Chapter 16

Morphological Analysis, Diffusion, and Patterns of Technological Evolution: Ferrous Casting in France and the FRG

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16.1 Introduction

The historiography of technical change has demonstrated that the process of technological diffusion is in itself also a developmental process. In other words, it is in its diffusion throughout the economy that a technology acquires its industrial and economic properties, transforms itself, and widens the initial market in which it was adopted. On the basis of these dynamic properties of the diffusion process, some authors have been hasty in inferring the theoretical impossibility of formal representation, since the objective of the diffusion is not the same at the beginning, in the middle, and at the end of the process. It appears to us, however, that the interest in a formal representation resides precisely in the possibility of periodizing the diffusion process, with the aid of criteria that can take into account the principal transformations of the technology under consideration. The diffusion process can thus be considered as a series of competitions at given times between a technology A, which is in the middle of a transformation, and other technologies (B, C, and D) with respect to those functions that A is successively able to assume. Generally these successive competitions will occur in ever larger markets as A progressively enlarges its initial functional characteristics. It is therefore possible to interpret the characteristics of the diffusion pattern of a given period on the basis of the manner in which competition developed throughout a previous period.

The first part of this chapter consists therefore in a complete and comprehensive morphological analysis (MA) of a set of (process) technologies for a particular industrial activity, in this case ferrous casting. Through the MA approach proposed, we will be able to define the criteria of the periodization of the diffusion process for the technology under consideration. More generally, we intend to show the importance and fruitfulness of an explicit and formal methodology in defining the technologies competing/diffusing in a particular market, which by its comprehensive nature, is not time-dependent or results simply from the aggregation level available in industry statistics.

In the second part we use the results of our MA of the technological trajectories in the casting industry to analyze their diffusion in two countries, France and the Federal Republic of Germany (FRG). We first describe the very different patterns of the technological trajectories in the two countries. We then continue to discuss the possible driving forces behind the *locking-out* of the gasifiable pattern process technology (GP process) in France and its diffusion in the FRG, followed by a quantification of the diffusion process based on standard diffusion methodology. This will be based on a simple Fisher–Pry (1971) type of technological substitution model. On the basis of the MA we describe the diffusion of the GP process as proceeding by successively filling two market niches: first, small batch-size production and later, following improvements in the technology, also mass production of ferrous castings. In the case of the FRG we point out the extreme importance of the early start of the diffusion process of the GP process technology inside a small initial market niche, which generates a process of accumulation of knowledge and learning (this was not the case in France) leading to the widening of the initial market niche.

The study of the diffusion trajectories (Section 16.3), which develop within a well-defined morphological space (Section 16.2), allows us to propose in the final section the historical pattern of evolution of casting technology. Thus our approach moves from a morphological arborescence to an evolutionary tree[1] with the help of the analysis of the diffusion and selection mechanisms for the technologies under consideration.

With respect to the results of this work, we can make one analytical and one methodological observation. First, this case study provides insights into the conditions for exit from a *lock-in* situation.[2] Second, the MA helps avoid misinterpretation and provides a clear theoretical rationale concerning the asymmetrical character and the discontinuities of the diffusion trajectory of the GP process.

Finally, it is our contention that the suggested three-step (morphological, standard diffusion, and evolutionary) analysis permits a better understanding of the historical pattern of evolution of a given technology.

16.2 Morphological Analysis of Technological Trajectories

In this section we propose a complete MA in order to construct the morphological space for the technological evolution of ferrous casting. The MA also permits us to define the relevant relations of rivalry between the technologies under consideration.

The Morphological Space of Casting Technology

MA is a technique for identifying, indexing, counting, and parameterizing a collection of all possible devices (processes) to achieve a specified functional capability. An MA is made up of the following steps: existence of a well-structured problem, identification of the parameters of the (technical, functional) characteristics, subdivision of each parameter into cases or *states* p^1k, p^2k, p^nk, and identification of the various combinations. In addition, we use the following definitions:

Morphological space (p^jk) consists of a set of discrete points or *coordinates*, each corresponding to a particular combination of parameters. The space has as many dimensions as parameters.

Morphological distance between two points in the space is the number of parameters differing from one another in two configurations.
Morphological neighborhood is a subset of points, each of which is morphologically close to the other.
Technological breakthrough is achieved when a new configuration is obtained.

An MA starts with the construction of a morphological space for a particular set of technologies or products in order to understand comprehensively the whole environment into which they are embedded, and thus not to *miss* a technological route of possible future development. The morphological space is defined by any number of dimensions and subdivided into elementary spaces which show the *state* of the technology considered.

Firstly, the functional capabilities of the technology must be stated precisely. In this case, the problem consists of realizing ferrous metal products by a casting process (molding technology). Then in connection with this definition, four characteristic parameters are identified and subdivided:

P_1: The nature of the pattern (P_1^1: permanent, P_1^2: lost);
P_2: The nature of the mold cavity (P_2^1: hollow, P_2^2: full);
P_3: The stabilization force (P_3^1: chemical, P_3^2: physical);
P_4: The bonding method (P_4^1: simple, P_4^2: complex).

Finally, a hierarchy of these parameters is defined in order to take into account the compatibility constraints between the various states of the different parameters. For example, in our case, a permanent pattern (P_1^1) is not compatible with a full cavity mold (P_2^2) which in turn implies the use of a physical stabilization force (P_3^2). This hierarchical relation between the parameters ($P_1 > P_2 > P_3 > P_4$) leads to the morphological space of the molding processes, being represented as an *arborescent structure* (*Figure 16.1*), which gives a systematic representation of all possible alternatives to the casting problem.

In terms of graph theory, an *arborescent* structure is a tree with an original node [that is a point (a), where each other vertex can be attained by a part coming from (a)]. A graph which possesses an original node is *quasi-strongly connected* [for all pairs x, y, there exists a vertex $z(x, y)$ from which a path to x and a path to y begins].

The properties of a quasi-strongly connected graph will be used in the following to define the relevant relation of rivalry between technologies in the morphological space with which we are concerned.

