11

Creation and Co-evolution of Strategic Options by Firms: an Entrepreneurial and Managerial Approach of Flexibility and Resource Allocation

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The success of a firm depends on its capability to create and exploit new projects, routines and technologies. Those projects are competitive opportunities that the firm must recognize, evaluate, and on which it has to be able to apply operating capabilities to take advantage of them. The general management responsible for the firm's strategic direction frequently fails to manage the organization's technological innovation process that creates these opportunities (Adner and Levinthal, 2004). To help managers in their decision-making process in uncertain environments new techniques and theories are developed; one of them is the real option theory. This conceptual decision-making framework is about to become a standard. The formal approach, originating from financial models, dealing with future uncertainty and the opportunities a firm can seize, is appealing to managers.

A major issue, almost ignored in this literature, is the question of the origin of the real options a firm possesses. A suggested answer is the use of the entrepreneur/manager duality to explain the creation of new options. The insights gained from considering real options and entrepreneurship are bidirectional. On the one hand, entrepreneurship, in a resource-based framework, can explain the origin of real options and contribute to a better evaluation of their value. On the other hand, real options can explain the direction a decision maker gives to the development of the new capabilities and resources, as an entrepreneurial activity, by suggesting another use of those resources. Combining entrepreneurship and real options explains the heterogeneity of the firm and its resources collection

and capability building. A conceptual model of the option chain (the successive steps of creation, development and use of an option) is presented by Bowman and Hurry (1993).

This conceptual representation highlights the necessity for the firm to change its structure (between entrepreneurial, physical and human capital) in order to be able to explore and create new options and exploit them accurately to survive the competition at the industry level. This work formalizes this conceptual representation into a simulation model.

The next section of the chapter outlines the real option approach and its implication in strategic management for describing exploration and exploitation decisions. The second section presents the model. The following two sections detail the results of the model. The final section wraps up the results.

11.1 Exploration–exploitation representation as an option chain

In the strategic theory of the firm (Teece et al., 1997) the most obvious of the long-term goals of the firm is its survival. Survival is achieved by seizing profitable opportunities when they arise or are encouraged to emerge. In the long run the profitability, survival and growth of a firm do not depend so much on the general efficiency with which it is able to organize production as it does on the ability of the firm to establish one or more wide and relatively impregnable competence 'bases' from which it can adapt and extend its operations in an uncertain, changing and competitive world (Penrose, 1959, p. 137).

An option gives the right but not the obligation to take a specific decision (invest, defer, alter) on an underlying asset, for a predetermined price at, or before, a certain time. For example, a firm can possess a production plant, and choose, depending on customer demand or competition, to build a bigger capacity plant to achieve economies of scale (a growth option) or, to the contrary, to temporarily shut down the plant (option to defer production). The firm has the right, but not the obligation, to change its production capacity. This option, depending on the information at hand at the moment of exercise, allows the firm to catch new revenue flows or to reduce costs.

Figure 11.1 represents the successive developments of the real option chain in the strategic management literature. The following discussion and presentation of the option chain and the introduction of the entrepreneur/manager rely on this figure.

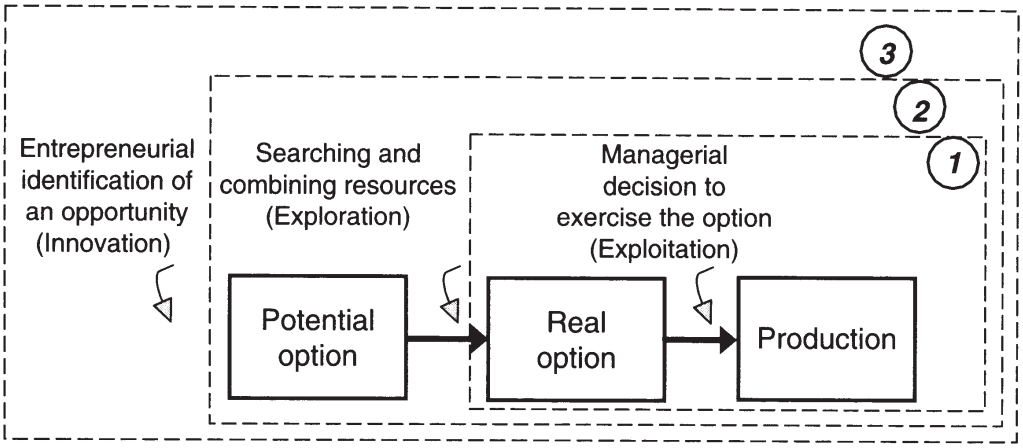

Figure 11.1 The option chain in the strategic literature

11.1.1 Standard option exploitation

The area labelled 1 on Figure 11.1 represents the initial step of the real option theory as it can be found in today's major textbooks on that topic (Amram and Kulatilaka, 1999; Trigeorgis, 1996). This short option chain is the following. The option is supposed to exist, to lie in the hands of the decision maker. The decision maker (always referred to as the 'manager' in this literature) evaluates the option contingently to the future possible states, and decides whether to exercise it or not. 'Exercise' means that the project enters a phase of building and operation. Once the firm is in an operational phase new options can arise such as expanding the size of the plant, diversifying production, or in the worst case, stopping production and shutting down the factory.

11.1.2 Exploration of the identification of opportunities, the emergence of the potential option

This development, as noted by academics in the strategic management field, makes the important assumption that the option exists and that the decision maker is informed of its existence. This is, obviously, not always the case. Bowman and Hurry (1993), struck by that implicit hypothesis, introduced the notion of a shadow option (or potential option as explained later on), the option that a firm could exploit, or at least consider in its portfolio of choices supposing it is aware of it. The option that a firm possesses depends on the resources and knowledge available inside the firm but ignored by decision makers.

Opportunities (and not yet options) come into existence when individuals have different beliefs in the possibilities offered by the available

or potential resources to transform some inputs into specific outputs that can be sold and raise a profit (Kirzner, 1979). An opportunity is a favourable, momentary circumstance or situation that has been recognized after one has sought it or it has spontaneously appeared. Once the potential option is taken into account (area 2 in Figure 11.1) the rest of the option chain can be considered in the same way as described above. When the shadow option is recognized, it moves from a potential option label to become a real option. The option has then to be evaluated, and compared with other options; one must also take into account probable interactions between them in the portfolio of option decisions available to the firm.

