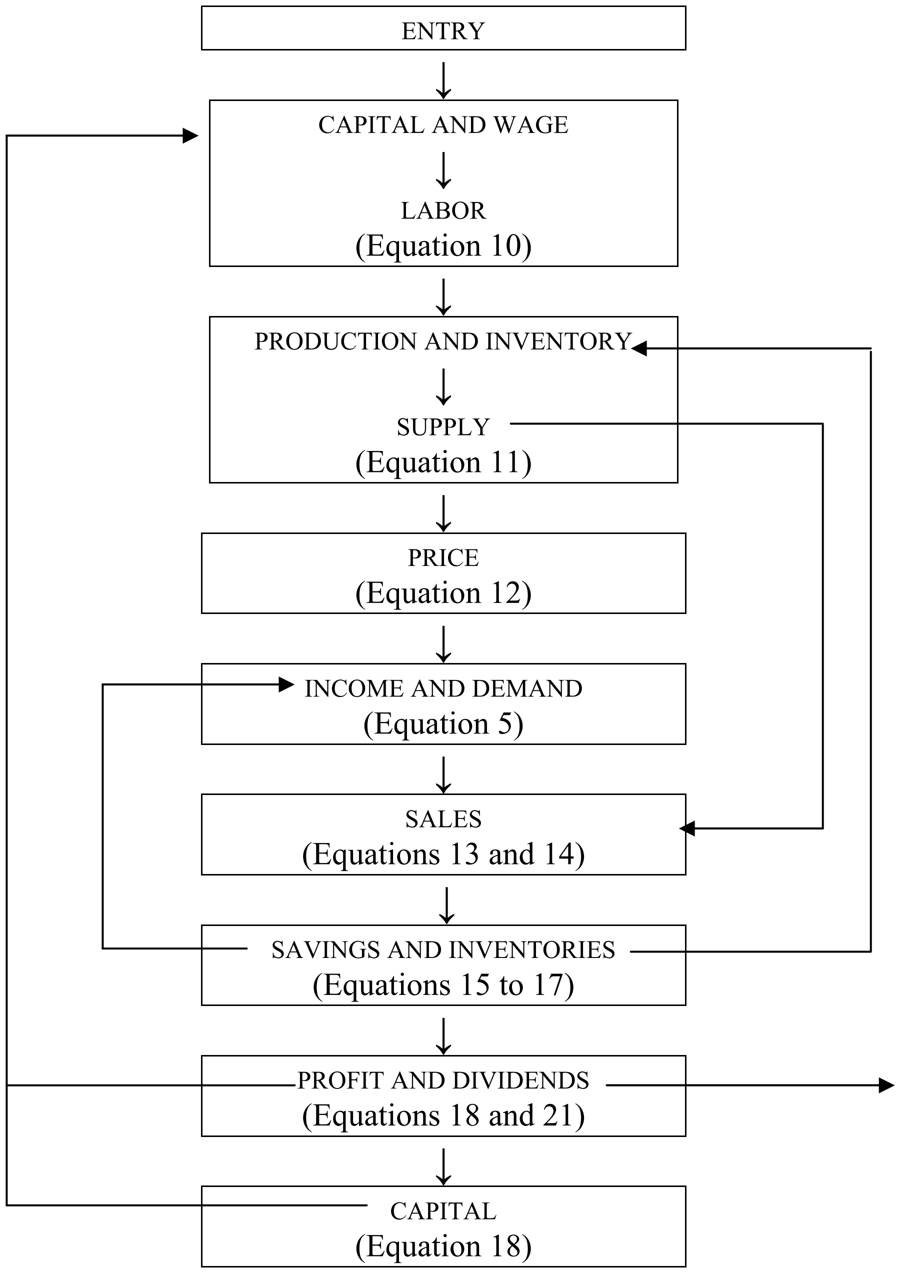
In this version of the model a simple way to simulate the entry of new producers is adopted. First, there is a limited number of technologies, and each firm has the monopoly of one single technology (A_f , F_f, and C_f). Since there is no information on which is the best technology, one random firm is drawn from the collection of technologies per period. Second, the financial system offers to the new producer an amount of capital equal to the average size of those active firms ($K^* = \sum K_f / N$). These two rules define how technologies are selected and the pattern of funding.

The entry of a new variety requires a third assumption. When a firm moves into the economy, consumers spend a share of income (E_f) buying the new variety equal to the number of varieties supplied: $E_f = Y / N$. Thus, consumers are relatively receptive to new products and always spend some income buying them. On the other hand, when a firm fails, consumers just exclude that variety from their demand and proportionally redistribute that share of expenditure among all other goods.