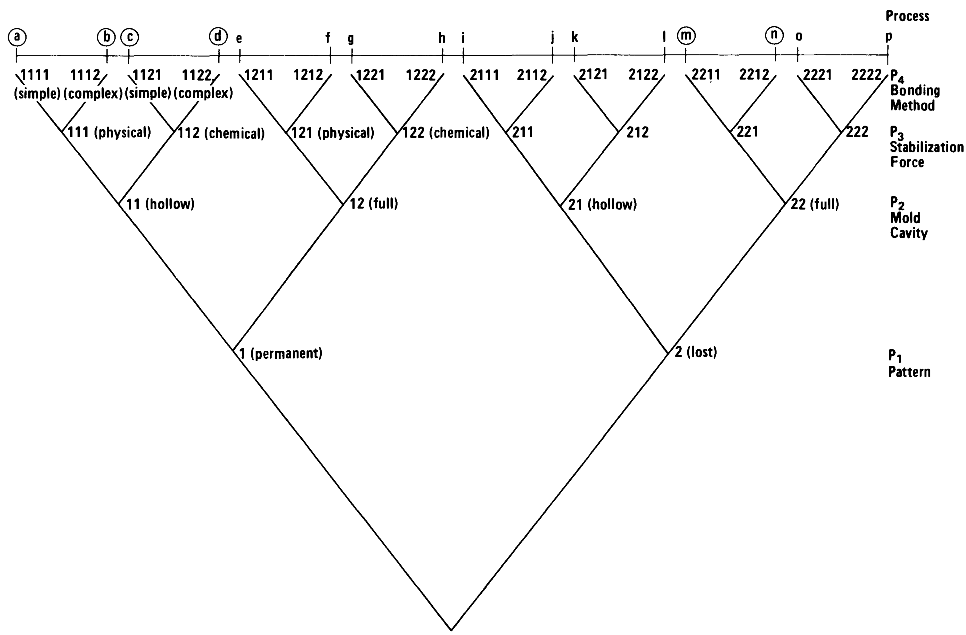

Figure 16.1. The morphological space of molding processes (with 4 parameters) and realizable (non self-contradictory) technological solutions suitable for mass production (a, b, c, d, m, n).

Let us now introduce some precisions:

- The 31 vertices of the tree do not represent the technical processes. These processes are located above the final branches of the graph. Thus, each process corresponds to a given combination of the states of the four parameters of the morphological space.
- The MA applied to molding technology results in 16 distinguishable combinations for four parameters (a to p in *Figure 16.1*), although some of them are self-contradictory: some states of one parameter are not compatible with some states of another parameter. Therefore, the combinations (e, f, g, h) are impossible, given the incompatibility between the permanent nature of the pattern and the full nature of the mold cavity. (p) is also a self-contradictory combination. When the impossible solutions are eliminated eleven solutions remain which must be considered.
- We are not yet capable of formulating any conclusion concerning the economic value of each combination, or their relative contribution to

the output (i.e., their market shares) of the sector. The goal of the MA is instead to provide a comprehensive definitional structure of the process technologies available and a taxonomy of their evolution. The second interest of the MA lies in the possibility of defining rigorously the competing technologies.

Morphological Neighborhood and Breakthrough: The Relation of Rivalry

The specification of rival technologies includes two notions:

- A notion of **substitutability**; two technologies that do not have the same basic function cannot be considered as being in competition. This basic function refers both to a dimensional criteria (for example, mass production) and to a qualitative criteria (for example, a given degree of complexity of products). According to this first constraint, we can conclude that five solutions (i, j, k, l, o) are inadequate for mass production and consequently not in competition. But, the solutions (a, b, c, d, m, n) are substitutable.
- A notion of **morphological distance** (MD); it is essential to define theoretically a technological change, either as an improvement of an existing technology, or as the emergence of a rival technology. We argue that competing technologies are separated by a given morphological distance which is estimated below. The MD will be calculated on graph G (*Figure 16.2*), from which the self-contradictory solutions are eliminated, as well as the solutions which are inadequate for mass production.

$G = (X, U)$, is the couple; constituted first by a set $X = (x_1, x_2, \ldots, x_n)$, and second by a family $U = (u_1, u_2, \ldots, u_m)$ of elements of the cartesian product $X \times X = [(x, y)/x \epsilon X, y \epsilon X]$.

This graph displays the properties of an arborescent structure as discussed above. In order to estimate the MD between two points in the space (i.e., the number of parameters differing from one another in two configurations), we use the notion of path.

A path of length $q > 0$ is a chain of a particular type: $\mu = (u_1, u_2, \ldots u_q)$, such as for each arc u_i (with $i < q$) the terminal extremity of u_i coincides with the initial extremity of u_{i+1}. The MD between two terminal vertices (two processes) is the length of the corresponding path μ, i.e., the number of arcs of the sequence:

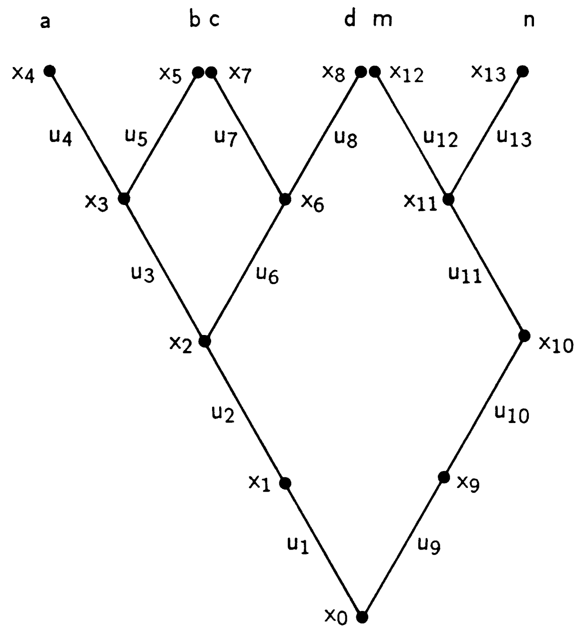

Figure 16.2. Representation of graph G defining process technologies for mass production of ferrous metal castings.

$$\begin{aligned} MD(a,b) &= \mu^2 = (u_4, u_5) \\ MD(a,c) &= \mu^4 = (u_4, u_3, u_6, u_7) \\ MD(a,m) &= \mu^8 = (u_4, u_3, u_2, u_1, u_9, u_{10}, u_{12}) \end{aligned} \quad (16.1)$$

On account of the hierarchical character of the graph, the estimation of the value of each arc should take into account a weighting coefficient reflecting its proximity to the original node.

We must then define a critical distance. Concurrent with this definition some technological changes occur inside a morphological neighborhood while others occur outside and can thus be defined as an emerging rival technology. According to the theory of the quasi-strongly connected graph, this critical distance is given by the radius of graph G.