The addition made by Bowman and Hurry (1993) does not completely answer the question of the origin of the real option; it merely shifts the debate. Instead of explaining the origin of the real option, the genesis of the potential option must be elucidated.

11.1.3 Introduction of the entrepreneurial resource

A historical approach of entrepreneurs in microeconomic theory (Barreto, 1989) shows that when authors need to introduce novelties or special variations into a theory of the firm they often refer to the figure of the entrepreneur. In this work we consider entrepreneurship as a resource of the firm and an opportunity exploiter (Cohendet et al., 2000). Kirzner introduced the concept of 'entrepreneurial alertness' as the special ability of the entrepreneur to see where products (or services) do not exist and can be profitably exploited. Alertness exists when one individual has an insight into the value of a given resource while others do not. From this perspective, entrepreneurial alertness refers to 'flashes of superior insight' that enable one to recognize an opportunity when it presents itself. As already mentioned, the starting point of the potential option is the identification of an opportunity.

Once the opportunity is identified one can note that the entrepreneur certainly does not have the specific knowledge and expertise in all domains necessary to fulfil his goal. He must still find and combine adequate resources for his endeavour. The acquisition of a new productive capability by building a new competence is not instantaneous. The building process is mainly path-dependent and involves the tacit knowledge acquired by learning by doing and experimentation. This implies that firms which create knowledge are also option-creating firms. By creating new knowledge these firms expand their cognitive frames, part of the real option heuristics. Here the value of the entrepreneurial resource

appears as having the ability to combine different expert knowledge with the aim of exploiting opportunities.

The decision to exercise the option and to turn to a production phase corresponds to a managerial decision-making process. The reason why the manager does not enter the option chain earlier comes from the nature of the output of the shadow option. The output of the knowledge-building process (what is done during the shadow option) is difficult to evaluate, knowledge is dispersed and the manager is not aware of all the pieces before the entrepreneur terminates his action. The managerial decision depends on the balance between entering the market with the actual resources and knowledge or waiting to absorb more capacities.

11.2 The model: creation of options and firms

This section details the model of creation of new options (discovery of technological alternatives) and the creation of new organizations. The formulations are directly inspired by the models of Miller and Arikan (2004), Nelson and Winter (1982), Winter (1984); Grebel et al. (2003) for the entrepreneurial representation. The market structure of the model is presented in Section 11.2.1; later we introduce a maximum level of development for each technology and then determine the alternatives (Section 11.2.2). In a third point we represent the creation of potential options by agents involved or external to an existing firm (Section 11.2.3).

Figure 11.2 schematizes the structure of the model. We distinguish three levels of analysis: the level of the agents, of the firm and of the industry. The entrepreneurial process creating the potential options begins at the agent level. An initial set of heterogeneous agents is generated. These agents are randomly paired. The gathered agents form a potential firm with a view to exploit an option discovered by one of them. This option is a new technology which enters the production process of a homogeneous good exchanged on the market. Their decision to build a firm is based on their joint evaluation of the economic situation which relies on the available economic indicators. If the agents decide not to found new firms, they return to the set of the potential agents for the following period. If the agents decide to found a firm, they are withdrawn from the set.

The firm is then established. The agents turn the potential option into real options that the firm can use to produce. At the industry level the new firm competes with existing firms. The competitiveness of the firm

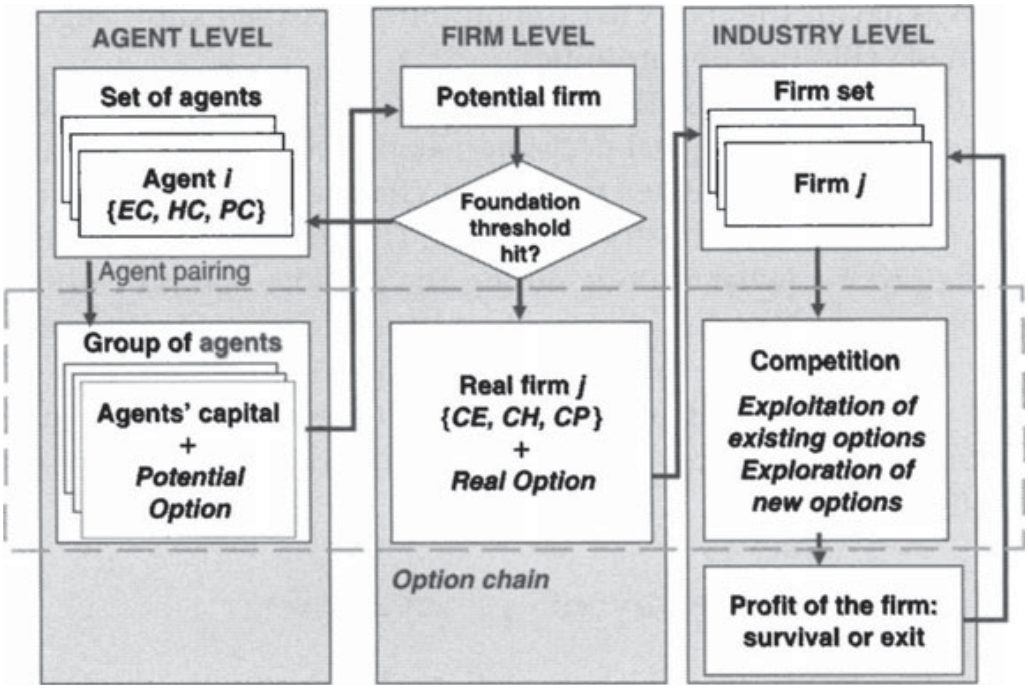

Figure 11.2 Interaction of the option chain with the agent, firm and industry

depends on the level of development of its technology and its stocks of physical and human capital. The process of selection that takes place is a competition over the quantity produced. At the same time as the competition for the development of existing technologies takes place, a competition for the exploration of new technologies occurs. Thus, within each existing firm, an entrepreneurial agent can at each period discover a new potential option. According to the reception reserved for this discovery by the firm, the option will be exercised within the firm and will increase the size of the technological portfolio of the firm. If the firm does not accept to develop the new technology a splitting of the firm into two entities takes place. One unit develops the new technology; the other focuses on the old techniques. The lengthy process of selection which takes place evaluates the entrepreneurial idea (the potential option), and the quality of the managerial decisions taken (transformation into real option) by the firms.

