Modelling the Product-Process R&D Dynamics

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Abstract

The aim of this paper is to outline the development and use of a framework for studying the complex dynamics of product development, process development and production within in the context of a resource-based view of firm activities. The development process is seen as a system of activities, resources and dynamic capabilities, which are located and take place at different places and time scales. The complexity of this system is manifested both by the interactions amongst different activities, as well as by the feedback effects exhibited through the commitment of resources in a path-dependent manner.

The behaviour of the system is explored through a modular system dynamics simulation model of all inter-related systems, focused on the strategic management of R&D efforts. Specific attention is given to the process development strategy and the interaction between the learning processes which occur before and after a production process starts operation. The proposed model can be used for understanding the complex relationships among the various activities that take place within a firm and the respective strategic decisions, as well as for developing effective R&D strategies.

Keywords: innovation management, process development, innovation strategy, capabilities, learning, system dynamics

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1. Introduction

In the innovation literature it is common to distinguish between product and process development for reasons of analytical distinction and clarity of communication. However, when dealing with the issues of product development management and strategy, the distinction is quietened down. Process development is viewed simply as a stage in (or part of) product development, unless it is the exclusive subject of development activity, whence it merits attention on its own.
Pisano (1998) has highlighted that in a diverse number of industries the strategic decisions dealing with the development of products and their respective production processes affect significantly the speed and cost of development. In this paper we are attempting to develop a model based, to a large extent, on Pisano's observations and assumptions and to test it in different dynamic settings.
The paper is divided in four sections. In the first section we discuss the broad theoretical perspective that underlines our model. Next, we describe the development of the system dynamics model. The main issues that the development of this model raises are discussed in the third section. In section 4, we present our experiments conducted using the model. Finally, we conclude by discussing the possibilities that system dynamics offers for the modelling of innovative activities from a resource-based perspective.

2. Capabilities for product-process development

The effectiveness of the development process may be measured along three dimensions: the cost at which it is delivered to the market, the quality of the first generation of products and time to market. These interrelated metrics depend on the capabilities of the firm as they are manifested through the product and its production process.

Pisano (1998) suggests that the result of the level of effectiveness of the technical innovation (development) process is the combination of two learning processes: 'learning by doing' and 'learning before doing'. Learning by doing takes place at the production process and is a result of experience and problem solving that takes place during actual production. Learning before doing occurs at the R&D lab during process development. It is the result of design and problem solving activities which take place before the product enters actual production. Investment in learning before doing affects the starting point of process effectiveness and defines the initial cost of production investment and scaling up. Therefore, the interdependence between learning by doing and learning before doing affects the capacity of firms to deliver a product competitively along its life cycle.

Pisano's approach implies that the development activities that lead to the delivery of a new product to the market take place in two distinct organizational entities. Underlying these activities are organizational resource endowments committed to specific patterns of allocation to an activity system (Ghemawat and Pisano, 2001). Therefore, the architecture of an innovation strategy is the result of endowment and strategic intent, as the latter determines the pattern of the firm's activity system (Porter, 1999), which in turn results in the accumulation of resources for further allocation.

In this analysis, the nature of resources plays a critical role. Penrose (1959) stressed the nature of the firm as a resource pool and its importance to firm growth. The Penrosian concept has been explored further, mainly in the resource-based school for the theory of the firm. Penrose herself indicated that there exist two types of resources: material (tangible) resources and intangible resources. Several analysts have explored the concept of capabilities (or competencies) as a specific type of resource, which is dynamic in nature.

Although different in their conceptual and operational content, both capabilities and competences share some critical properties. They combine tangible and intangible resources in unique, firm specific ways. They constitute organizational resources in the sense that they take specific organizational forms according to the choices made and the organizations objectives and commitments. Teece et al. (1997) have distinguished a specific set of dynamic capabilities, which play an active role in the formation of the resource endowment of the firm. Amongst dynamic capabilities, learning deserves a special indication (attention) as that capability which contributes to the development of specific sets of capabilities. Capabilities are formed as the result of learning processes that occur due to the choices made as well as a product of the experience gained through the activities performed.

Hence, the accumulation of resources in terms of capabilities is a path-dependent process determined by two sets of factors: commitment decisions and learning. In other words, the interaction between capabilities, commitments and activities forms the basis of path-dependent evolution in firms in two ways. First, commitments determine which activities will be carried out and what resources will be devoted to each activity. Second, the execution of activities results in the generation of experience, which feeds back into the capabilities that supported it in the first place. Thus, activities not only consume resources, but they also contribute to their accumulation.

