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an application to MNEs strategies of internationalisation of production and R&D investment

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INTEGRATED GRAPHICAL FRAMEWORK ACCOUNTING FOR THE NATURE AND THE SPEED OF THE LEARNING PROCESS: AN APPLICATION TO MNES STRATEGIES OF INTERNATIONALISATION OF PRODUCTION AND R&D INVESTMENT

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Abstract

Existing illustrations of the learning phenomenon either stress the relationship between flows and stocks, neglecting the chronological time variable, or the speed of knowledge accumulation along time, neglecting the nature of the underlying learning process. In this paper we present a graphical depiction stressing, in an explicit way, both the nature of interplay between flows and stocks and the intensity of the learning process. The four-quadrant graphs that we develop overcome considerable simplification in literature by deriving, by construction, a measure of dynamic gains of knowledge following the interplay of stock of scientific and technological knowledge and the flow of effort in R&D. This scheme is then applied to study the internationalisation of production and R&D, which are strategies followed by multinational firms. Two types of innovation – process innovation and product innovation – are therefore studied constructing, in each case, an industry performance measure adequately indexed to the cumulated knowledge stock at a given moment in time. In any case, the dynamic efficiency measure adopted naturally takes into account both the absolute changes in the technology indexes and the time delays to reach them, which are properly discounted. Regarding multinationals strategies - internationalisation of production and R&D investment -, we begin with the question of finding a new location for using a now well developed production technology, and then deal with the problem of selecting a region of excellence in research to take gains of concentration advantages and local externalities.

Keywords: Learning; knowledge; technology; R&D; MNEs

JEL-Codes: O31; O32; F23

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1. Introduction

In this paper we develop a unifying graphical framework for analysing the process of knowledge accumulation, which simultaneously stress the nature and the speed of the learning process. The four-quadrant graph that we develop overcomes considerable simplification in literature by deriving, by construction, a measure of dynamic gains of knowledge following the interplay of stock of scientific and technological knowledge and the flow of effort in R&D. This scheme is then applied to study the internationalisation of production and R&D, which are strategies followed by multinational firms.

One well-known mathematical expression of both the nature and the intensity of the process of knowledge accumulation is the transformation of a dynamic equation where the flow of knowledge is explained by a product of a technical parameter, a variable of effort in R&D, and the stock of knowledge indexed at some moment of time (see, for an example, Romer (1990)). To our knowledge, however, graphical depictions stressing, in an explicit way, both the nature of interplay between flows and stocks and the intensity of the learning process are non-existing. Instead, the existing illustrations of the learning phenomenon either stress the relationship between flows and stocks, neglecting the chronological time variable; or stress the speed of knowledge accumulation along time, neglecting the nature of the underlying learning process.

The paper is structured as follows. In the next section, the nature of the learning process is described and then (Section 3) a unified graphical framework for accounting for the nature and the speed of the learning process is detailed and discussed. After, we apply this framework to MNEs' strategies, namely the internationalisation of production (Section 4), and R&D (Section 5). Finally, Section 6 concludes the paper.

2. The nature and the speed of the learning process

In order to understand the nature of the process of knowledge accumulation we need to realize first of all the unconventional properties of technology and the differences between various sorts of technological inputs or components. Whereas a design for a new product is a nonrival input, human capital required to develop a technology is a rival input. Technological knowledge and human capital, or researchers' and engineers' efforts, are used in an interactive way to produce new knowledge. This analytical treatment is different from the learning-by-doing formulation in Arrow (1962), where there is no room for intentional investments in research and development made by the firms. The nature of the learning process is illustrated in Figure 1.