The directed distance $d(x_i, x_j)$ is the length of the shortest path from x_i to x_j. The "associated number" of a vertex x_i is $e(x_i) = max\ d(x_i, x_j)$ with $x_j \epsilon X$ and $x_j \neq x_i$. The "center" is a vertex x_o with a minimum associated number. $e(x_o)$ is called the "radius" of graph G and is denoted as $p(G)$. In *Figure 16.2*, $p(G) = 4$. Thus, $(MD \leq 4)$ defines a morphological neighborhood and ($MD > 4$) defines a technological breakthrough (i.e., the emergence of rival technologies).

This morphological procedure results in the identification of two competing technologies: the sand molding (SM) process, corresponding to the combination of parameters (a, b, c, d) and the gasifiable pattern (GP) process, corresponding to the combination (m, n). Technological competition, which will generate a macrostructure in the industry, occurs therefore at the level of the parameter P_1 (permanent or lost pattern, *Figure 16.1*). Indeed, that is the level where the choice of firms can be analyzed in terms of continuity (i.e., technical change within a morphological neighborhood, for example from a to b) or of a morphological breakthrough (for example, changing from a to m). While technical change within a morphological neighborhood implies only a change of artifacts (incremental innovation), the incorporation of a rival technology (i.e., the commitment in another technological trajectory) implies both changes in artifacts and in the knowledge base.

Let us now discuss some of the aspects concerning the economics of technological competition for the case of molding technology.

Economics of Technological Competition

From an economic point of view, we attempt to characterize the technologies in competition (SM process versus GP process) at two complementary levels.

- *Technical complexity and simplification of the operating methods.* This first level refers to one of the characteristics of technical evolution (Foray, 1985): as technological processes become more complex, operating methods tend to become more simplified. The main steps of production used in both the SM and GP process are shown in *Figure 16.3*.

  Thus, the GP process enables an extreme simplification of the operating methods:

  > The GP process involves investing an injection molded foamed polystyrene pattern in a free flowing magnetizable molding material. Immediately prior to pouring, the molding material is rigidized by a powerful magnetic field. During casting, the polystyrene pattern volatilizes in the face of incoming metal stream which occupies the void left by the gasified pattern. Shortly after the casting has solidified, the magnetic flux is switched off and the flask containing the casting is taken to the knock-out station [Gupta and Toaz, 1978].

  But this simplification of operating methods is associated with increased technical complexity: a low level of complexity (SM process)

SM process (permanent pattern)	GP process (lost pattern)
The making of pattern equipment, including patterns and pattern plates, coreboxes, running systems, core assembly fixtures and checking gauges	The making of pattern equipment including gasification pattern, boxes and molding materials
↓	↓
The preparation of sand for molding and core making	The inserting of the lost pattern in the box
↓ The formation of molds; ↓ The preparation of cores (in order to form castings with internal hollow sections)	↓
↓	Underpressure
The insertion of cores in the mold	↓
↓	The casting in the mold (evaporative process)
The casting of molten metal in the mold	↓
↓	Pressure, chipping, and cleaning
Knocking-out the casting from the mold	
↓	
De-coring, chipping, and cleaning	

Figure 16.3. The main production operations used in the SM and GP molding processes.

corresponds to more complicated operating methods, while a high level of complexity (GP process) corresponds to more simplified operating methods. The history of the casting industry's technical progress clearly shows a process of increasing technical complexity and a corresponding simplification of operating methods.

- *Structure of costs and economies of scale.* The importance of learning in the finishing processes plus the relatively minor level of learning in the

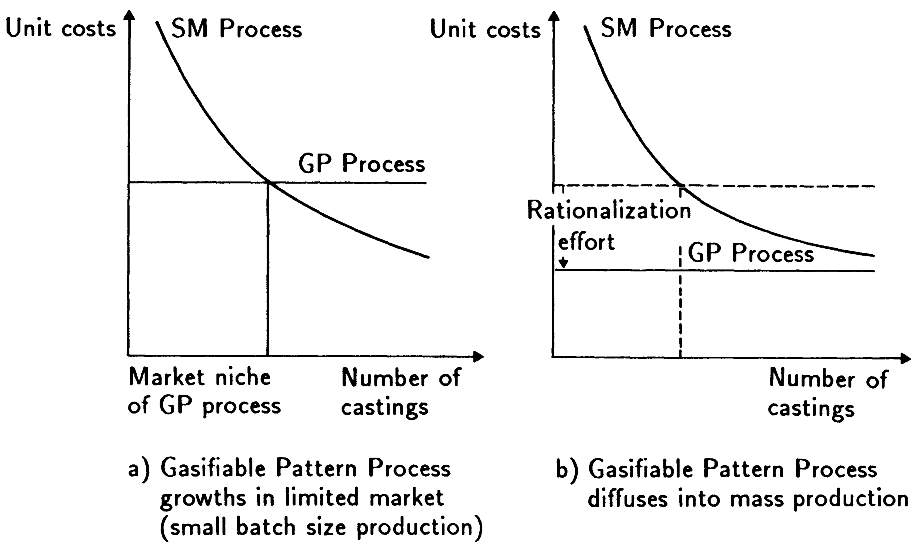

Figure 16.4. Evolution of the cost structure and two successive steps of market penetration for the gasifiable pattern (GP) process: (a) the GP process grows in a limited market (small batch-size production); (b) the GP process diffuses into mass production.

preparation and pouring processes, are features which affect the conditions for economies of scale in both SM and GP technologies. However, the problem as to whether pattern costs are included in the initial costs or not, represents a key-discriminatory feature between the competing technologies: in the case of SM processes one of the main economies to be achieved by increasing output of individual castings is the distribution of pattern costs. The higher the relative importance of pattern costs (the cost of a wooden pattern would be about 25% of the cost of a metal pattern) the more crucial is the search for mass production.

On the contrary the cost of a lost pattern cannot be included in the initial costs. Given that a lost pattern can be utilized for a unique casting, it is necessary to produce as many patterns as products. Therefore there is no direct relationship between the pattern cost per unit and the importance of the run, so that the decrease of the pattern cost per unit produced can be achieved only by the rationalization of the production of patterns. Until such rationalization efforts are effected, the GP process is thus inadequate for mass production [*Figure 16.4(a)*]. This flat pattern of the costs per number of castings explains both the limits of the GP process and its competitive advantage over the SM process for the production of small batch sizes: in this period the GP process diffused inside a small market niche only where it was in competition with the SM process for the unit production of very complex and large products. After the rationalization of the production of patterns [*Figure 16.4(b)*], the GP process also became economic for mass production: competition between the SM and GP processes becomes more and more important.

Thus, the evolution of the cost structures for the GP process implies a periodization of the diffusion process, the formal analysis of which is presented in the following section.