11.2.1 Market and industry

The market is represented by N firms producing the same homogeneous good. At the beginning of the simulation, each active firm F_i in the industry has two technologies, perfectly substitutable, with the same initial productivity and the same maximum capacity of development.

Each firm is determined by a quadruplet:

$$F_{i,t} = \{g, \{EC_{it}, HC_{it}, PC_{it}\}\} \tag{11.1}$$

In this expression g represents the gender of the firm, either an evolutionary firm, or an option-based reasoning firm. The gender is invariant for the firm over all the duration of the simulation. An evolutionary firm is a firm that only uses one technology as long as a satisfaction criterion is met; an option-based firm is a firm developing a portfolio of different options – see Miller and Arikan (2004) for a definition of those firms.

The elements *EC*, *HC* and *PC* respectively represent the entrepreneurial, human and physical capital (machines) of the firm. These elements are positive or nil. The combination of these three elements enables us to represent the creation of the potential and real options as well as the creation of new firms.

11.2.1.1 Demand and supply

The quantity of goods produced by a firm is Q_{it}. At each period, firms produce at the maximum of their capacity. The demand absorbs all the production emanating from the firms (with an adjustment of the prices); there is no limitation in terms of inputs of production as long as the firm is able to finance its expenditures. As in the model of Nelson and Winter, the total offer of the market is Q_t.

$$Q_{it} = T_{it}^{*} \cdot (q_h HC + q_p PC) \tag{11.2}$$

$$Q_t = \sum_{i=1}^{N} Q_{it} \tag{11.3}$$

where T^* represents the best technology used by the firm to produce. The *HC* element is an aggregate representing the whole human resources of the firm, both the agents in charge of production and the researchers. *PC*, the physical capital, corresponds to the machines used for production. The parameters q_h and q_p have several attributes. When the parameters are defined for the unit [0; 1] they represent the share of agents and physical capital dedicated to the production. When the parameters are dependently defined ($q_h + q_p = 1$), they can be interpreted as the share of human capital necessary for production compared to the share of machines. Lastly, leaving aside these scales, they make it possible to calibrate the model. Price P_X for the homogeneous good is obtained

by the following expression, identical to that employed by Nelson and Winter:

$$P_X = D(Q_t) = \frac{D}{Q^{1/\varepsilon}} \tag{11.4}$$

with D the demand, and ε elasticity of the demand to the price.

The calculation of the sales turnover of the firm ($CA_{i,t}$) and profit is given by

$$CA_{i,t} = P_X \cdot T_{it}^{*}(q_h HC + q_p PC) \tag{11.5}$$

$$\Pi_{it} = CA_{it} - c_e EC - c_H HC - c_p PC \tag{11.6}$$

where the c's represent the various production costs per unit of capital.

The firms, who make a positive profit, invest it in R&D in order to develop technologies which they have in their portfolio and in their physical and human capital.

11.2.1.2 Investment in capital and R&D

We assume that the costs of acquisition of human, physical and entrepreneurial capital are constant. The profit released at the end of each period is allocated in the following way:

$$\Pi_{i,t} \equiv \Delta PC_{i,t} + \Delta HC_{i,t} + \Delta EC_{i,t} + S_{i,t} \tag{11.7}$$

where $S_{i,t}$ is the capital invested in the improvement of existing technologies.

The variations of the different types of capital follow these expressions:

$$\Delta PC_{i,t} = \text{Min}\left[0; \left(\frac{q_p}{q_h + q_p} - q_e\right)(\Pi_{i,t} - S_{i,t})\right] \tag{11.8}$$

$$\Delta HC_{i,t} = \text{Min}\left[0; \left(\frac{q_h}{q_h + q_p} - q_e\right)(\Pi_{i,t} - S_{i,t})\right] \tag{11.9}$$

$$\Delta EC_{i,t} = \begin{cases} \text{Min}[0; q_e(\Pi_{i,t} - S_{i,t})] & \text{if } Tn < TN \\ 0 & \text{otherwise} \end{cases} \tag{11.10}$$

with

$$q_e = \frac{q_h}{2(q_p + q_h)}$$

Since our model aims at determining the effects of the creation and exploitation of technological options we give priority to the expenditure in R&D. The allocation of profit remaining after allocation to research depends on the choice made by the firm whether or not to develop several technologies in parallel. When *Tn* the number of alternative technologies the firm holds reaches *TN* (the maximum number of technologies it wishes to have in its portfolio), it stops investing in entrepreneurial capital; in the opposite case a remaining share of the profit is allotted to the entrepreneurial resource. When the profit is negative the firm sells its physical capital until it reaches a level of minimum capital which forces it to leave the industry.

After having clarified the mechanism of profit allocation, we now present the mechanism of alternative technology generation and development.

11.2.2 Determination of alternative technological options

We introduce the possibility of having *TN* technologies. Each technology allows the production of the same homogeneous good but with different potentials of development. A new technology is composed of two indications, the probability that this alternative is discovered and its maximum development potential. We model each one of these points according to several specifications, taking as a starting point those retained by Nelson and Winter.

11.2.2.1 Determination of the maximum productivity of a technology

The maximum level of development of an alternative technology, T_{n+1}, is computed according to two methods: (i) on the level reached by the firm and (ii) a technical progress which depends on the evolution of basic science with time. Whenever a new technology is given on the basis of the level reached by the firm, the maximum level is obtained by a random draw according to a normal law, so that

$$T_{n+1}\,\max = N(T_n^*;\, EC + HC) \tag{11.11}$$

where T_{n+1} max represents the maximum level of development that technology $n+1$ can reach. The T_n^* variable has different significances depending on the case considered. In the case where the next technology

is based on the maximum level of a firm, T_n^* represents the maximum level reached by the firm at the time when it seeks an alternative technology.

The parameters *EC* and *HC* are used to compute the standard deviation in the random drawing, so that $\sigma = (EC + HC)$. The summation of the two parameters can be interpreted as the ability of the entrepreneur to seek and combine (human) resources in order to give form to his creative idea.