6. EVOLVING INDUSTRIES

The goal of this topic is to test the model described above. The basic tool used to simulate the artificial industry is a multi-agent system. In a multi-agent system, sets of agents (e.g. consumers and firms) perform different tasks. The current state of each agent depends on its transitional rules and previous states, and also on the current states of all agents in the system or in some close neighborhood. The set of rules of each agent (micro-behaviors or routines) guides agents into the environment, and macro-structures emerge "bottom-up" from the interaction of several agents. Markets, industries, and several social networks can be described as systems with heterogeneous agents that dynamically interact with each other. Thus, a multi-agent system seems to be a good tool to deal with the intricate network represented by heterogeneous and bounded rational firms and consumers spread on an economic space (Albin & Foley, 1992; Epstein and Axtell, 1996; Foley, 1998; Resnick, 1997).

To simulate the microeconomic model presented in the previous sections, the agents were defined as consumers, firms, and technologies. To each type of agent was assigned specific tasks (e.g. production, sales, delivery, and consumption), states (e.g. quality, stock of goods, amount of labor, capital, and localization), and transition rules (e.g. pricing rules, allocation of income, and production). The software used to simulate the "artificial industry" is NetLogo 2.1, and the appendix presents the program. The basic structure of the program is:[5]



[5] For more information on Netlogo software, see Wilensky (1999) at http://ccl.northwestern.edu/netlogo/. The complete model used in the simulations is available by request.

6.1. MODELING ASYMMETRIES

In the artificial industry introduced above firms have different product and process technologies. The asymmetric allocation of income among varieties depends on their qualities (A_f) and prices, which depend on the process technologies (C_f and F_f). To create asymmetric technologies, a set of random floating numbers that represents firm quality (A_f), fix cost (F_f) and labor productivity (C_f) were generated:

$$A_f \in \{1,\ldots,(1+\alpha)\},$$

$$F_f \in \{F,\ldots,(1+\alpha)\,F\}, \text{ and}$$

$$C_f \in \{C,\ldots,(1+\alpha)\,C\} \qquad (24)$$

The parameter α represents a general measure of asymmetry ($\alpha \geq 0$). An industry with relative homogenous technology (low α) will have firms with their main technological parameters close to 1, F and C. The opposite happens to industries with differentiated technologies (high α), where A_f, F_f and C_f may differ by large values from the parameters 1, F and C, respectively. Each firm has its markup, and it must be $Mk_f > (1+\gamma)$. To simulate different markups, a fourth normally distributed variable with mean γ was generated:

$$Mk_f \in \{(1+\gamma),\ldots,(1+\alpha)(1+\gamma)\} \qquad (25)$$

An exogenous interest rate γ sets the dividend policy, which means that γ% of the capital is distributed to shareholders. By the equation 22, equilibrium profit rate has to be $(\pi_f/K_f) = \gamma$. Thus, the industry is allowed to evolve up to the time when all firm have their profit rate equalized to γ, which is a measure of the supply side equilibrium.

6.2. SLOW DOWN DEMAND

The cobweb models describe a dynamic equilibrium in an industry when demand or supply sides have lags. As it is well known, the convergence to equilibrium occurs when the demand is less elastic than supply or vice-versa. The model described above is a typical cobweb model, and the higher the elasticity of substitution σ, the faster the changes in demand, and the faster price adjustment should be. Hence, to reach the equilibrium, it was supposed that consumers relocate their relative expenditure slowly (E_f), which allows firms to adjust prices and stock level. A simple way to delay the expenditure adjustment is:

$E_f = (P_f\, Qd_f) / Y$, where Qd_f is given by the equation 4 (26)

$E_f^* = \mu\, E_f + (1 - \mu)\, E_{f\,(t-1)}$, where $0 < \mu < 1$ (27)

$Qd_f^* = E_f^*\, Y / P_f$ (28)

These equations merely say that the actual expenditure of product is a weighted average of the expenditures in the previous period (weighted by 1- μ) and the expenditure computed for the current period (weighted by μ). Of course the dynamic equilibrium depends on the values of μ, which decreases as σ increases. This artifice delays changes in demand and keeps supply and demand sides balanced.