16.3 Diffusion Trajectories in France and the FRG

In *Figure 16.5*, which shows the output of the foundry industry in France and the FRG, two important features can be observed and documented. First, the evolution of the foundry industry follows a very similar path in terms of output volume both in France and in the FRG. A period of saturation and contracting markets followed the period of growth and expanding markets and in each case the turning point occurred in the early 1970s. Second, since 1960, the GP process started to diffuse in the FRG while in France it was *locked out*, and remained in a very minor market share position.

Figure 16.5 also shows that in the case of the FRG, the diffusion pattern of the GP process was not influenced by the contraction in the global market (i.e., decline in output volume) of the industry. Furthermore, the output figures of the GP process were apparently not affected by the strong fluctuations in the total market volume. On the other hand the evolution of the output of the SM process appears to follow closely the decreases in global output volumes and market fluctuations.

It is our contention that it is important to differentiate in diffusion research between two important situations with respect to the evolution of the market in which technologies compete. In the first place, when the market expands rapidly, diffusion takes place via differential growth rates, i.e., changing relative market shares are the result of one technology growing faster than another. This is in sharp contrast to the diffusion of a technology in a saturating, even declining market, as in our case. We maintain that under such market conditions, effective diffusion calls for a higher comparative

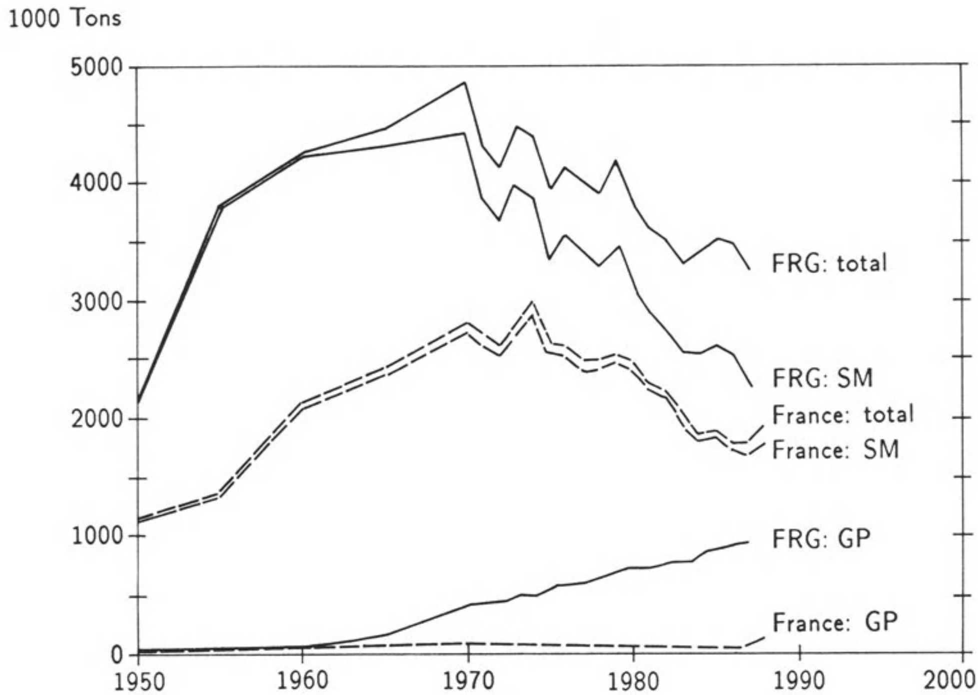

Figure 16.5. FRG and France: Casting by SM and GP processes and total market volume.

advantage than in the first case as diffusion can proceed only via replacing existing capital vintages.

It is interesting to point out the situation in the FRG as shown in *Figure 16.5*. Despite strong market fluctuations the output figures of the GP process evolve very regularly, i.e., they are not affected by short-term business cycle variations in market volume. Conversely, the SM process takes the full burden and acts as the *swing supplier*, i.e., in response to demand fluctuations.

It is our contention that the difference in behavior toward demand fluctuations is indicative of a high comparative advantage differential between the two processes in the FRG.

16.3.1 In search of specific factors of diffusion in France and the FRG

The preceding discussion of the morphological structure of the technological trajectories leads us to conclude that prior to 1970, the GP process could compete only for the casting of small batch sizes. In a second period, after a technological breakthrough involving the conditions of production of lost patterns, the GP process (which corresponded then to the combinations of parameters m and n) could effectively diffuse also in mass production and compete with the SM process. Thus, in order to explain the differences between the national patterns of diffusion, it is necessary to divide the adoption process of GP technology into two phases: the diffusion into the first market niche of complex, small-series production; and the subsequent diffusion into the mass production market.

The substitution curve, the parameters of which will be commented upon in Section 16.3.2, is illustrated in *Figure 16.6* and shows that a rapid substitution of the SM by the GP process in the first market niche of complex, small-series production took place in the FRG during the period 1960–1975. We must therefore explain the reasons for this rapid first diffusion period in FRG and then identify its influence on the diffusion trajectory of the second period.

Dynamics of Demand Structure and Profitability

The first driving force relates to the market niche for complex, small-series production. This highly specialized market expanded rapidly in the FRG in the early 1960s (this was not the case in France) and was (as discussed at the beginning of Section 16.2) an important factor in the rapid diffusion in the first phase. The documentation of this factor is, however, seriously hampered owing to the absence of relevant statistics prior to 1970. A second factor deals with the specific comparative (economic) performance of the GP process in the FRG during the first diffusion period. *Figure 16.7* depicts the sharp differences between the relative value-added for the two processes, in particular during the first phase of the diffusion of the GP process. The low level (factor 1.1) of the comparative advantage (value-added) in France could explain the disinterest by the French firms in the new process. Furthermore, the evolution of the relative value-added between the GP and SM processes (from 1.4 to 1.1) in the FRG between 1970 and 1987 correlates with our hypothesis that two phases exist in the diffusion of the GP process.

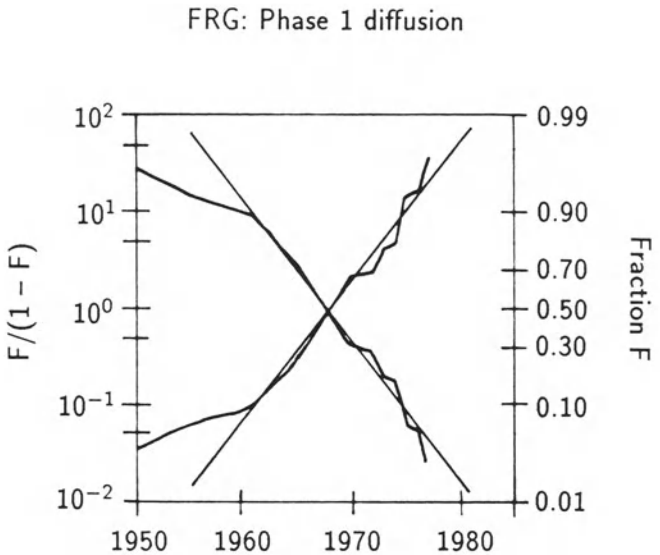

Figure 16.6. The substitution process of SM by GP technology in the first diffusion period (competition for small batch-size production only) in the FRG.