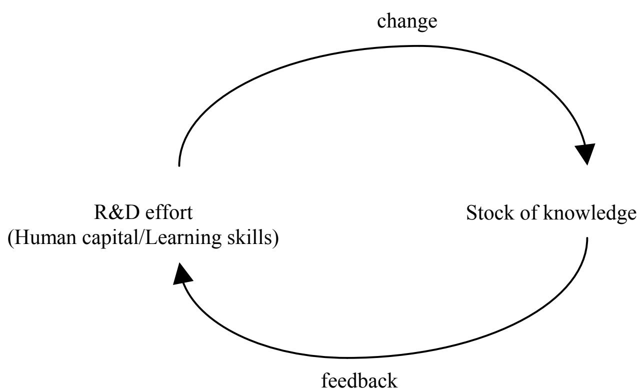


Figure 1: The nature of the learning process

It should be clear that, from an analytical perspective, only the chronological sequence of moves and events matters to understand the interaction between the two different sorts of technological knowledge at stake. Conversely, to establish the precise calendar time of moves and events would be totally inconsequential. It is important, however, to have in mind that the picture shall illustrate that the feedback loop arising from an increased stock of knowledge has an effect upon the productivity of all individual researchers and engineers doing research and development only after a somewhat vague and undefined future. Feedback loops are time consuming.

Romer (1990) specifies the process for the accumulation of new knowledge (consisting in new designs in his model) in the research sector as follows: $\frac{dA}{dt} = \delta H_A A(t)$.

where δ is a productivity parameter in the research sector, H_A is the total human capital employed in research and $A(t)$ is the stock of knowledge at time t. Everything else being equal, the more R&D effort that goes into the knowledge accumulation, the larger the stock of knowledge. Furthermore, everything equal, the larger the stock of knowledge, the larger the flow rate. These two sentences are essentially captured in the equation above.

The mathematical equation explaining the rate of production of new knowledge describes the relationship plotted in Figure 2.

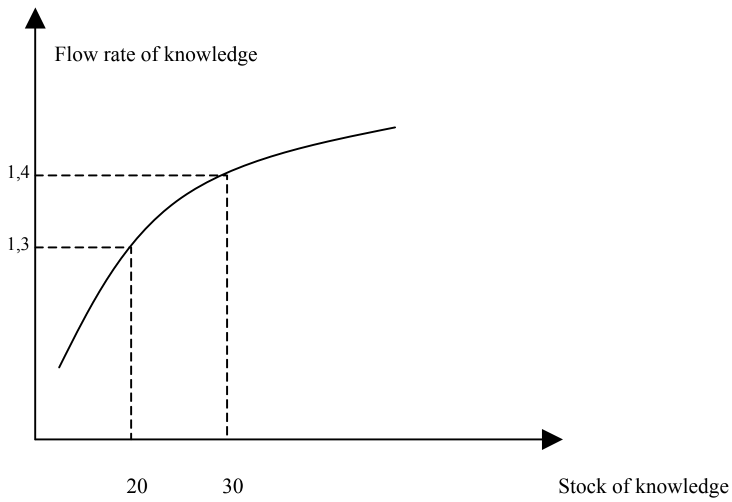


Figure 2: The relationship between stock and flow rate of knowledge in numbers

This figure relates the flow rate of knowledge to the knowledge stock as follows. An increase in the stock of knowledge has the effect of speeding up the absolute rate of growth of knowledge. By hypothesis, we choose to depict a concave function of the stock of knowledge, instead of a function where the flow rate grows proportionally to the stock of knowledge as in Romer (1990).

This figure, showing the flow of knowledge per unit of time as a function of the stock of knowledge, can be in turn decomposed in two other, as shown in Figures 3 and 4 next. The expositional gain is that chronological time is introduced and so we know when technological diffusion begins and benefits are spread in society. The loss is that we lose sight of the interaction between flows and stocks of knowledge.

By definition, research and learning activities affect cumulatively the stock of knowledge over time. We would like to model how these economic activities determine the stock of knowledge and its speed of growth. For that matter it is important to distinguish carefully between stocks and flows and then compare the stock of knowledge with the flows of knowledge over time. The stock of knowledge, or the number of designs as defined in Romer (1990), is indexed to a point in time.

The following figure depicts how a small initial stock of knowledge grows over chronological time. The only way to grasp how the rate of growth of knowledge evolves over time in this figure is to look at the slope of the curve plotted at different points in time. The greater the slope of the curve plotted, the greater the additions to the stock of knowledge per unit of time reached.