6.3. Illustrative Simulations

The artificial industry of the simulations has the following setup: (1) 100 potential firms or technologies; (2) the consumer income is $1,000; (3) at the beginning of the simulation (time = 0), the economy has just 10 firms and each of them has an initial capital of $10; (4) the nominal wage is $1; (5) in each period of time one firm is added to the industry; and (6) the interest rate or dividend policy is $\gamma = 0.1$. When a firm fails, its technology is expelled from the industry and do not return. Hence, the simulations show an industry evolving from a small "industrial seed" to a set of the most efficient suppliers.

The agent-based model is quite flexible and allows the simulation of several industries by changing product and process technologies (A, F and C), markups (Mk), and consumer behavior (σ). Additionally, different values for α can endow firms with different technologies and markups.

In the simulation below, four typical industries are created. The first industry is a competitive industry (no economy of scale and homogeneous product); the second is a differentiated industry (no economy of scale and differentiated product); the third is a concentrated industry (large economies of scale and homogeneous product); and the fourth is a concentrated-differentiated industry (large economies of scale and differentiated products). The parameters of these four industries are shown in table 2. The industrial structures of the simulations are summarized in tables 3 to 6.

Table 1: The Artificial Industry – Size and Behaviors

Consumer Income ($)	1000
Maximum number of firms	100
Initial Funding ($)	Average capital of firms
Number of entry per period	1 firm
Dividends policy or interest rate (γ)	0.10
Profit rate at steady state ($\pi_f / K_f = \gamma$)	0.10
Quality (A_f)	$1 \leq Af \leq (1 + \alpha)$
Fix cost (F_f)	$F \leq F_f \leq (1 + \alpha)\ F$
Input requirement (C_f)	$C \leq C_f \leq (1 + \alpha)\ C$
Markup (Mk_f)	$(1 + \gamma) < Mk_f \leq (1 + \alpha)(1 + \gamma)$

Table 2: Technologies of Four Industries

	Fix Cost (F)	Marginal Cost (C)	Elasticity of Substitution (σ)
Industry 1	0.1	0.75	10
Industry 2	0.1	0.75	5
Industry 3	2.5	0.75	10
Industry 4	2.5	0.75	5

The first industry has a low fixed cost F and economies of scale. This industrial structure is quite close to a perfect competitive industry when $\alpha = 0.00$: firms have symmetric technologies and consumers see all products as homogeneous goods (high elasticity of substitution). Hence, any price asymmetry tends to produce large change in demand, and eventually expel varieties and technologies. That is the reason of 47 failures when $\alpha = 0.50$. Technological asymmetries produces large industrial concentration, albeit the limited economies of scales (Table 3).

The second industry has also limited economies of scale (low fix cost F), but its products are seen as differentiated (low elasticity of substitution σ). Because products are differentiated, consumers resist changing the consumption of varieties when prices diverge. The combination of asymmetric technologies and low price elasticity of demand create an industry where firms have different sizes and prices. Thus, when $\alpha = 0.25$ there is no failure, and the potential technological advantage of the leaders are not able to overcome the preference for varieties related to product differentiation (Table 4).

Table 3: Performance of a Competitive Industry
(F = 0.1, C = 0.75, σ = 10, μ = 0.10)

Technological Asymmetry (α)	0.00	0.25	0.50
Number of Firms	100	87	53
Avg. Size	9.091	10.449	17.153
Std. Dev. Size	0.000	8.654	21.518
Avg. Price	0.834	0.948	1.005
Std. Dev. Price	0.000	0.067	0.126
Avg. Markup	1.110	1.225	1.389
Std. Dev. Markup	0.000	0.076	0.148
Avg. Quality	1.000	1.133	1.328
Std. Dev. Quality	0.000	0.070	0.127
Avg. Fix Cost	0.100	0.112	0.121
Std. Dev. Fix Cost	0.000	0.007	0.014
Avg. Input Req.	0.750	0.844	0.893
Std. Dev. Input Req.	0.000	0.052	0.103
Avg. Profit Rate	0.100	0.100	0.100

Table 4: Performance of Differentiated Industry
(F = 0.1, C = 0.75, σ = 5, and μ = 0.10)

Technological Asymmetry (α)	0.00	0.25	0.50
Number of Firms	100	100	99
Avg. Size	9.091	9.091	9.183
Std. Dev. Size	0.000	3.539	6.828
Avg. Price	0.834	0.937	1.058
Std. Dev. Price	0.000	0.061	0.141
Avg. Markup	1.110	1.259	1.383
Std. Dev. Markup	0.000	0.071	0.161
Avg. Quality	1.000	1.125	1.253
Std. Dev. Quality	0.000	0.070	0.143
Avg. Fix Cost	0.100	0.114	0.126
Std. Dev. Fix Cost	0.000	0.007	0.016
Avg. Input Req.	0.750	0.839	0.935
Std. Dev. Input Req.	0.000	0.052	0.110
Avg. Profit Rate	0.100	0.100	0.100