In the second representation the maximum level a technology can reach is based on the assumption of a growth of knowledge underlying the technologies so that

$$T_{n+1} \max = N(\theta t^*;\ EC + HC) \tag{11.12}$$

Thus, the maximum level that technology $n+1$ can reach depends on the moment t^* where the random draw occurs and on a parameter θ representing the drift of the knowledge growth. The parameters $EC + CH$ have the same function as previously indicated. These specifications give the maximum level of development that a new technology can reach; this level is unknown to the entrepreneur and to the firm. It is only when the firm decides to develop a technology and that its development does not produce any further progress that it knows that the maximum limit has been reached (if there is no improvement during τ periods, the firm stops investing in that technology).

11.2.2.2 Creation of an option as a technological alternative

We retain several forms of options creation related to the nature of the firm and the nature of the option. The options can be potential or real, and can be created within an existing firm or by an entity resulting from the work of an entrepreneur (newly created firm or splitting of an existing one). Thus the creation of the options influences the dynamics of an industry since the entries and exits of firms on the market are directly dependent on them.

11.2.3 Creation of a potential and real option within an existing firm

The creation of a new potential option is represented as an entrepreneurial action based on the existing structures of the firm. It is the result of a random draw from a uniform law, such as

$$\begin{aligned} &\text{Prob[creation of a potential option, } P_{\text{PO}}(t) = 1] \\ &= \text{Min}[\omega(EC_t), 1] \end{aligned} \tag{11.13}$$

where ω is a calibration parameter. The probability that the firm agrees to develop this potential option, to exercise it, in order to obtain a real option is given by

$$\text{Prob[exercise the potential option, } P_{\text{RO}}(t) = 1]$$
$$= \text{Min}\left[\frac{\Omega}{\omega}\left(\frac{HC_t + PC_t}{EC_t}\right), 1\right] \tag{11.14}$$

where Ω is a calibration parameter.

The creation of potential options, according to this description, corresponds to an innovation within the meaning of Schumpeter Mark I. In this approach the introduction of an innovation is independent from the human and physical capital of the firm (researchers and laboratory). A formulation describing the creation of a potential option as an innovation made by a laboratory (a large company) within the meaning of Schumpeter Mark II would be obtained by introducing into equation (11.13) the human capital *HC* which contains agents dedicated to R&D. An alternative solution would be the implementation in the model of an additional equation where the creation of potential options would depend on the human capital of the firm. However, we prefer the approach above since it respects the dichotomy between radical and incremental innovations (Abernathy and Utterback, 1978). Our description corresponds to a situation where laboratories ($HC + PC$) make innovations of the incremental type by developing real options. The radical innovations, the potential options, are then introduced by another team of researchers, those who have an entrepreneurial spirit.

The numerators and denominators of expression (11.14) are influenced by the investments in the various capital of the firm (*EC*, *HC*, *PC*). This ratio implies that a firm which obtained a potential option and has a low level of human and physical capital compared to entrepreneurial capital may refuse to exercise the potential option and does not develop the technology as an alternative. However, parameter *EC* depends on the number of alternative technologies *TN* which the firm wishes to have.

11.2.4 Creation of an option and creation of a firm

We describe a population of agents, among whom some will work out a potential option, who need to find resources (human and financial) with other agents to constitute a new firm, which will allow them to exploit the potential-real option.

11.2.4.1 Description of the agents

The agents are heterogeneous from the point of view of their initial endowment in physical capital and competences. The agents are composed of three elements, the entrepreneurial capital (*EC*), the human capital (*HC*) and the physical capital (*PC*). The entrepreneurial capital element determines the creative potential of the individual in the sense of the Schumpeterian entrepreneur. A higher value of this element increases the probability that the individual becomes an innovative entrepreneur and creates a potential option. The human capital corresponds to the stock of knowledge of the agent, both theoretical and practical. The physical capital represents his contribution if he decides to create a firm; it represents at the same time a contribution in liquidity, machines, buildings... It results from this formulation that the absence of entrepreneurial capital excludes an agent from the creation of an option, that the absence of human capital does not enable him to develop this option, and that the lack of physical capital prevents him from creating his own firm. Also, to be able to exploit an option and to enter into competition the agents must acquire their capital.

Each variable of the triplet determines whether an individual agent belongs to the interval [0,1]. According to a cardinal scale, a higher value indicates a higher level of the element considered. An agent $a_{i,t}$ with $i \in \{1, \ldots, n\}$ is described at each moment t by a vector of the following form:

$$a_{i,t} = \{EC_{i,t}, HC_{i,t}, FC_{i,t}\} \tag{11.15}$$

Each element of the triplet is obtained by a random drawing from a uniform distribution [0,1]. The initial population of agents, A_t, is obtained by generating n vectors a_i.

At each period a subset of k agents are randomly paired in order to evaluate their chances to create a firm together. For that the triplets of the agents are considered additive to obtain a potential $pf_{q,t}$. Formally:

$$pf_{q,t} = \begin{pmatrix} \sum_{i=1}^{k} ec_{i \in k,t} = EC \\ \sum_{i=1}^{k} hc_{i \in k,t} = HC \\ \sum_{i=1}^{k} pc_{i \in k,t} = PC \end{pmatrix} \tag{11.16}$$

k is determined by a random draw from a uniform distribution limited by [2; *CE*max] where *CE*max corresponds to the maximum entrepreneurial capital observed in an active firm in the industry. The passage from

a potential to a real firm depends on the characteristics of the potential firm and on the environment. For this the threshold ψ_t, based on the median value of stocks of capital of the firms present in the industry, must be exceeded. If the *k*th group of agents, which corresponds to the potential firm pf_q has a capital exceeding this threshold, the firm is created.

We compel the new firm to have only two technologies during a certain lapse of time, for two reasons: (i) to allow the firm to correctly enter into competition with the firms already present in the market, and (ii) since the firm was created with the aim of developing and exploiting a precise option, it would not be justified to seek alternatives immediately. If the threshold is reached the agent returns to the initial set which will be used during the next period to generate new potential firms.

11.2.4.2 Splitting of the firms

At the time of the development of a new option within a firm many divergences of opinions can appear. These divergences can lead a number of the individual agents of a firm to leave the organization to form a new one. In such a case a splitting takes place and various stocks of capital are divided to form two new entities. When the two firms split, each new entity is entitled with a set of technologies. One obtains the two best technologies in the portfolio, the other gets the newly discovered technology with the use of the potential option. The splitting takes place by drawing a random number X according to a uniform law [0; 1]. The first entity receives X per cent of the capital and the second the complement. The other parameters are identical for the two firms except for the technologies used.