In product development and commercialisation we may immediately point out two types of learning that lead to the accumulation of capabilities. In production, learning by doing, which occurs primarily through failure and experimentation, has been thoroughly explored in the past. In product and process development learning occurs through experimentation, technological search and gate-keeping, competition observation and market research. Burgelman *et al*. (1996, pp. 672-673) have stressed the importance of learning across projects as a decisive factor in R&D effectiveness. They also point out the difficulty of learning across projects, which they attribute to two main reasons. First, they note the complexity of interactions within the development system:

> "… the connection between cause and effect may be separated significantly in times and place. In some instances, for example the outcomes of interest are only evident at the conclusion of the project. While symptoms and potential causes may be observed by individuals at various points along the development path, systematic investigation requires observation of the outcomes followed by an analysis that looks back to find the underlying causes."

Second, they acknowledge that pressure to proceed to the next project hinders the organization from bearing the cost of learning. The need for learning and the benefit from the required investment have to be made apparent and obvious to the interested parties.

Thus, the accumulation of capabilities is the result of multiple learning processes that take place in parallel. These learning processes occur in different places (organizational functions) and at different time scales. The complexity of the picture intensifies as the results of the various learning processes are combined at the resource level and interact for the delivery of the final product. So, the product of one learning process contributes to the development of resources which may – according to the rational of intentions decided – be committed to any of the related activities that may result in further learning. Resource commitment may be assumed that is founded on the perceived rents expected. These will be estimated on the basis of past performance and emerging opportunities. Experience shows that the former is more likely to happen (Murmann and Tushman, 1997).

In other words, it may be said that the firm is rather an ensemble of interacting pools of resources and dynamic capabilities, which are located in different parts of the organization, than a single pool of resources. Thus, organizational architecture (structure) appears to be both a product of learning processes and a determinant of activities.

The question of strategy therefore lies in the decision about which activities and learning processes to commit resources to and for how long. Pisano (1998) has provided empirical evidence that the answer depends on the nature of the industry and the technology involved and the impact of learning to the overall performance of the firm in terms of end products. In the following section, the interactions amongst activities, learning processes and resource commitments are represented in a system dynamics model, which is focused on the role of the management of process development for the overall product development project.

3. The dynamics of the development factory

In a manufacturing environment, the launch of a new product to the market typically involves the development of the product itself and of the production process that will deliver it. In his research, Pisano (1998) outlines his hypothesis that the level of investment in process R&D affects not only the short-term, but also the long-term efficiency of production and the eventual return on investment in new products. Placing his focus in production efficiency, Pisano points that there are two distinct ways to shape efficiency: through process R&D and through learning by doing. The former determines the initial productivity that a production process will operate with, through 'learning before doing'. The latter will improve efficiency by way of experience, through problem solving and trial and error.

The initial dilemma is set between continuing process development and passing to the stage of production. The more the production process is developed the more efficient it is expected to be. Early start of production may cause errors and loss in quality, resulting in reduced productivity. However, there is a trade off. Delayed production results in loss of revenue (Figure 1). Many companies prefer to bring a product in full production as fast as they can and then to fix any problems that may show up. This is a strategy that appears to be optimal on a project-by-project consideration. It is important to note here that there is an adaptation period for learning the new process. As the whole production system gets used to the new product's specifications and demands, its productivity is improved along the product life cycle, which in turn has a positive effect on the total cost. Hence, the higher the productivity is, the lower the product cost (balancing loop B1).