The third and fourth industries add to the first and second industries economies of scale (high fix cost F). The third industrial structure has homogeneous products (high elasticity of substitution σ) and large economies of scale. Since products are almost perfect substitutes, the firm with a large production would have lower prices and tends to control a large share of the market. In the first case (the competitive industry), due to the limited economies of scale, small firms can face the concurrence of large firms, but in this third case that does not happen. Even though the similar level of technological asymmetries, the high economies scale is a force that expels small firms, block the entry of latecomers with limited initial capital, and pushes the industry to high levels of concentration (Table 5).

Table 5: Performance of Concentrated Industry
(F = 2.5, C = 0.75, σ = 10, and μ = 0.10)

Technological Asymmetry (α)	0.00	0.25	0.50
Number of Firms	32	13	9
Avg. Size	29.326	69.930	101.010
Std. Dev. Size	0.000	31.706	71.509
Avg. Price	0.902	0.924	0.948
Std. Dev. Price	0.000	0.047	0.054
Avg. Markup	1.110	1.242	1.432
Std. Dev. Markup	0.000	0.066	0.160
Avg. Quality	1.000	1.223	1.440
Std. Dev. Quality	0.000	0.021	0.037
Avg. Fix Cost	2.500	2.790	3.001
Std. Dev. Fix Cost	0.000	0.205	0.384
Avg. Input Req.	0.750	0.799	0.826
Std. Dev. Input Req.	0.000	0.026	0.033
Avg. Profit Rate	0.100	0.100	0.100

Table 6: Performance of Differentiated-Concentrated Industry
(F = 2.5, C = 0.75, σ = 5, and μ = 0.10)

Technological Asymmetry (α)	0.00	0.25	0.50
Number of Firms	57	28	22
Avg. Size	15.949	32.468	41.322
Std. Dev. Size	0.000	10.459	17.388
Avg. Price	0.978	0.962	1.008
Std. Dev. Price	0.000	0.067	0.098
Avg. Markup	1.110	1.238	1.399
Std. Dev. Markup	0.000	0.066	0.183
Avg. Quality	1.000	1.198	1.427
Std. Dev. Quality	0.000	0.037	0.070
Avg. Fix Cost	2.500	2.816	3.078
Std. Dev. Fix Cost	0.000	0.191	0.358
Avg. Input Req.	0.750	0.788	0.834
Std. Dev. Input Req.	0.000	0.032	0.058
Avg. Profit Rate	0.100	0.100	0.100

The fourth industry has differentiated product and technologies plus high economies of scale. In this case, the low substitutability blocks the centripetal force represented by the economies of scale. Because consumers see product as differentiated, they change demand only if prices are extremely asymmetric. The low price elasticity of demand gives thus some resistance to firms and creates an industrial fringe characterized by relatively small firms with high price and differentiated products (Table 6).

To illustrate how the industry evolves, figures 1 to 6 present the time-path of the concentrated-differentiated industry when $\alpha = 0.25$. Figure 1 presents the firm population evolving. The figures 2 and 3 show the price and markup structures at the steady state. As it is shown, there is a negative relation between price and firm size, but the relation is not as smooth as one could expect. Figure 3 presents the markup and firm size. There is just a weak relation between these two variables because technologies are asymmetric and products are differentiated. Figure 4 presents the technologies (parameters F_f, C_f, and A_f) and firm size. Once again there is no clear technological pattern because the firm technological capability is a mix of three parameters, and there is nothing that guarantees firms will have the same performance in all of them. Figure 5 shows the firm size distribution, and figure 6 presents the progressive move toward to equilibrium profit rate ($\pi_f / K_f = \gamma = 0.10$).

The simulations also show that industries reach a steady state even when firms and consumers are asymmetric. That is not the case of the standard Dixit-Stiglitz models of monopolistic competition, such as Krugman (1979 and 1980). Fujita *et al* (1999, chapter 4) observes that several mainstream models have quite “unrealistic” assumptions and generates “odd industries”, such as: (i) in the supply side all firms have the same size; and (ii) in the demand side consumers have “symmetric differentiated preferences”. Figure 7 illustrate the curious industrial structures that emerge from simulations when the assumption of symmetric technologies is adopted. When $\alpha = 0.00$, all firms have the same technological structure, thus at the steady state they are identical: size, market share, prices and so on.