During the first phase, the market niche is made up of complex, small-series production and the comparative economic advantage of the GP process are correspondingly higher than during the second phase of diffusion where it approaches the value-added of mass production (i.e., a relative value-added ratio of 1).[3] Thus, the differential represents an initial explanation for the rapid diffusion of the GP process in its first market niche in the FRG. One question remains to be answered. How did the diffusion pattern in the FRG in the first period influence the outcome of competition in the second period?

Knowledge Accumulation and Learning During the First Period of Diffusion in the FRG

During the first period of diffusion the GP technology was rapidly adopted in the FRG, in spite of the fact that its adoption entailed a strong technological breakthrough for the innovative firms. The fundamental feature in this first diffusion phase is what occurred to some extent *underground*. The first diffusion phase generated a process of accumulation of knowledge, and included, via adequate institutional arrangements, the creation of a

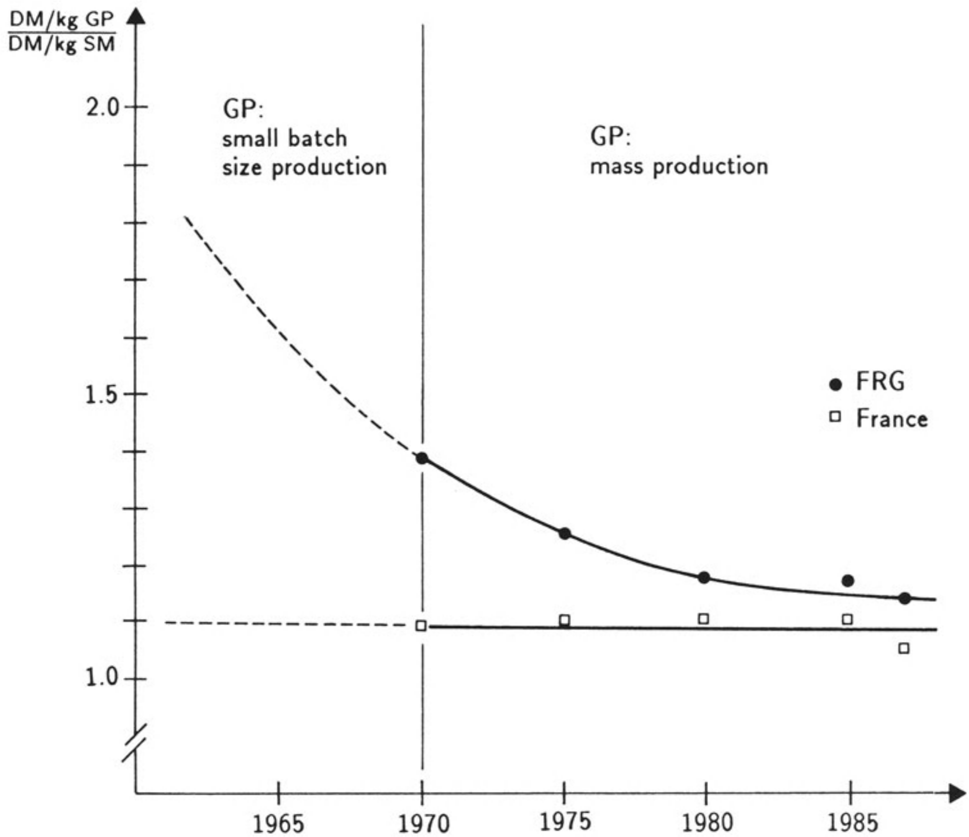

Figure 16.7. FRG and France: Relative value-added (profitability) between the GP and SM casting processes.

technological foundation in Ludwigshafen am Rhein, with strong participation by German firms (foundries and chemical enterprises). Research programs were oriented toward improvements in the use of polystyrene patterns to produce metal castings and the systematic generation of minor innovations, which were required for the industrialization of the GP process.

Thus, optimal pouring rate, adequate density of polystyrene, etc. were systematically investigated. After the seminal conception of the process (which can be interpreted as a jump in technical knowledge, i.e., a breakthrough, in our terminology), research programs were conducted in the FRG to solve the technological problems which continually occurred during the initial diffusion phase (Foray and Lebas, 1986). Thus, knowledge was accumulated during the first phase of diffusion also through an adequate institutional arrangement. More generally, this initial diffusion in a highly specialized market permitted the GP process to access, for the first time, those mechanisms (*cf.* [2]) related to increasing returns to adoption, learning by using, economies of scale in production, and informational increasing returns, while at the same time being *protected* by a high value-added differential.

Thus, the first phase of diffusion facilitated a learning process, resulting in the transformation of the technical process (from *o* to *m* or *n*, *Figure 16.1*), enlarging its initial functions, thus providing the basis for experimentation, incremental improvement innovations, increasing returns to adoption, etc., necessary for subsequent diffusion into the whole market niche.

The Dynamics of the Two Phases

As far as exiting from a *lock-in* situation is concerned, the German and French examples are quite instructive. The *lock-in* concept allows us to explain how a new and intrinsically superior technology may be impeded from supplanting an older technology. This is supported by the following quote:

> New inventions are typically very primitive at the time of their births. Their performance is usually poor, compared to existing (alternative) technologies as well as to their future performance [Rosenberg and Frischtak, 1983, p. 147].

Thus, when a new technology is introduced in its initial (and therefore primitive) form, it has virtually no chance of asserting itself, even if the old technology is *inherently inferior.* The latter has profited from its monopolistic period and entrenched itself materially (via technological interrelatedness) and intellectually (via *sui generis* evaluation norms) as the dominant productive paradigm. In this respect, our case study illustrates the crucial importance of an initial diffusion in a highly specialized market in order to overcome a technological *lock-in.* In this first period the new technology, *protected* by a high value-added differential, may improve within a *quasi in vitro* environment. Thus shielded, the new technology acquires industrial properties via the mechanisms related to increasing returns to adoption, gradually armoring itself for competition. Between 1950 and 1970, the GP process improved in a virtually underground fashion in the FRG; it was later able to enter the main competition arena under auspicious conditions. Having missed the first phase, France is now missing the second one also.