11.2.4.3 Exit from the industry

The firms which are not sufficiently competitive leave the industry. This occurs when the physical capital falls under a minimum stock of capital threshold (*PC*min) corresponding to the formulation retained by Winter (1984). Let us recall that when the firm makes negative profits it sells its physical capital. This negative profit can have two origins. It can come from the technology employed by the firm which is not sufficiently good to allow the firm to produce at a rather low average cost to compete with the other firms on the market. Or it can come from a exceedingly high stock of capital that generates costs higher than the sales turnover of the firm; this is in particular the case for firms with too much entrepreneurial capital. Thus, a firm which explores too many new technologies because of excessive entrepreneurial capital is rapidly forced to leave the market.

11.3 Results of simulations

This section offers an overall representation of the results of the model. The presentation is made according to the homogeneity or the heterogeneity of the firms compared to particular parameters. Importance is given to the distribution of indicators such as productivity, concentration and the profit of the firms.

11.3.1 Global evolution of the industry

We followed the protocol of Nelson and Winter (1982), with five starting situations corresponding respectively to markets with 2, 4, 8, 16 and 32 firms; a protocol of simulations of this type is used by other authors (Andersen, 2001; Yildizoglu, 2002). The number of firms retained also enables us to modify the percentage of firms of the evolutionary type and of the option type present at the beginning of the simulation. Five configurations were retained:

- Evo-opt0: 100% of evolutionary firms
- Evo-opt1: 75% of evolutionary firms, 25% of the option type
- Evo-opt2: 50% of evolutionary firms, 50% of the option type
- Evo-opt3: 25% of evolutionary firms, 75% of the option type
- Evo-opt4: 100% of firms of the option type

Case 1: All the firms are homogeneous

For each competing structure the firms are homogeneous at the beginning of the simulation in terms of stock of capital and technologies. The values chosen ensure that exploration–exploitation is the same in each configuration and that industry records the same technical progress in the first steps. Thus, the effect of the structure of the industry will only intervene during the simulation.

The first results relate the number of real options created during simulations and the firm entries and exits in the market. Figures 11.3(a)–(e) are average results observed on 100 simulations. The industry initial configuration (percentage of firms of a certain type) always affects the results. Figure 11.3(a) represents the number of options created by firms (already existing or created) during simulation. Two tendencies can be distinguished, according to the axis 'number of firms', and according to the axis 'composition of firms'. First of all, an increase in the number of firms involves an increase in the number of options; in addition, the increase in the proportion of firms with a reasoning based on options leads to a reduction in the options created. This is explained by the fact that

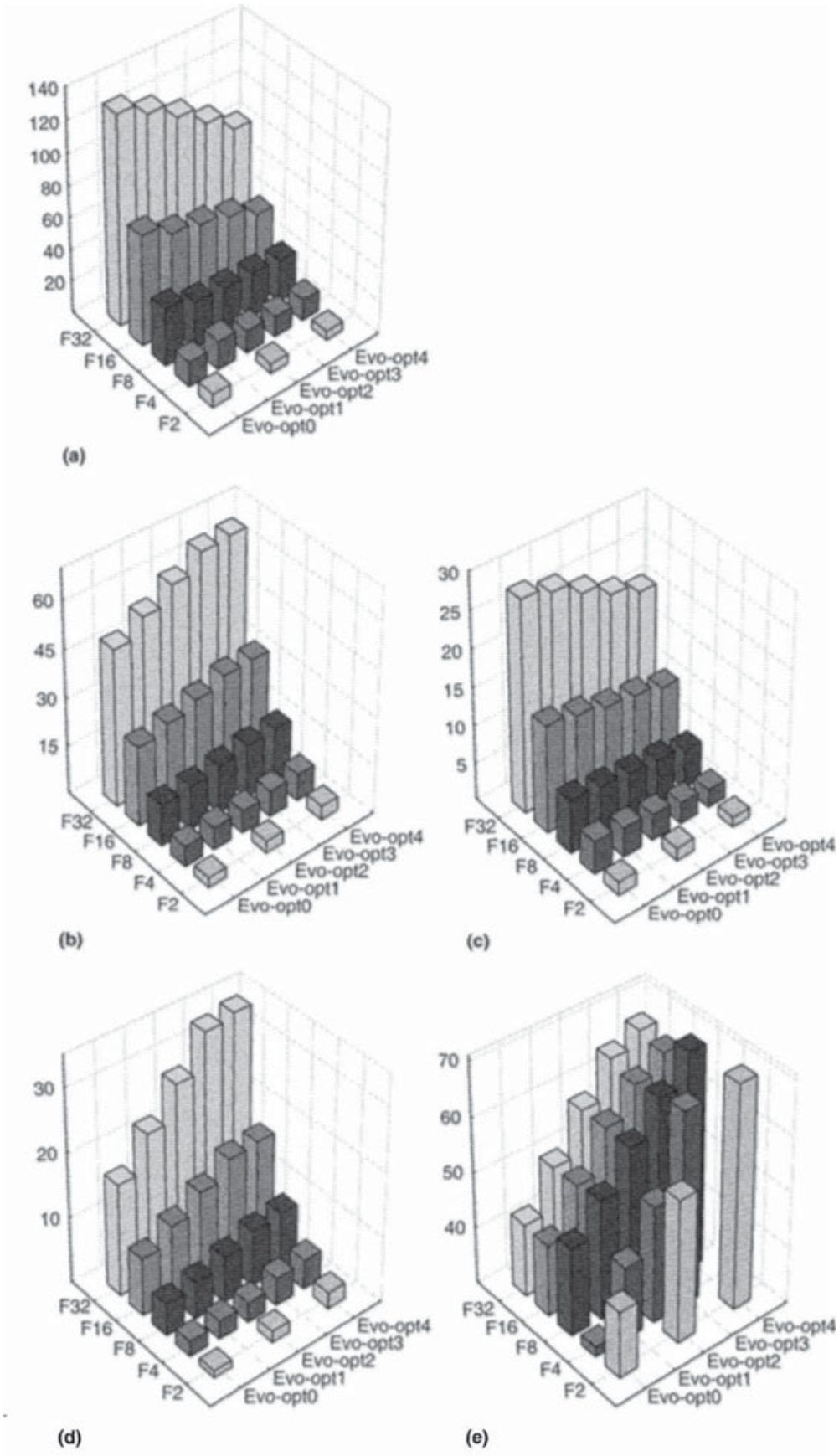

Figure 11.3 (a) Real options created; (b) total number of firms during all the simulation; (c) firms active at the end of the simulation; (d) firms created; (e) firms that exited the industry

option-type firms preserve their options for a longer time so that their portfolios of alternative technologies change slowly. The fact that option-type firms preserve their options at greater length leads the entrepreneurs who discover potential options within these firms to leave them and to create new entities. Figures 11.3(b) and (d) represent the total number of different firms which were active at one time during the simulation and the number of firms created by splitting or newly founded by entrepreneurs outside the industry. An increase in the option-type firms at the beginning leads to a clear increase in the creation of firms during the simulation.