In the model proposed above it is possible to drop some “unrealistic” assumptions and generate industrial structures where firms have persistent heterogeneous technological capabilities, variations in size, and asymmetric market shares and prices. Beside that, the industries display skewed distributions of firms even when they reach a steady state (Figures 6 and 7). Hence, the model seems to be able reproduce some empirical regularities of industrial organization, such as those presented and commented by Axtell (2001), Kwasnicki

(1998), Mazzucato & Semmler (1999), Winter, Kaniovski & Dosi (2000 and 2003) among others.

There are several theoretical and empirical aspects of the model and simulations that would deserve a more extensive and careful comments. For example, an important topic is related to how firms behave when expectations are not confirmed. It was supposed that firms adapt to market conditions following one single set of rules: they invest all capital hiring workers, managers set prices adding a fixed markup to the average cost, firms do not innovate or search for new techniques, and finally, firms have no memory and do not form expectations on price and production.

The routines to the simulations form a regular and predictable behavior of firms. They are not intended to be strictly accurate or reliable in every situation, and alternative routines could be added to the model, for example: research and development routines, procedures of hiring and firing workers, management of inventories, different reactions to demand changes, and several pricing rules. For sure, these different behaviors would change the industrial structures described above.

Figure 1: Firm population evolving
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

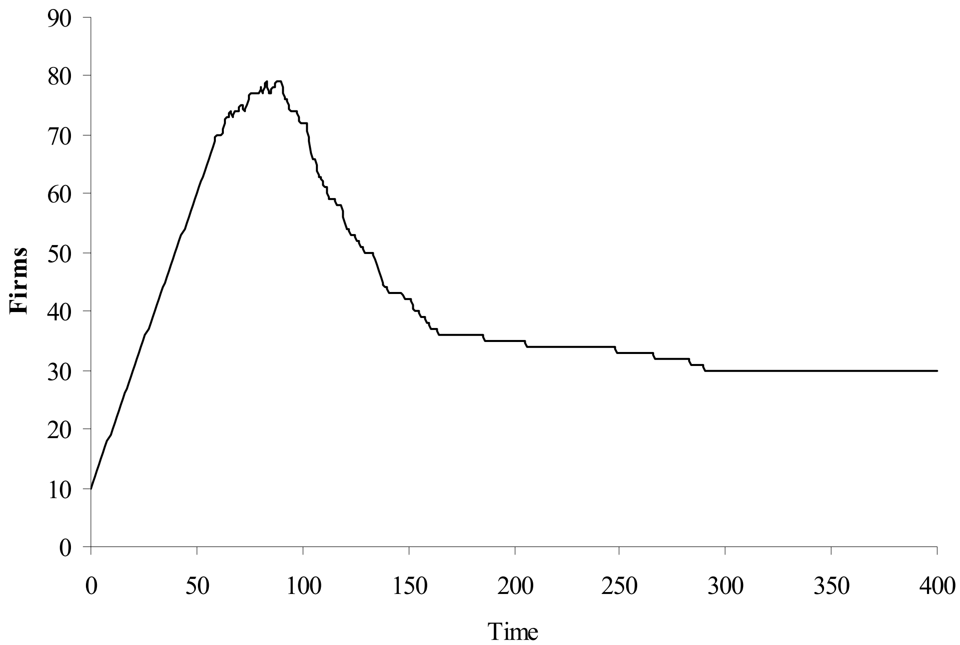


Figure 2: Firm price at steady state
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