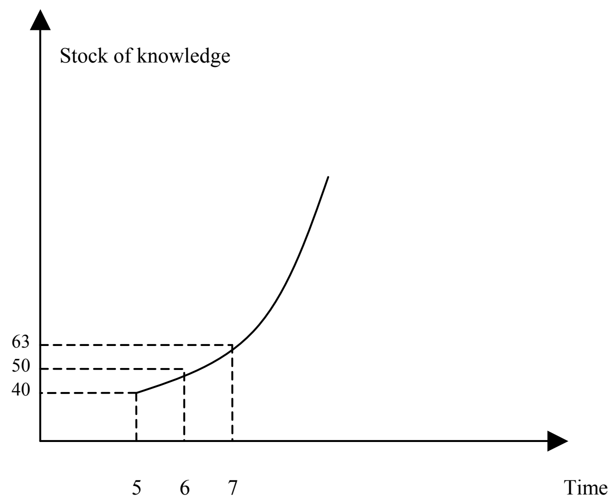


Figure 3: The evolution of the stock of knowledge over time

Alternatively, we can directly plot how, starting from a small stock of knowledge, the flow rate of knowledge changes over time.

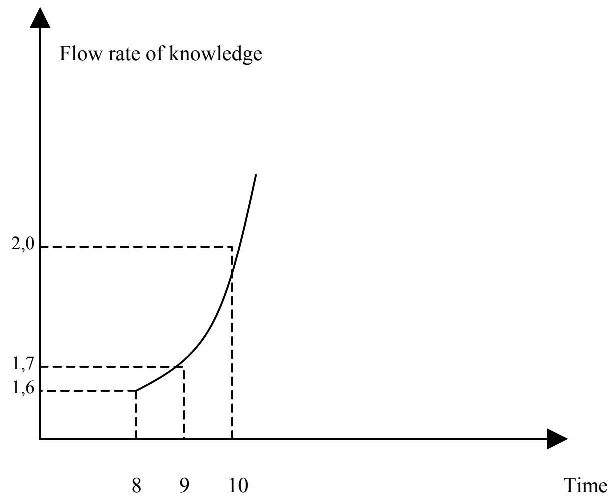


Figure 4: The evolution of the flow rate of knowledge over time

Of course, we can always reverse this expositional procedure, simply by combining Figures 3 and 4 in order to relate the flow rate to the stock of knowledge as depicted in Figure 2 above. And again showing in a graph the technological relationship between the flow rate and the stock of knowledge implies the omission of chronological time. And calendar time is relevant to assess the dynamic efficiency gains arising from the research and learning activities. We argue that it is possible to illustrate within a single integrated picture both the nature and the intensity of the learning process. The following Figure 5 shows precisely that.

3. Accounting for the nature and the speed of the learning process. An integrated graphical framework of analysis

Our modeling procedure unifies four plans in a single four-quadrant figure in order to tackle simultaneously the nature and the speed of the learning process. R&D efforts and learning skills as well as the stock of knowledge are the variables to be represented in the two axes of the 2^{nd} quadrant of Figure 5. The basic nature of the learning process is illustrated with the plotting of a set of contour lines representing different flow rates of knowledge. Fixing the value of either explanatory variable of knowledge growth at a time, we can then move from one contour line to another of higher value simply be increasing the value of other explanatory variable.