Figure 11.3(c) represents the number of active firms at the end of the simulations and Figure 11.3(e) the number of firms who left the market. The exit rate is stable for the same ratio of evolutionary/option-type firms and increases with the proportion of firms of the option type. The smaller firms created to explore and exploit new options are more vulnerable than the larger firms installed which capitalize on a technology. The result from this is an increase in the exit rate from the industry.

These general results are obtained when all the firms are identical at the beginning of the simulation. Let us see how the results are modified when heterogeneity is introduced for some parameters.

Case 2: The firms are heterogeneous according to a characteristic

The modification of some characteristics also allows us to reconsider the interactions between the various elements of the model. The consequences of these modifications are presented below.

Stocks of human and physical capital. If the capital of a firm at the beginning of a simulation is higher than the capital of other firms, then this firm will produce more than the other firms. As a consequence Q, the total quantity offered, increases and P_X the price of the good drops compared to the basic case we presented. Since P_X is an element of the determination of the rate of profit this rate will fall. The stock of capital of all the firms will decrease accordingly. The same levels of P_X and Q as in our preceding simulations will be obtained but a firm will have a profit higher than the others, although the rate of profit is the same. The rapid fall in the price of the good leads to the exit of a greater number of firms from the market.

The costs of acquisition of capital. An increase of the costs for a firm induces a reduction of the capital it can acquire for the same amount

of profit. This firm will not be able to acquire the same quantity of capital as the competitors and thus will not be able to produce as much. Conversely, a firm with lower costs will gradually dominate the market.

The starting technology. When the technology employed by a firm improves, its production and profits increase. Thus, a firm can acquire more productive capital and allocate more resources to its R&D to develop its technology again.

A notable advantage in one of these three characteristics leads the firm to dominate the long-term market.

11.3.2 Structure of industry at the end of the simulation

The following analyses are based on Figures 11.4(a)–(f). All these figures are obtained with an initial configuration of 32 firms but other configurations lead to close results. The representation of the box plots retained corresponds to the minimum and maximum for the whiskers and to the median for the point. For Figures 11.4(a) and (b) the value 100 corresponds to the starting situation of technologies. For Figure 11.5 the x-axis represents time and the ordinate corresponds to a stacking up of the results of 10 simulations, which makes it possible to appreciate the variations from one simulation to another.

11.4 Co-evolution of the options, industry and technologies

The preceding analysis allows us to conclude that the dynamics of the industry and the results of the firms are related to the characteristics of the options and technology. However, these analyses only took into account variations in one parameter. In the following we provide variations of several parameters. These parameters are fixed following the notion of technological regimes (Malerba and Orsenigo, 1993, 1995). First, we show the characteristics of each regime used (Section 11.4.1). Secondly, the results obtained for each regime are presented (Section 11.4.2).

11.4.1 Specification of the technological and market regimes

We retained two main categories of characteristics to distinguish the two technological and market regimes (TMR1 and TMR2), the technological characteristics and the characteristics related to the structure of the market. These characteristics as well as the scales of parameters and variables which we retained to specify them are summarized in Table 11.1.