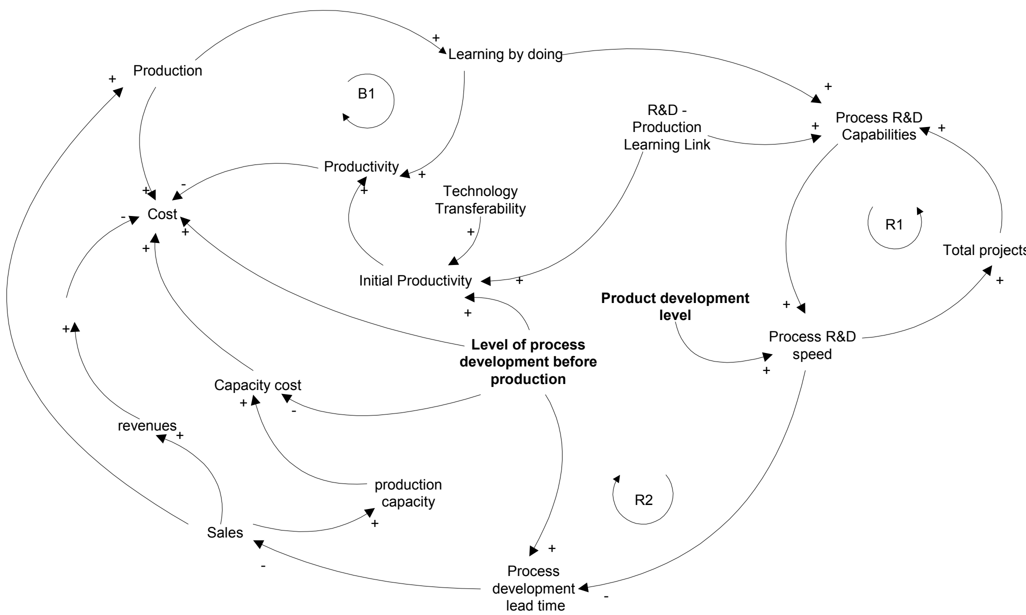
The other option that a company has is to wait until more knowledge is accumulated, so that the process is more efficient upon the launch of production, reducing the possibility of a breakdown.

Such an approach, however, fails to capture the learning effect that occurs within process R&D. Depending on the degree to which a firm has invested on its ability to learn from accumulated experience in process R&D, it may benefit from it. Thus, carrying a project into further development would mean that more experience is accumulated for future projects to exploit. This of course would be at the expense of early product launch. Pisano argues that while this strategy would not produce favourable results in the short term, it would have a positive impact on the long term. Subsequent projects of process development would be accelerated, as the R&D efficiency would benefit from the accumulated experience. He quotes evidence that shows that in the long term such a strategy should result in bringing the process development sub-project outside the critical path of the whole product development project.

There is however the provision, that technology transfer from R&D to the shop floor would not limit the realization of designed process efficiency in actual production. Thus, the effectiveness of such a strategy depends on the degree to which process technology is codified - rather than tacit – and on the efficiency of communication between R&D and production. Conversely, one might argue that the same may hold for the transfer of knowledge accumulated at the shop floor – through learning by doing – to the R&D department for codification and further exploitation in subsequent projects. Thus, the effectiveness of any strategy would be tentative depending on the 'maturity' of the technology employed (the life-cycle stage at which it is).

A second decision dilemma concerns the starting point of process development with respect to the level of product development progress. Depending on the stage of development, the product-specific information that relates to process development affects both the speed of process development and the efficiency of the production process. This also means that the firm has the opportunity to wait until sufficient information has been collected about the product in order for the process development strategy and choices to be less risky. Additionally, this increased process development speed usually results in an increased number of final projects. This can lead to large experience in addition with an improvement in company's process development capabilities (Reinforcing loop R1). Learning by doing results in increasing knowledge so the company can be more effective in subsequent generations' products. We also have to underline the significant effect that R&D- production learning link has in the development of these capabilities. The more intense this link is, the more R&D may take advantage of the technology accumulation taking place at the shop floor.

Figure 1: The dynamics of product-process development



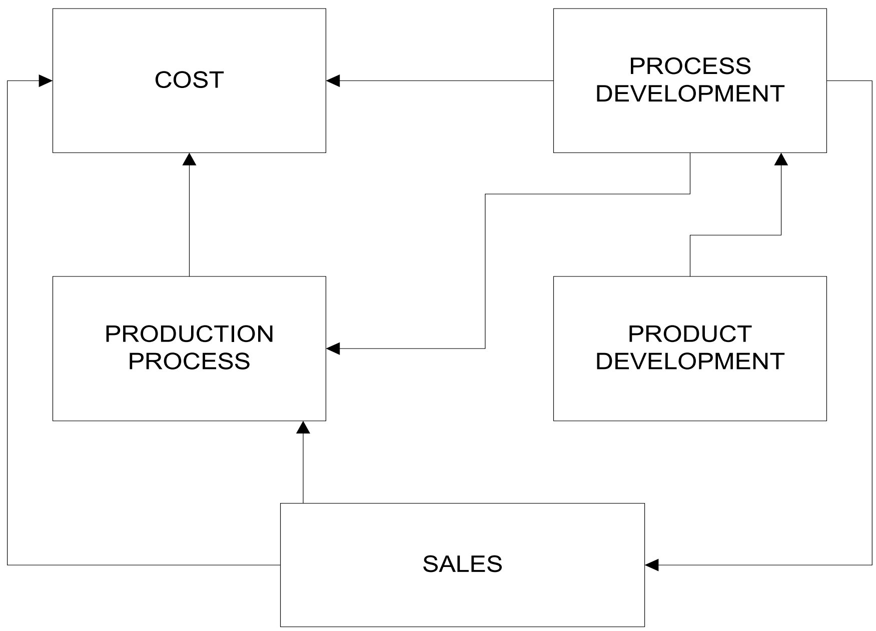
4. The model on process development dynamics