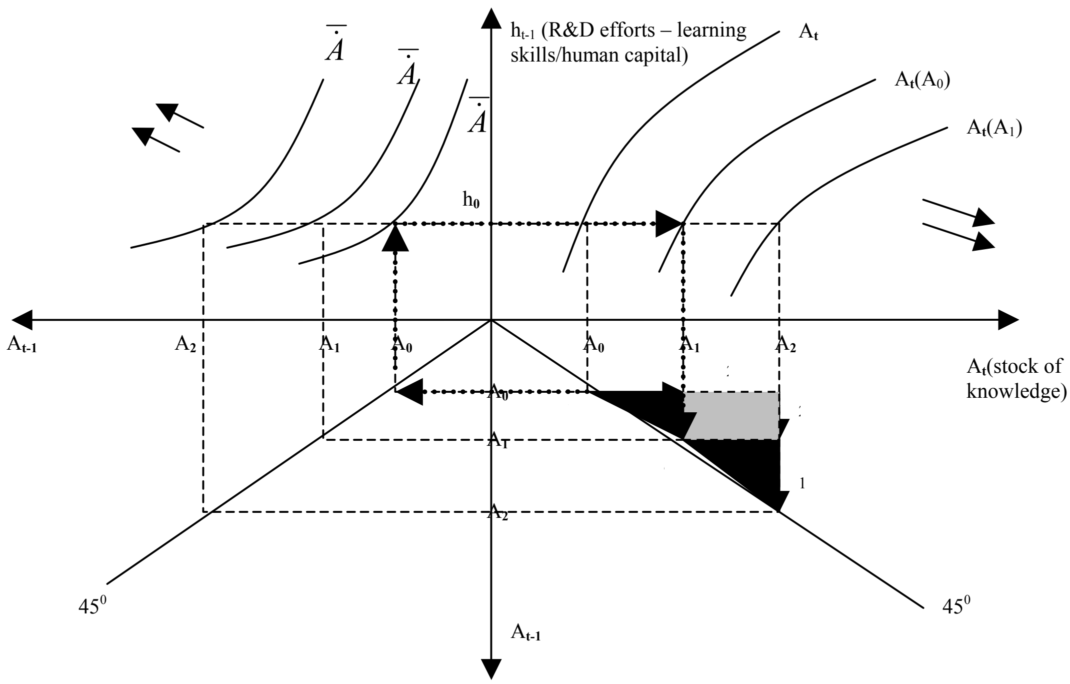
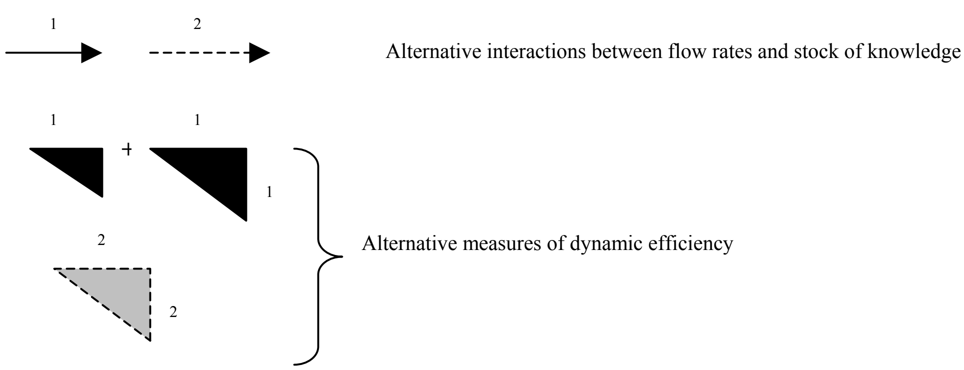


Figure 5: The whole picture of the learning process in action

Legends (IV quadrant):



The curves of the 1st and 3rd quadrants will be transformed in subsequent sections in representative learning curves and production functions of innovation. The application of this integrated framework to the problems of the internationalization of production and R&D will make use of these two important conceptual relationships.

We devise a way to construct a geometrical measure of the dynamic efficiency gains in the 4^{th} quadrant linked to the representation of the interactive nature of the learning process in the 2^{nd} quadrant. We assume, for that purpose, discrete units of calendar time and index the explanatory variable of the 4^{th} quadrant at any two immediately successive moment of discrete time. The 45 degree ray plotted there represents all the industrial situations where the stock of knowledge does not grow in a short span of time. Points close to that ray represent industry outcomes where flow rates of knowledge are weak.

To illustrate this integrated modeling in action, we demonstrate the endogenous nature of the process of knowledge accumulation with the help of the four-quadrant framework. Consider first a single learning loop. Call this learning loop α-ω. It starts at α point located somewhere on the 45 degree line (stock level A_0 for instance). The dynamics of the process directs our attention to the 3^{rd} quadrant (with $A_{t-1} = A_0$) and then to the 2^{nd} quadrant. There it is determined in some iso-flow curve the flow rate for the next period *t* associated with the same constant human capital and R&D effort of every period (by hypothesis) and the stock of knowledge of the industry at time *t-1*. As a result, the stock of knowledge increases by that addition and that shows in the 1^{st} quadrant, where we determine the stock of knowledge at time t (A_1). Once we plot this new value on the 45 degree ray we reach our ending point ω. This process repeats itself over time, with a succession of α-ω loops beginning and ending along the 45 degree ray, either to continue endlessly or to fade way as soon as learning opportunities begin to disappear.