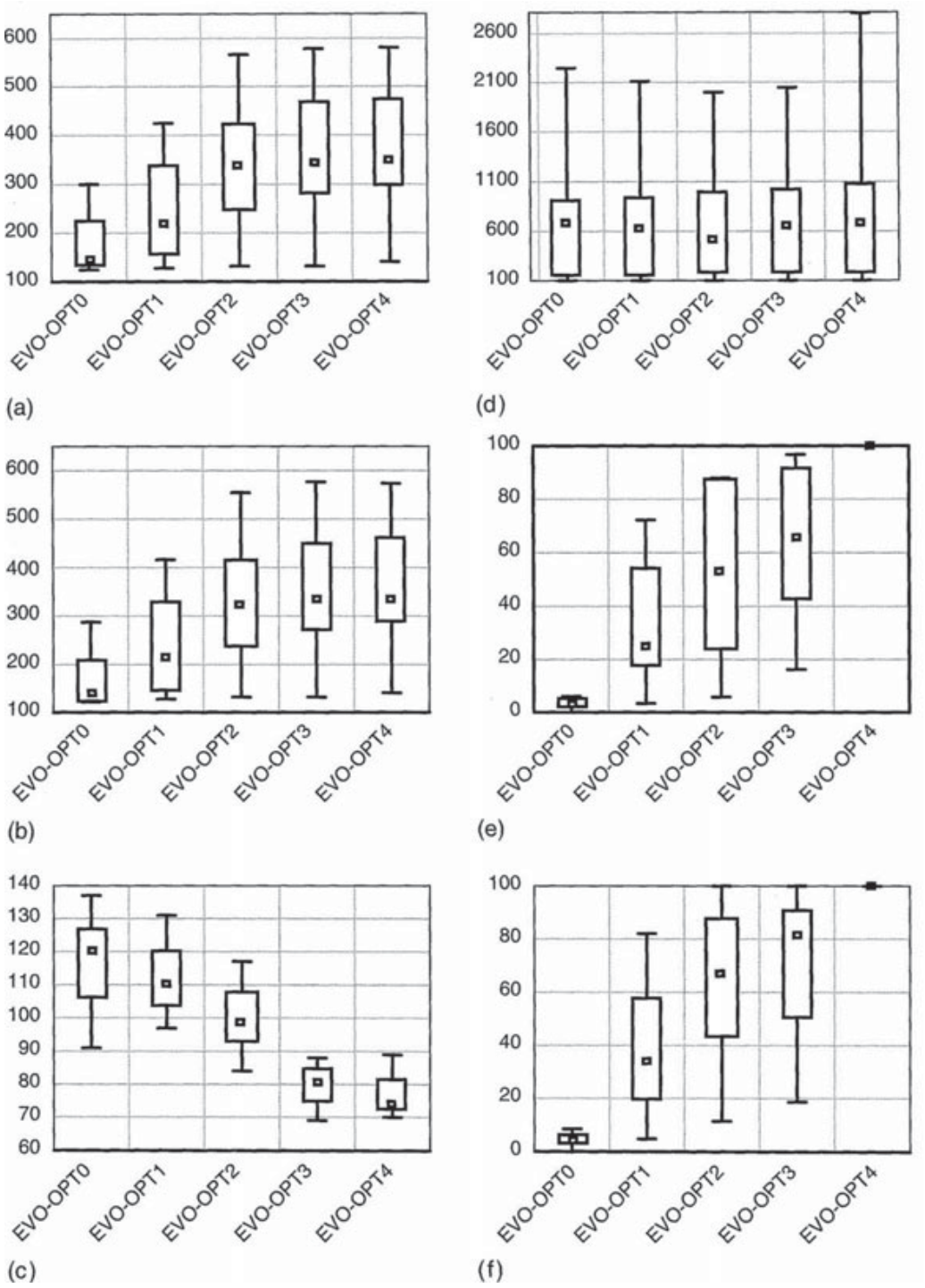

Figure 11.4 Box plots for 32 firms: (a) Average level of the technology; (b) maximum level of the technology; (c) number of alternative technologies; (d) average profit; (e) option-type firm profit part; (f) market share of option-type firm

11.4.1.1 Technological characteristics

We distinguish the two technological regimes according to five characteristics. These characteristics are related to the origin of the options (or the innovations), the transformation of the potential options into

Table 11.1 Specification of the technological and market regimes

Characteristics of the regime/ Parameters used	*Technological and market regime 1 Entrepreneurial*	*Technological and market regime 2 Managerial*
(a) Technological characteristics		
Origin of the options/ Entrepreneurial capital	Small entrepreneurs $Ce/CE > 1$	Big firms $Ce/CE < 1$
Transformation potential option to real option/ Ratio $(CH + CP/CE)$	Small CH and CP small	High CH and CP high
Effect of knowledge accumulation	Small	High
Learning by doing	$b1 = 1$	$b1 > 1$
Allocation of R&D credit	$b8 = 1$	$b8 > 1$
Appropriation of innovations	Small	High
Numbers of alternative technologies desired	$TN = 2$	$TN = 3$
Technological progress/ Maximum development potential of discovered technologies	Based on the firm	Based on fundamental science
(b) Characteristics of the market		
Firm entry rate on the market/ Entry threshold	High First quartile of capital stocks	Low Median of capital stocks
Size of entrant	Small entrepreneurs	Big firms
Number of agents needed to form an entrant firm	K small	K high
Concentration	Low concentration	Concentrated
Number, size and type of firm at $t = 0$	$N = 32$, 50% of firms are option type, all the same	$N = 32$, 50% of firms are option type, heterogeneous

real options (the use of technological opportunities), the importance of knowledge accumulation and the determination of the characteristics of the new technological alternatives.

Technological alternatives. We defined two modes of determination of the characteristics of new technologies: firm based or fundamental science based. In the regime we define below, the representation of the

knowledge employed is different. Thus, for the regime TMR2, the evolution of knowledge is based on the development of fundamental science. The latter is supposed to be linear with time. The regime (TMR1) which corresponds to small entrepreneurial companies uses the maximum level of technology obtained by the firm to define the maximum potential of the technological options. This mode corresponds to a more practical than theoretical knowledge and requires a lower stock of knowledge for the creation of a new option.

Origin of the options. The potential options in our modelling can have two sources. They emanate either through entrepreneurs employed by an existing firm or not. As regime TMR1 is of an entrepreneurial type, agents not employed by firms have a stock of entrepreneurial capital higher than the stock of entrepreneurial capital of the active firms.

Transformation of the potential options into real options. When a new option is created by an entrepreneur, it seeks the physical and human capital which it lacks in order to turn the potential option into a real option. The change of option type within a firm depends on the relative stocks of the various types of capital, which constitute the opportunities, and on the facility offered to an entrepreneur to develop the option in-house. Mode TMR2 characterizes firms with large R&D laboratories which offer better conditions to develop the options in-house, by having a higher ratio $(CH + CP/CE)$.

11.4.1.2 Market characteristics

We distinguish the two regimes according to three characteristics related to the structure of the market at the beginning of the simulation: concentration, rate of entry and size of the firms entering the market.

Concentration. For the two regimes, the set of simulations is carried out with 32 firms, half of which are of the option type. Regime TMR2 is characterized by the existence of large companies; in addition, these firms have larger stocks of physical and human capital. These firms produce a greater part of the good exchanged on the market.

The rate of entry into the market and the size of the entering firms. Regime TMR1 corresponds to a more dynamic entrepreneurial structure than mode TMR2, with a large number of firms entering but of a smaller size. The entry is eased by reducing the threshold of necessary capital.

The next section analyses the results of the simulations made according to the defined regime modes.

11.4.2 Creation and evolution of the options in differentiated regimes

Figure 11.5 presents the results for each regime. To facilitate the reading and the interpretation of the results, we chose to present them expressed on the same base (100). Thus, the regime which leads to the smallest result according to the measure selected is taken as a basis of calculation to express the value obtained in the other regime.

11.4.2.1 Co-evolution of the structure of the industry and the options

In the two regimes the concentration is stronger at the end of the simulation than at the beginning. But the differential between the concentration at the beginning and at the end of the simulation is more important in regime 1. The number of active firms at the end of the simulation is higher in regime 1; this is explained by a larger amount of firm splitting (+89 per cent) and the number of entries of new firms. Lastly, the price is higher by almost 30 per cent in regime 1. The more stable structure of regime 2 creates less potential options, but develops them in a more effective way into real options. On average, the same technological option is used more than four times longer by the firms belonging to this mode. The best technologies are preserved and developed at greater length.