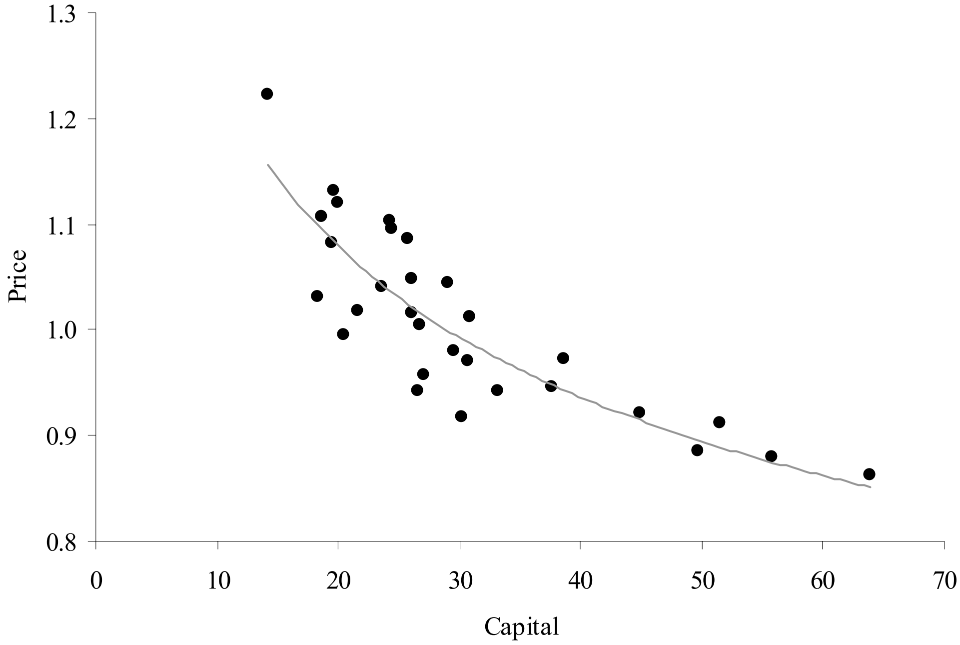


Figure 3: Firm markup at steady state
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

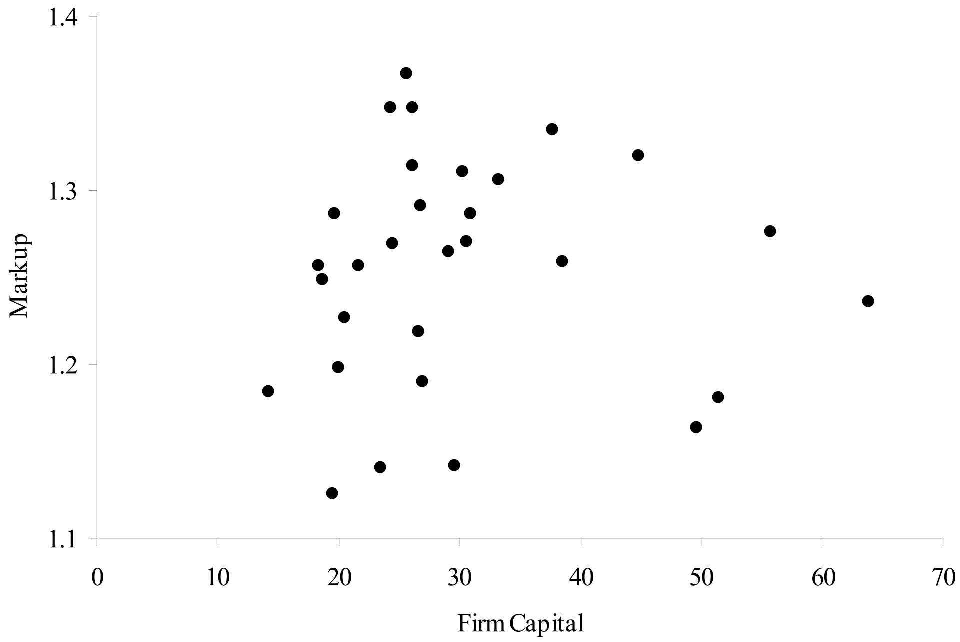


Figure 4: Technologies at steady state
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