The model developed explores the effect of the interactions amongst learning processes that take place in three areas - product development, process development and production – and their effect on the firm's operational profitability. All these interact in the context of the adoption rate as it occurs in the sales sub-model (which is not described here, as it is an extension of the Bass model (Sterman, 2000: 332-339) (Figure 2). Below we briefly describe the operation of the four subsystems/sub-models.

4.1 The Product Development subsystem

The product development subsystem is the simplest, as its interaction with the rest of the system and its internal dynamics are not dealt with in full detail. It is assumed that there is a constant product development effort, which represents the activities that take place in product development. As a result we have a smoothly progressing product development process. When product development reaches a desired level then concurrently the process development effort commences.

Figure 2: The generic model of Product Development Dynamics



4.2 The process R & D subsystem

This subsystem deals with the process development for a new product, taking into account the firm's experience accumulation rate and the rate according to which this experience is converted into useful knowledge for a next generation product.
Progress here depends primarily on two variables:

- On the level of product development (and consequently on the process information that is useful) at which process development begins.
- On the process R&D capabilities of the firm. These include both organizational capabilities (project management) and technological capabilities.

Accumulated R&D capability is a decisive factor in overall process R&D performance. The accumulation of R&D capabilities is the combined result of three factors:

- The experience which is accumulated as the number of projects realized increases.
- The learning capability that characterizes the process R&D functions.
- The inter-departmental learning capability, from production to process R&D. This is a measure of organizational integration and cohesion, as they are materialized through concrete organizational routines.

4.3 The production process subsystem

With every new product, new production capacity needs to be deployed as older technology is devalued. New capacity embodies a leap in productivity as a result of learning before doing in process R&D.

The productivity of the production function is also affected by the experience accumulated as successive production runs exit the shop floor. Thus, the technological capability that sustains productivity and contributes to its improvement is the joined result of learning by doing and learning before doing.