Now we are ready to derive the measure of dynamic efficiency gains in the 4^{th} quadrant. Notice, first of all, that points α (coordinates (A_0, A_0)), (A_0, A_1) and ω (coordinates (A_1, A_1)) in the 4^{th} quadrant form a triangle. Its area depends on the magnitude of the flow rate of knowledge attained between two successive periods of time. Notice, furthermore, that every new period of time is reached whenever one such α-ω loop in the learning process is completed. And that shows in the 4^{th} quadrant: another point on the 45 degree ray representing an higher stock of knowledge and another triangle with vertices being two points on the ray an the other above and to the left of the 45 degree ray.

And so we can count the number of periods to attain a given increase in the stock of knowledge just by looking at the 45 degree ray in the 4^{th} quadrant. And we can assess the impact of those dynamic effects upon the social welfare just by adding the values of the areas of the resulting triangles.

Of course, we can always consider a quicker alternative path to attain a given increase in the stock of knowledge, say, lasting a single period of time instead of several periods of time. Supposedly the dynamic gains to society would be necessarily higher in this alternative case. In fact, the triangle arising from this single loop case encompasses the several small triangles of the slower path case. The area of the first larger triangle is larger than the sum of the areas of the small triangles.

The difference between these two sums of areas associated to two different paths is taken to be a representative measure of discounting in time. In this procedure the successive increments of knowledge are discounted heavily for a limited period of time. The more jigsaw-like is the contour line around the successive learning loops the smaller the sum of the areas of the triangles due to discounting. On the other hand, the single loop case is a special case of no discounting.

4. Applying the integrated framework to MNEs' internationalisation of production strategy

In this section we apply our graphical methodology to the phenomenon of the internationalization of production. Vernon (1966) argues that as the innovative product reaches maturity, it becomes standardized and production costs lower with mass production methods. Multinational firms contemplate then the possibility of transferring production to a Developing Country.

The decision problem a multination firm is expected to face is assessed in this paper in terms of the importance of the reductions of the unit cost of production associated with alternative strategies available to the firm.

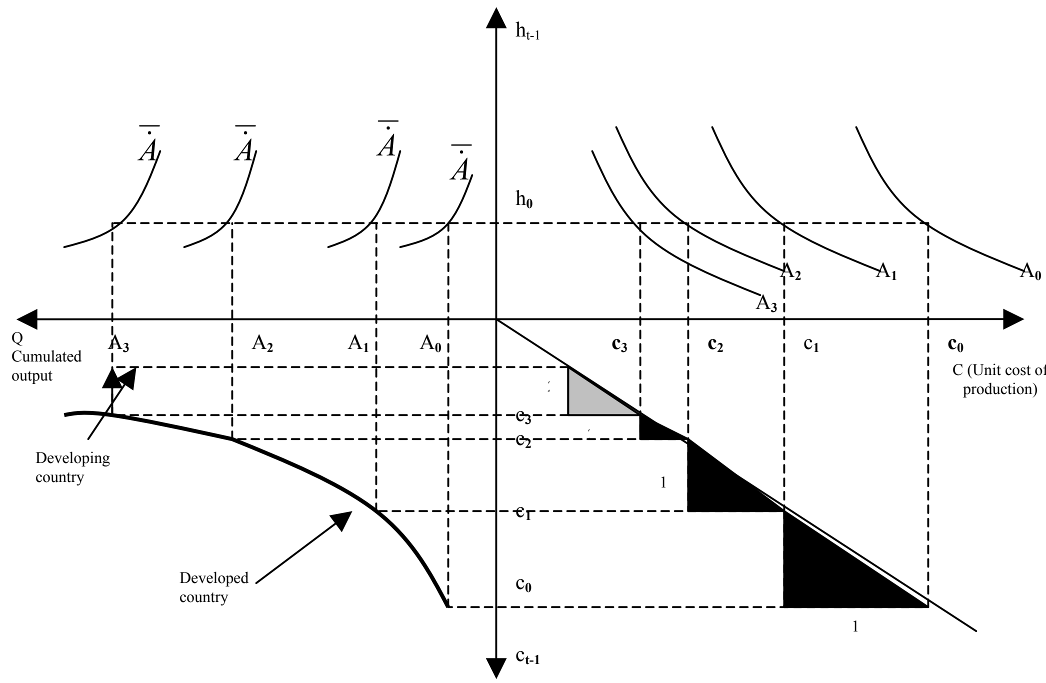
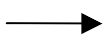