The diffusion of an innovation in a relatively minor market probably represents a unique tool for *preparing* the new technology for competition in its industry's major market. As Utterback (1987) suggests:

> Because performance will be initially unreliable and costs higher, a new technology will tend to start in a relatively small market niche where its unique performance advantages are critical – one ordinarily not occupied or of not great importance to the producers of the established product. Crude as it is, the new technology will gain ground by competing in these submarkets and its use will expand by means of its capture of a series of them.

The specificity of the national diffusion trajectories in France (*lock-out*) and the FRG (diffusion) is therefore based on the link between the two phases. According to Silverberg (Chapter 8): "A technology policy that does not take the interdependence of these two aspects into account will always be inherently flawed."

16.3.2 The formal analysis of the diffusion trajectories

A formal analysis of the diffusion trajectories of the GP process in the FRG through two successive market niches – small batch-size production prior to 1970 and mass production thereafter – is, however, seriously hampered by the absence of relevant disaggregated production statistics. For the diffusion trajectory within the first market niche for small batch-size production we assumed that a constant volume of complex castings was produced in small series in the FRG in the period prior to the mid-1970s in order to calculate the fractional market share of the GP process. For the second phase of diffusion we calculate the diffusion trajectory on the basis of the fractional share in total (tonnage and value) output. This is based on the conclusions of the morphological analysis, which has yielded that the GP process is also in effective competition for mass production in the post-1970 period.

Table 16.1 and *Figure 16.8* summarize the quantification of the diffusion trajectories in the case of the FRG, based on a simple Fisher–Pry type of technological substitution model. The properties and underlying assumptions of this now classical model will not be repeated here; details on the estimation algorithm used can be found in Grübler, Nakićenović, and Posch (1988).[4] In order to increase the analytical resolution of the formal description of the second phase of the diffusion (substitution) trajectory, we have used, in addition to output tonnage, output value (measured in current DM) by casting process in the period since 1970 (data source: Deutscher

Table 16.1. Phases in the diffusion of the GP process in the casting industry of the FRG: diffusion model[a] parameters.

	Fraction of GP in tonnage output	Fraction of GP in output value
Phase 1 (small batch-size market niche), period: 1960–1977	Δt = 13.1 (14.74) t_o = 1967.8 (14.74) n = 10 R^2 = 0.965	No data available
Phase 2 (total market including mass production), period: 1970–1987	Δt = 52.4 (45.76) t_o = 1997.7 (45.99) n = 18 R^2 = 0.992	Δt = 61.58 (17.70) t_o = 1997.9 (17.88) n = 18 R^2 = 0.991

[a] Δt: diffusion parameter, time in years to grow from 10% to 90% market share; t_o: inflection point (50% market share), time of maximum growth rate of market shares. Values in parentheses refer to t statistics of estimated diffusion model parameters.

Gießereiverband, 1975, 1980, and 1987). The estimated diffusion parameters are consistent between the two measures, with the diffusion rate of the GP process calculated on the basis of output value being around 17 percent slower than for output tonnage figures.

In keeping with the differential for the specific value-added (i.e., DM per kg of product) between the two process technologies discussed above, we note that the diffusion rate of the GP process into the first market niche of complex, small-series production is significantly faster (by a factor of 4) than in the second phase of diffusion, i.e., into the lower-value mass production market niche. This indicates that in addition to the higher specific value-added (as a proxy for its relative profitability) for the GP process technology (at least 1.4 in 1970, and most likely larger in the period before), other comparative economic advantages, such as lower production costs in small series, are influential factors which help explain the rapid diffusion of the GP process into the first market segment.

In *Figure 16.8* we show the diffusion (substitution) trajectories in the two successive market niches of the GP process. Particularly noticeable is the regular pattern of the second diffusion phase since 1970. In order to illustrate the decisive structural difference between the technological base in the casting industry between the FRG and France, we have compared the diffusion trajectory in the case of the FRG with the trajectory of the market share fraction of the GP process in France, which appears *locked*

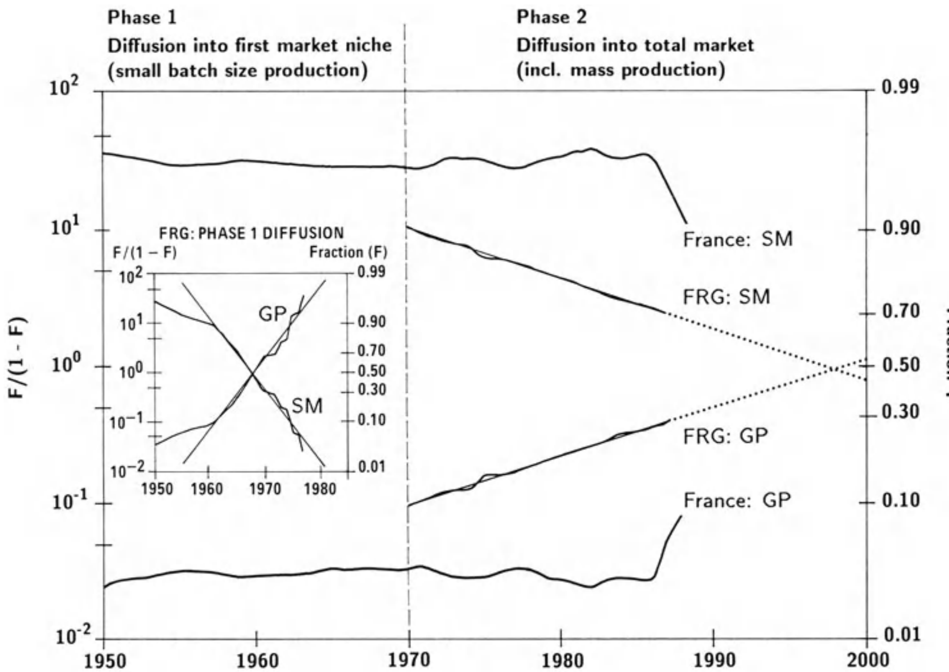

Figure 16.8. The two diffusion phases of GP casting technology in the FRG and its *lock-out* in France.

in at a constant market share fraction below the two percent level. Since 1986, however, this share has increased rather rapidly to the present level of below eight percent of total casting tonnage in France. This could be a first indication that the GP process might be at the beginning of a similar diffusion takeoff as was the case in the FRG some decades earlier.