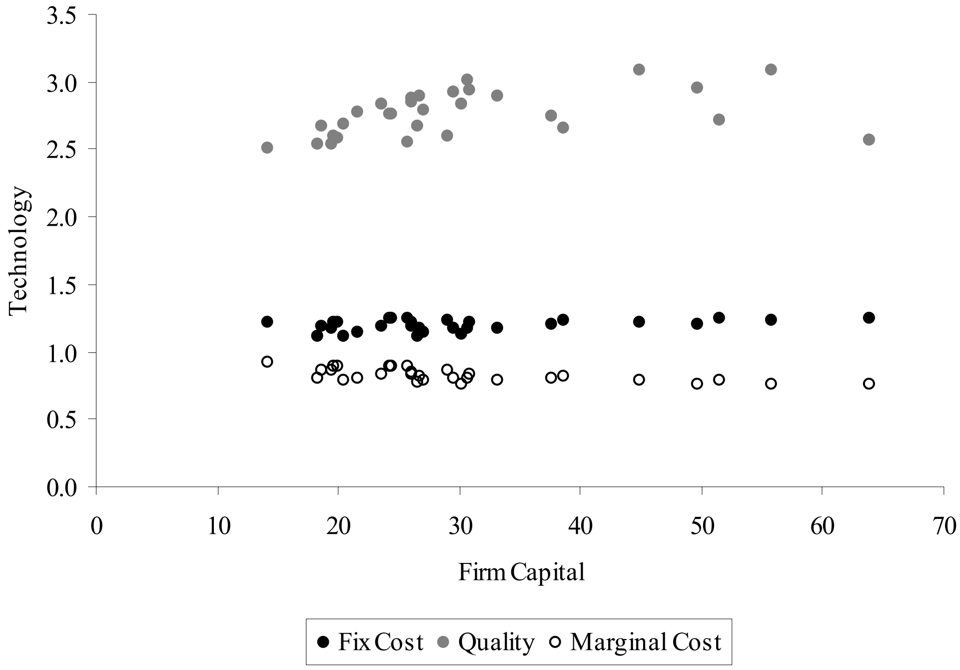


Figure 5: Firm size distribution at steady state
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

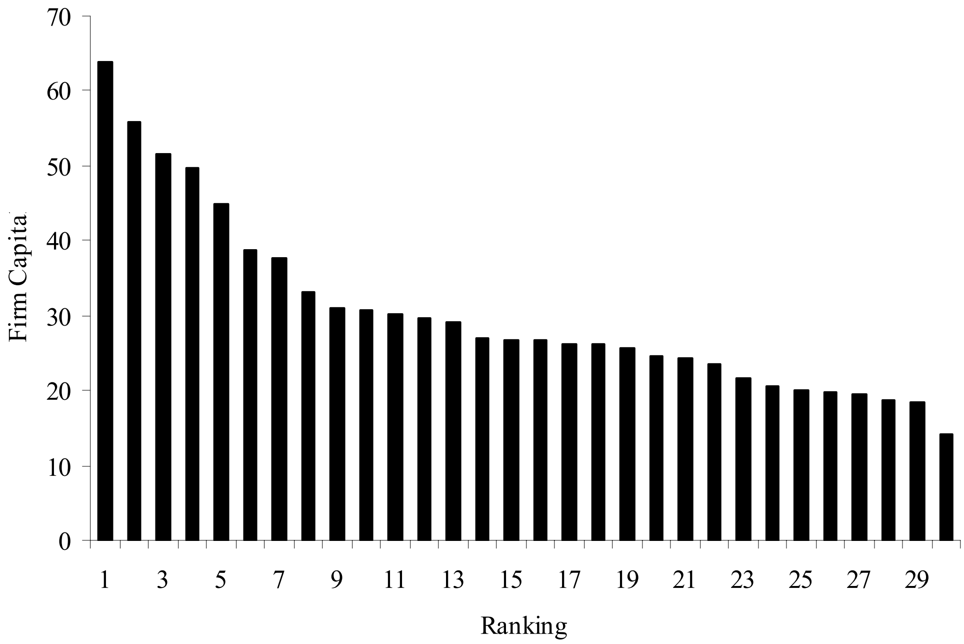


Figure 6: Equilibrium Profit Rate and it Standard Deviation
(F = 2.5, C = 0.75, σ = 5, and α = 0.10)