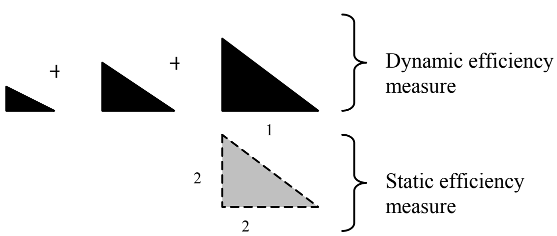
Figure 6: The learning curve, comparative advantage and the internationalization of production

Legends (III quadrant):



Movement of a segment of the production process from a developed country to a developing country

Legends (IV quadrant):



Thus, it is required that now the production function of the 1st quadrant in Figure 6 establishes a relationship between decreases in the unit cost of production and the learning skills employed, measuring the contribution of human capital to process innovations. According to this production function for process innovations, the greater the learning inputs, the quicker any absolute cost reduction one has in mind is successfully reached. In the 3rd quadrant we depict a standard learning curve, which show how quickly the unit cost of the product lower with accumulated experience as measured in by cumulative output. Cumulative output is assumed to be an appropriate proxy for the stock of technological knowledge of some production process or industrial sector at some moment in time. In the 4th quadrant of Figure 6 we construct our efficiency measures associated with the possible solutions found by the multinational firm for its decision problem. As in the previous four-quadrant figure, the 2nd quadrant depicts a series of iso-flows of knowledge in the stock of knowledge-learning inputs plan.

The study of the internationalization of part of the production process to be decided by some multinational firm requires dealing with the questions of when and where to transfer some segment of the production process of the firm. The multinational shall benefit from the learning effects in the production of some component as long as the learning opportunities are important. As soon as the learning curve begins to flatten out, the multinational firm shall consider the possibility of transferring its production technology to some Developing Country where the relationship between cost of labor and qualifications of local human capital is regarded as interesting in economic terms by the multinational firm. The transfer of production shall be advantageously directed to some foreign low-labor country as soon as the cost reductions in labor savings more than compensate any anticipated benefit resulting from betting on doing process innovation.

To illustrate this conclusion, we can think of a particular specification for the learning curve. The special case we have in mind depends on two parameters and can be seen in Arrow (1962). In this paper, Arrow adopts the form found in the study of learning curves for airframes, which was conduct by Wright (1936). After taking natural logarithms, the ordinate at the origin and the slope of the transformed learning curve are determined by the values taken by those two parameters. Transferring production to a Developing Country implies that the learning process is now taking place in other learning curve. We can then depict in Figure 6 such learning curve relative to the industrial sector under study for the Developing Country, obviously with two different values for the two parameters of the special specification chosen for the learning curve. This learning curve after logarithmic transformation has both lower slope and lower ordinate at the origin relative to that of the multinational firm originating from some Developed Country. It is plausible to assume that the Developing Country is deprived of precisely those skills which are adapted to developing the process technology under consideration, and therefore it will heavily depend upon any technical resources devoted to technological development eventually deployed by the multinational firm in the foreign country. Rosenberg (1963), for instance, is concerned with explaining the creative process on the part of the capital goods industries and understanding the observed failure of poor countries to develop techniques with the adequate and required factor-saving bias. It is the lack of those technical skills which are needed for technological development, or of substitute mechanisms and institutions to the producer-user relationship observed in rich countries that, according to Rosenberg, explains the continuing technological dependency and passivity of poor countries.