16.4 Patterns of Evolution

The study of the diffusion trajectories, which develop into a well-defined morphological space allows us to reproduce finally the historical evolution of the casting technology. In relation to the MA (*Figure 16.1*) we are only interested now with the technical processes (located above the final branches in *Figure 16.1*), as industrial applications of the various possible combinations of parameters of the morphological space. However, the MA still remains the basis for the construction of an *evolutionary tree* by identifying two principal alternatives (i.e., the SM process versus the GP process route). All morphological combinations possible will, however, not be described. Only those that have actually evolved and diffused into the industry will be considered.

This last step of the analysis allows us to highlight some characteristics of technical progress: its cumulative character (i.e., evolution of trajectories defined on the basis of stable morphological combinations) on the one hand, and the localized character of learning processes on the other.

16.4.1 Construction of the graph

According to the result of the MA, two trajectories can be distinguished: SM processes (a, b, c, d) and GP processes (m, n). Both trajectories are based on the stability of the P_1 parameter (*Figure 16.1*) concerning the nature of the pattern. One trajectory describes the evolution of permanent pattern technology, and the other, the evolution of lost pattern technology. Apparitions of new morphological combinations are indicated by ramifications (b for SM and r for GP), while all other improvements, which do not create new morphological combinations, are incorporated simply by extending the existing branches of the trajectories. We make use of a data base consisting of 50 innovations in the foundry industry with a technical description and a historical dating of their introduction.

16.4.2 Describing the dynamics of technology

Figure 16.9 emphasizes three key features:

- Clustering of chemical based innovations between 1955 and 1975: lost molds predominantly or completely bonded by chemical means (development of the existing trajectory by changes at the level of the P_3 and P_4 parameters, see *Figure 16.1*).
- Emergence of a rival technology: the GP process (creation of a new trajectory by changes at the level of the P_1 parameter).
- Clustering of physical based innovations between 1970 and 1985: lost molds predominantly or completely bonded by physical means (development of the existing trajectories by changes at the level of the P_3 and P_4 parameters).

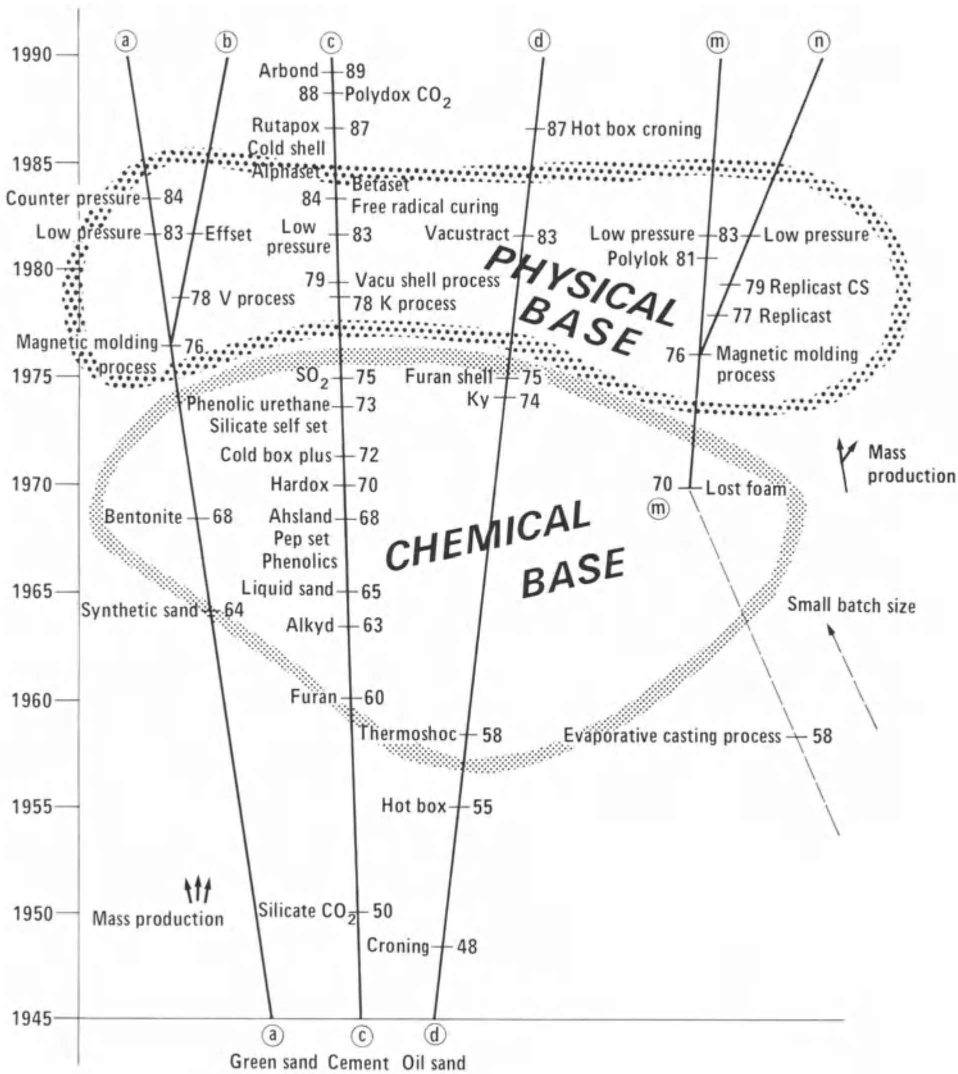

Figure 16.9. Trajectories of the molding processes and clusters of innovations (1945–1989).

The First Cluster of Innovations

The figure shows a first cluster of innovations during the period 1955–1975. This cluster was oriented toward the use of a chemical method for the stabilization of the mold. Originally the chemical methods were used by applying cement, CO_2 gas, oil sand, and shell molding (the croning process) (see bottom of *Figure 16.9*). Then improvements in the application of inorganic and organic binders determined a cluster of innovations (furan, alkyd, phenolics, pep set, bentonite, thermoshoc, etc.). According to the MA, these technological changes cannot be considered to be the emergence of a rival technology (all morphological distances are inferior to the radius of graph G). Since 1958, the GP process was used, but given its specific cost structure discussed above, it was devoted to small batch size and thus was not in competition with the mass production of castings.

The Emergence of a Rival Technology

In 1970, significant improvements concerning the GP process occurred. In particular rationalization in the production of lost patterns (pre-expansion and molding processes of expandable polystyrene) made this process adequate for mass production, so that the GP process (combination of parameters m) became substitutable for all existing SM processes (a, c, and d):

> The future of the gasifiable pattern process appears to be in large production runs using molded polystyrene patterns in unbonded sand. This is in contrast to its original use which was in the production of large short run castings [Bailey, 1982].