11.4.2.2 Co-evolution of technology and the options

There is a great disparity in the results concerning the maximum technology reached on average during the simulations. Regime 1 leads to twice more productive technologies, but obtaining such a technology is the prerogative of some firms only. So the average productivity of the technologies used by the firm is higher in regime 2 by almost 65 per cent. Regime 2 is based on continuous science development, while the entrepreneurial regime is marked by discontinuities in the form of technological jumps. These discontinuities, when they are repeated, thanks to favourable probabilities in the creation of the options, generate for regime 1 a fast technological progress, which explains the strong difference in the maximum productivity of technologies reached. The nature of knowledge, the turning-over of the options and the size of the technological portfolio condition the evolution of the productivity of technologies. The variation of one of these parameters modifies the average and maximum productivity observed.

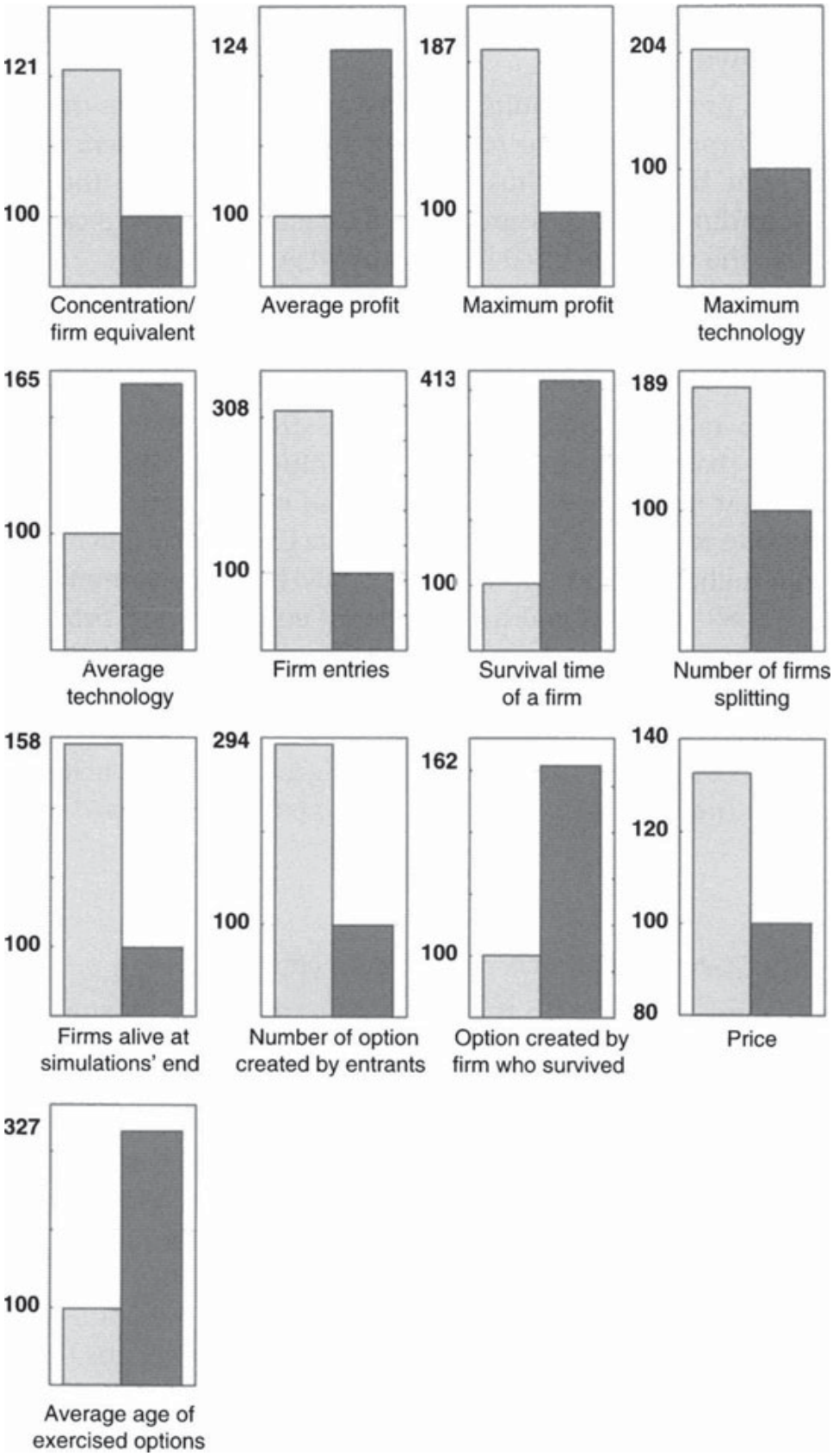

Figure 11.5 Technological and market regimes. Regime 1 (entrepreneurial) is always on the left, regime 2 (big firms/managerial) on the right. The smallest value of each is taken to express the second on a 100 basis

11.4.2.3 Co-evolution of the firms and the options

Observation of the indicators of Figure 11.5 related to the firm shows that regime 2 is accompanied by a higher profit (+24 per cent). The rate of survival of the firms is considerably higher in regime 2 and the number of splitting is lower. This is explained by higher capital allowing certain firms to produce more during the first period, leading to a fall in prices and eliminating the smallest firms quickly. The evolution of the firms, the growth of stocks of capital and the profits are related to the cycle of creation and exploitation of options. The firms of regime 2 develop them with more productive capital *HC* and *PC* than entrepreneurial capital.

11.5 Conclusion

The main results of the model are the following. First, the model shows that the firm that utilizes an option-based reasoning obtains higher profits than others and leads to a more advanced technology for the industry and a higher concentration of the industry. Secondly, the firms that dominate the industry are those that modify the proportion of entrepreneurial, human and physical capital between the creation step and the exercise of the option and those that master the different steps of the option chain. In this view, this approach develops and completes the debate on the duality between entrepreneur and manager in evolutionary theory (Cohendet et al., 2000).

The results presented in this section highlight the determining role of the characteristics of the technological environment and the structure of specific industries belonging to each regime on the creation and the development of options. This effect is not one-sided, since options determine in their turn future technologies and the evolution of the firms. Initially, we focused on the links between the options and the structure of the industry which enable us to detect the importance of the entries of new firms and their effects on production and the level of price. In a second step, we were interested in the links between the nature of knowledge, technology and the options. We observed the existence of a double effect which these parameters have on the options, both on the creation of new options and the development of the existing ones. Lastly, in the third phase we noted the existence of a co-evolution between the profits released by a firm, its composition compared to the various types of capital and its options.

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