In this analytical setting we can therefore envision a situation where the multinational firm needs to deal with a trade-off between dynamic efficiency and static efficiency. A measure of static efficiency accounts for the once-for-all reduction in the unit cost of production due to the lower wages of the Developing Country. The comparison between the two measures is made for the same time span. When learning effects are beginning to fad way in the Developing Country, the multinational firm considers the possibility of taking advantage of lower wages for producing some product component in some Developing Country endowed with relatively qualified man power. In graphical terms, the multinational firm compares the triangle of the static efficiency with the jigsaw contour of the dynamic efficiency measure in the 4^{th} quadrant. The solution for the decision problem of the multinational firm is then found.

5. Applying the integrated framework to MNEs' R&D strategy

In this section we analyze the phenomenon of the internationalization of R&D. Evidence on the subject matter of the globalization of technology can be found in Dunning (1993) and Howells and Wood (1993).

For that analytical purpose we adopt the same graphical methodology with some necessary modifications. This time the performance measure selected and depicted in Figure 7 deals with quality improvements that result from product innovation. Every period there is the possibility of reaching another quality ladder and a better final product as the outcome of the R&D activities taken by profit-seeking firms.

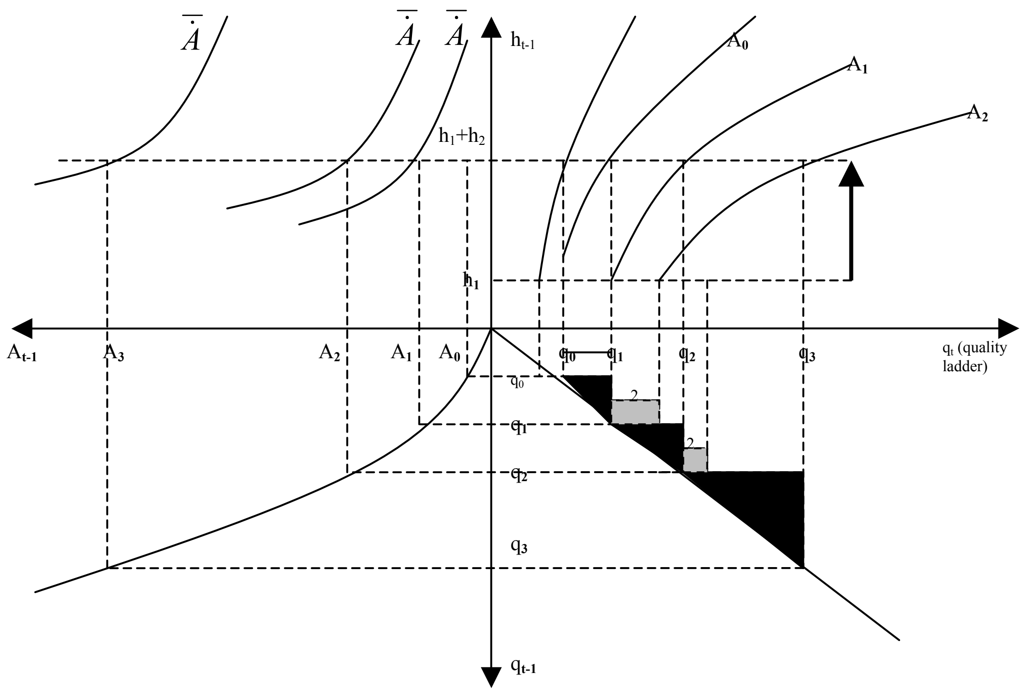
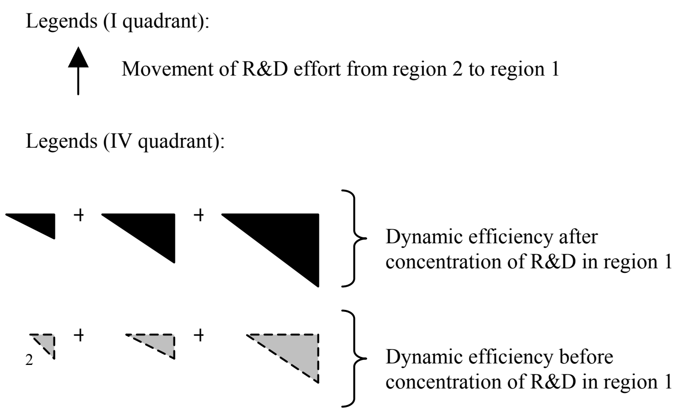