According to the MA, this technological change can be considered to be the emergence of a rival technology, given the substitutability of the processes and the morphological *distance* between the two competing processes (superior to the radius of graph G).

The Second Cluster of Innovations

The cluster of physical based innovations (the use of vacuum and magnetic fields) occurred after 1975, the year of the first industrial application of magnetic molding. The magnetic molding was introduced both for SM processes (magnetic molding, V process) and for GP processes. These technical changes were based on new morphological combinations (b and n) without altering the stability of both states of the P_1 parameter (i.e., the stability of both main trajectories).

16.4.3 The national patterns of evolution

Figure 16.10 shows the differences between the technological structures of France and the FRG. This figure is consistent with the results of our previous analysis concerning the diffusion trajectories in France and in the FRG. While the German pattern occupies the total area of the morphological space, the French structure leaves a large part uncovered, i.e., the GP trajectory is *locked out.*

16.5 Conclusion

Our case study was particularly appropriate in showing the advantage of a morphological analysis (MA) approach in technological diffusion analysis. Indeed, the MA of the structure of technological trajectories in the casting industry (*Figures 16.1* and *16.2*) avoids any misinterpretation concerning the asymmetrical character and the discontinuities of the diffusion trajectory of the GP process. On the basis of the morphological space of molding technologies, we can establish that the molding process under consideration (GP) cannot be thought of as a unique unaltered artifact throughout the period of diffusion. In fact, there are two diffusion trajectories corresponding to two combinations of parameters and therefore to two successive market niches. This breakdown into two periods allowed an exit from a *lock-in* situation by emphasizing the crucial nature of the first period of diffusion, where knowledge is accumulated and a process of learning within a *quasi in vitro* environment occurs, allowing a rival technology to develop capable of competing within the industry's entire market.

Notes

[1] Notions of arborescence and tree are used here in their specific meaning of graph theory.

[2] The theory of *lock-in* effects (Arthur, 1989) provides a clear understanding of the mechanisms (increasing returns to adoption) by which a technology may overcome its rivals and how it then generates its own defense mechanisms against – even inherently superior – technologies. The principal sources of the increasing returns to adoption are: learning by using, network externalities, economies of scale in production, informational increasing returns, technological interrelatedness, and the production of *ad hoc* evaluation norms. The last two sources allow us to explain the phenomena of maintaining mature technologies in the long term.

FRG

FRANCE

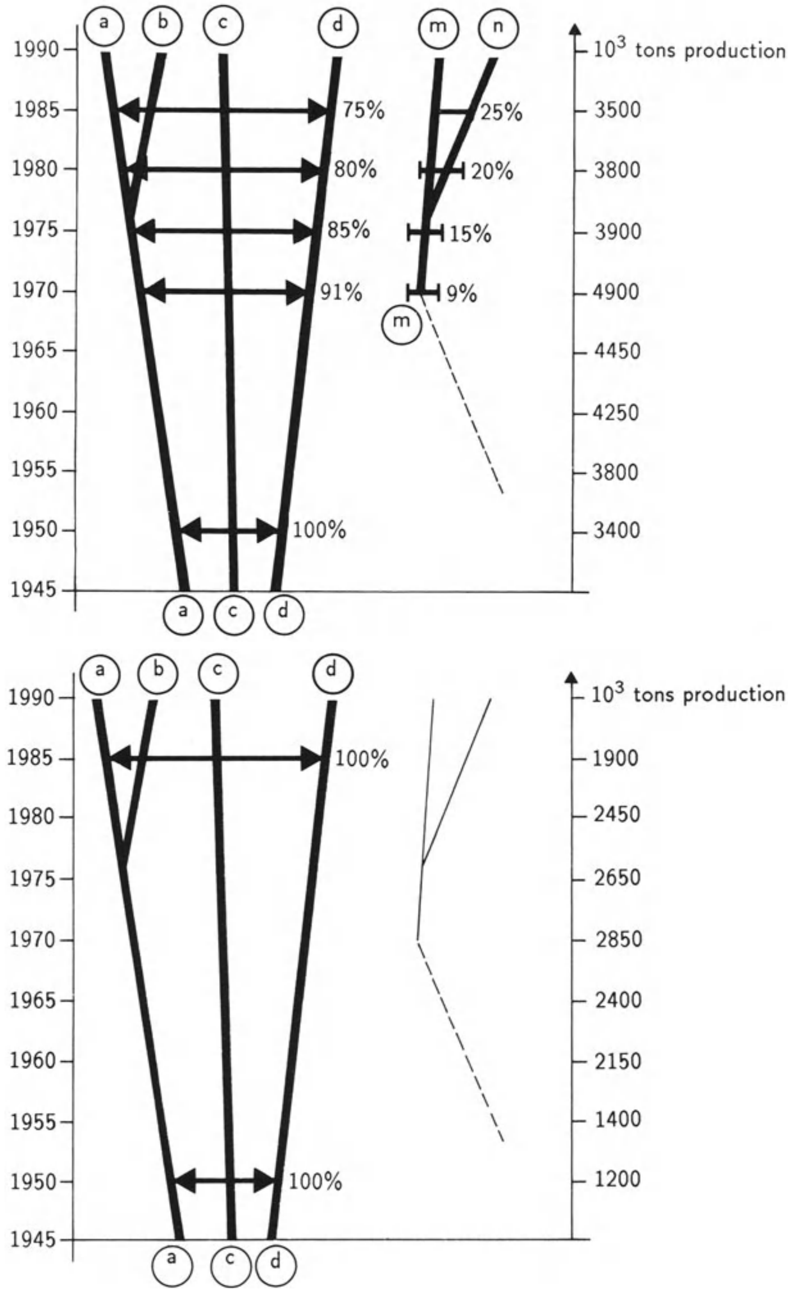

Figure 16.10. National patterns for the trajectories of the molding processes (mass production).

[3] Clearly, the nominal value-added differential illustrated in *Figure 16.7* should be presented in real terms. However, the estimation of real price deflators faces the difficulty that both the structure of the market and the product are changing (as demonstrated in the discussion above) and are consequently not reflected appropriately in the price index published by the industry.

[4] The use of the Fisher–Pry model to describe the diffusion of the GP process in two distinct periods is based on the argument that the theoretical structure of this model is appropriate for taking into account this mix between a phenomenon of continuity and a two-period analysis. However, the question of the use of other types of diffusion models (threshold/probit models) still remains open.

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