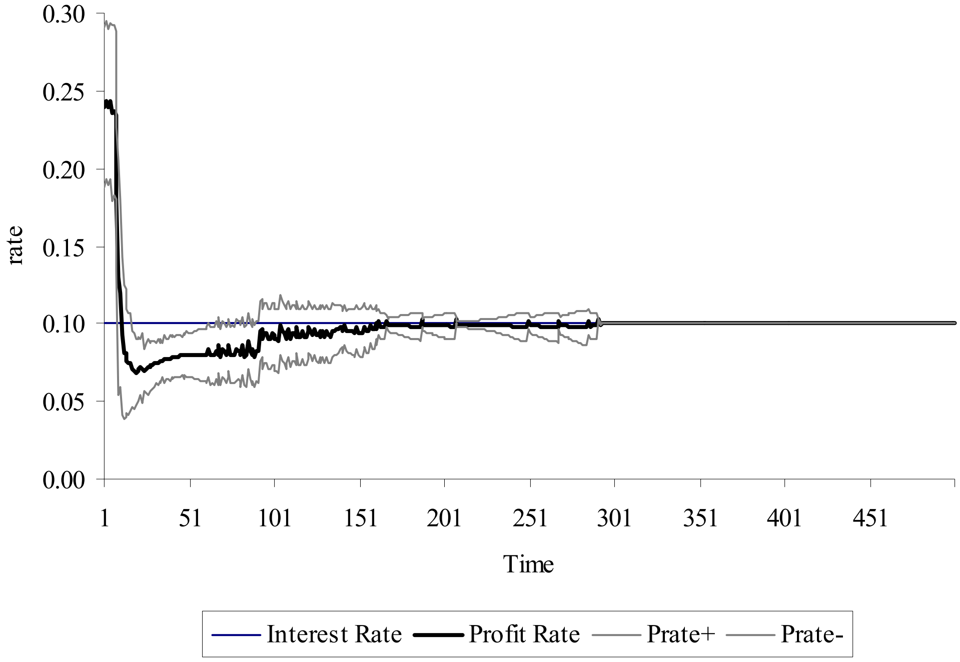
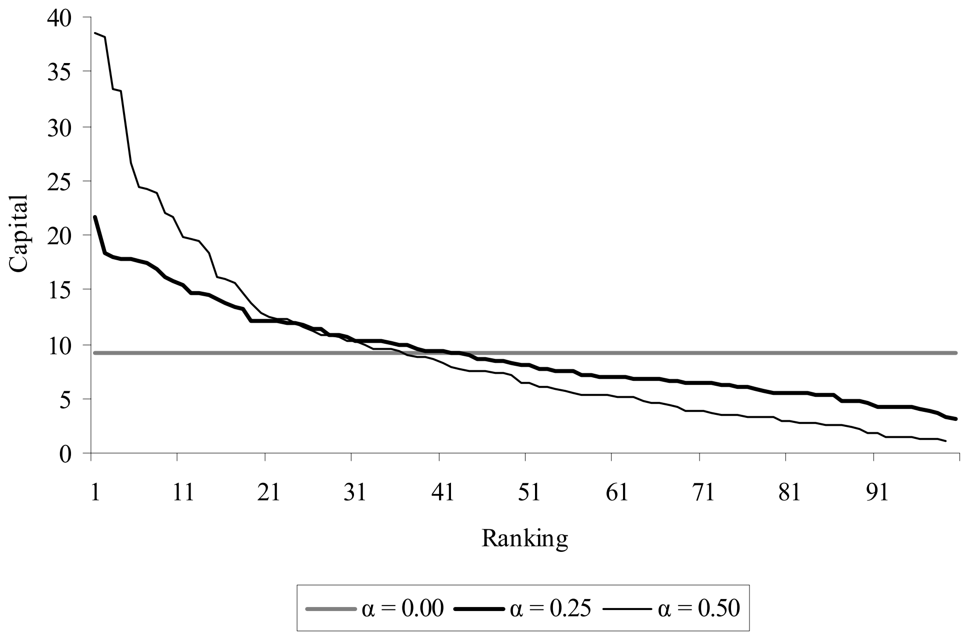


Figure 7: Firm size distribution at steady state
(F = 0.1, C = 0.75, and σ = 5)



7. CONCLUDING REMARKS

The preceding topics outline a microeconomic model with heterogeneous agents. The industry was shaped by a large collection of asymmetric firms that took decisions in a complex environment following simple routines. Although the work explored a limited range of behaviors, the simulations showed that coherent industrial structures emerged in world with limited information and populated by low-rational and heterogeneous agents. The simulations also demonstrated that the model was able to mimic some stylized facts, such as firms with different sizes and market with asymmetric prices. In sum up, the model suggests how industrial structures can be created "bottom-up" in a non-Walrasian world.

The theory developed here, like any other theory, abstracts away from complications that inevitably arise in applications. A number of theoretical problems were left untouched, in particular the routines employed by firms when setting prices and investing, the absence of any speculative behaviors (expectations), the role of different financial system, and diffusion and imitation procedures.

Nonetheless, there is a positive aspect that must be emphasized: the ability of the model to simulate industrial structures where agents (firms, investors, and consumers) have their own endowments, memories, preferences, and behaviors. It allows researchers to work with the whole population of agents. Multi-agent kits make possible to drop measures of asymmetries and introduce the whole population of agents with all their idiosyncratic quantitative and qualitative characteristics. For those that want to move beyond microeconomic models with instantaneous equilibrium, representative agents, and full rational agents, that is a welcome feature.

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