Figure 7: Quality ladders, external economies and the internationalization of R&D



The production function of the 1st quadrant of our graph this time relates quality improvements with R&D effort and the modified learning curve of the 3rd quadrant establishes a relation between quality improvements and cumulative knowledge. The derivation of a measure of dynamic efficiencies in the 4th quadrant this time uses differences of quality between two immediate time periods. The only unchanged quadrant of our four-quadrant figure is the 2nd. We still have here, as in the two previous four-quadrant figures already shown, contour lines depicted in the stock of knowledge-R&D effort plan.

In order to understand the multinational firm decision problem of where to locate its R&D laboratory, which can remain near its headquarter or be moved to some foreign country, we adopt the following modeling procedure. One multinational firm could place its R&D laboratory in another country with research centers of excellence and take advantage of the local external economies associated with the concentration of learning efforts in a single region. The stock of knowledge has the attributes of a public good as it is freely spread around the region and is freely accessible to any economic agent there located. Any firm can benefit from this externality just by moving into the dynamic region and collaborate with the other firm by doing R&D. We model R&D concentration in a single region simply as a sum of two effort variables. Antonelli (2001), for instance, models external increasing returns as a function of the number of firms engaged in complementary innovative activities located in some dynamic region. It is assumed there that the external learning effects are an increasing function of the number of firms, until some maximum number of firms and some maximum number of communication channels among them is reached.

We would like to assess the dynamic efficiency gains associated with the internationalization of R&D and compare it with the alternative strategy available. The benchmark model used for such purpose is the setting up of an independent and autonomous R&D laboratory with most of the additional knowledge there generated being protected in some way (for instance, by legal property rights). One can assume then that technological knowledge is mostly private property. It is also assumed in drawing the areas of dynamic gains that the positive external effects in the research sector, though causing incomplete appropriation of benefits on the part of the private innovative firm, do not significantly undercut the amount of human capital and development skills devoted to research. Due to external effects in the region, the producer a new design or of a new quality ladder captures only a fraction of the net benefit to society, which lower by itself the private incentives to innovation.

The two measures of dynamic efficiency representative of the two alternative R&D strategies under consideration, that is, the independence of R&D and the concentration of

R&D in a single region, are depicted in the 4^{th} quadrant of Figure 7. The difference between the two depicted areas measuring dynamic efficiency translates in effect the relatively greater speed of the learning process underlying the second model of R&D organization. The greater the more prolonged in time the external learning effects, the larger the difference between our two measures of dynamic efficiency. Stated differently, any given increase in quality we think of, the concentration of R&D can get it quicker and with lower time discounting.

Geographic proximity increases knowledge spillovers and, consequently, firms can increase their R&D productivity and innovative performance by moving to regions with a substantial technological dynamics. And our graphical analysis shows that implication.

6. Conclusions

Chronological sequence and chronological time are required to understand both the nature and the speed of the learning process. To understand and explain the basic nature of the creative, learning process we do not need to establish the exact time at which resource allocation decisions were made nor the exact time delay required for the feedback loop come to its conclusion. All we need to know is that the interactive nature of the learning process requires the contribution of all sorts of technological knowledge in sequential turns. However, to assess the impact of technological knowledge upon the social benefit (be it in the form of production cost decreases or quality improvements of products), we need to know when the new knowledge and information (arising from either process or product innovations) becomes available to the economic agents, users of the new technology. Any measure of dynamic efficiency gains due to technological developments recognizes that chronological time of arrival of new knowledge matters.

We show in a four-quadrant graph that it is possible to illustrate simultaneously both the nature and the speed of the learning process. We then apply this integrated framework to the phenomena of the internationalization of production and internationalization of R&D.

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