4.4 The cost and revenue (performance) subsystem

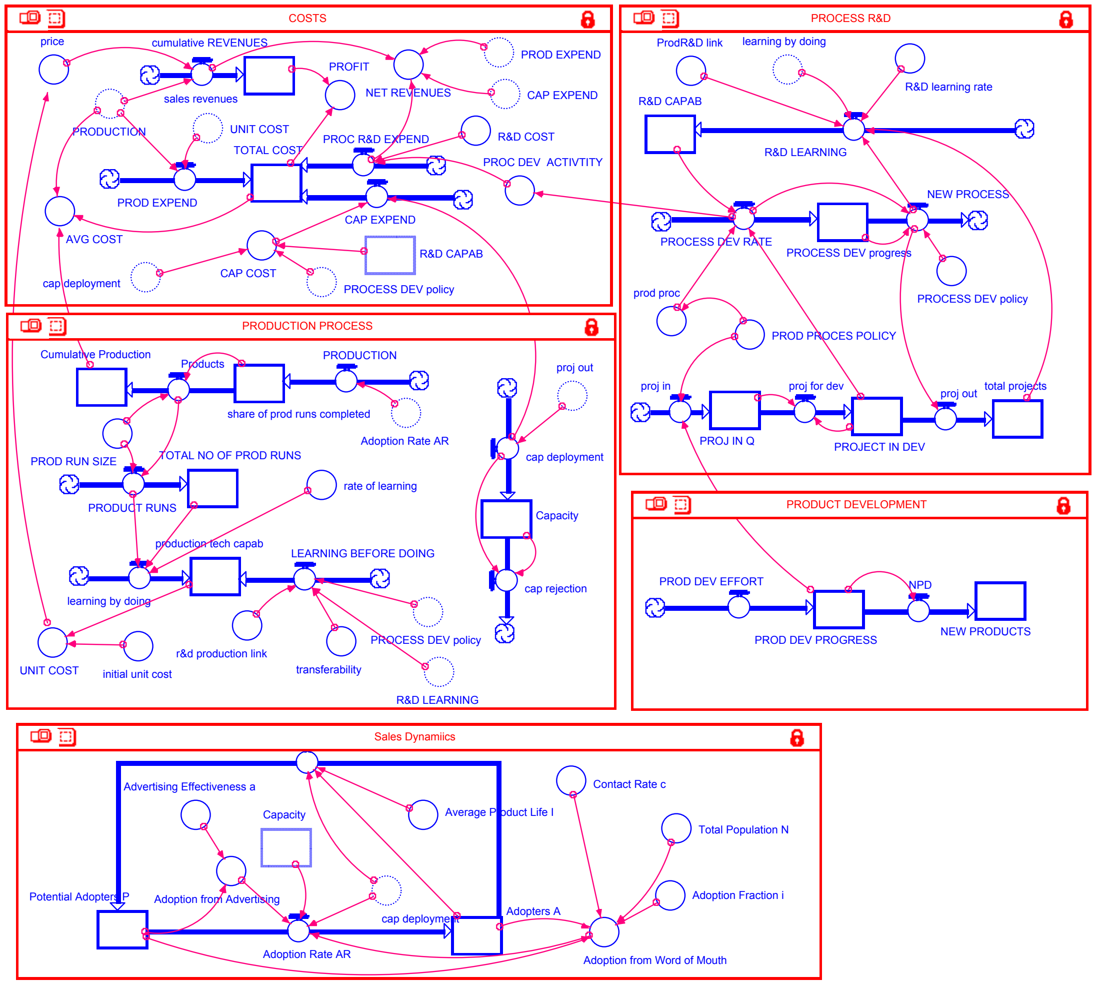
This is a subsystem, which represents the evolution of the economic performance of the firm as the production function operates and new products and production technology are introduced. It should be noted that the cost of new capacity depends on the accumulated technological capability in process R&D. Thus, successive process generations embody better terms of productivity.

In order to simulate the interactions among the different sub-systems, one has to take into account the fact that they take place in different places, at different rates and in different time frames. The latter are often determined according to policy in respect to other activities: commencing process R&D depends on process development progress and production built up depends on process development target fulfilled. Product R&D speed is slower than process R&D (in our example).

As it has already been noticed elsewhere (Morecroft, 1999), the stocks and flows formalism of system dynamics is compatible with the resource-based approach to strategic management (Dierickx and Cool, 1989). Resources (products and processes developed, production capacity, etc.) and capabilities (e.g. R&D capability) are accumulated (stocked) at rates (flows) defined, implicitly or explicitly, by the decisions of the firm's management (the rate of process development, the product development effort, etc.) Accordingly, these elements can be easily modeled using the language of system dynamics (Warren, 1996).

In developing our model, however, we were faced with an additional challenge. The difference in the time scales of individual projects (which have their own dynamic behavior) on one hand, and the long-term evolution of the firm which executes successive project, on the other. To cater for this, discrete-event modeling concepts were introduced as a means of enactment of the individual project dynamics at specific time intervals (e.g. when to start process development in relation to the level of the progress of product R&D). A detailed view of all of the above sub-systems is shown in Figure 3.

Figure 3: The System Dynamics Model of Product and Process Development



5. Learning in different places and at different time-frames (simulation experiments)

A series of experiments were conducted on the above model. First, the behaviour of process development in the framework of the overall product-launch project was explored under different circumstances of process R&D learning capability and for different sets of process development strategy choices. For a given rate of learning by doing in production, two scenarios of R&D learning capability were investigated, with respect to the early or late start of process development (in relation to the product development progress) and high or low target for process development progress level. These scenarios are shown in table 1. An early start strategy means a 40% progress in product development, while on the other hand a late start strategy means a 70% progress in product development. The results for the early start strategy scenario are shown in Figure 4(a-d) and for the late start strategy scenario in Figure 5(a-d) (the vertical axis shows the percentage of progress towards completion of product and process development and the horizontal the time span of the simulation).

Table 1. Scenarios for the evaluation of the economic performance of process development strategies

	R&D learning rate (% of progress)	*Process development Policy (% of progress)*
Scenario1	*5%*	*90%*
Scenario2	*10%*	*90%*
Scenario3	*5%*	*70%*
Scenario4	*10%*	*70%*
Scenario5	*10%*	*90%*
Scenario6	*20%*	*90%*
Scenario7	*10%*	*70%*
Scenario8	*20%*	*70%*

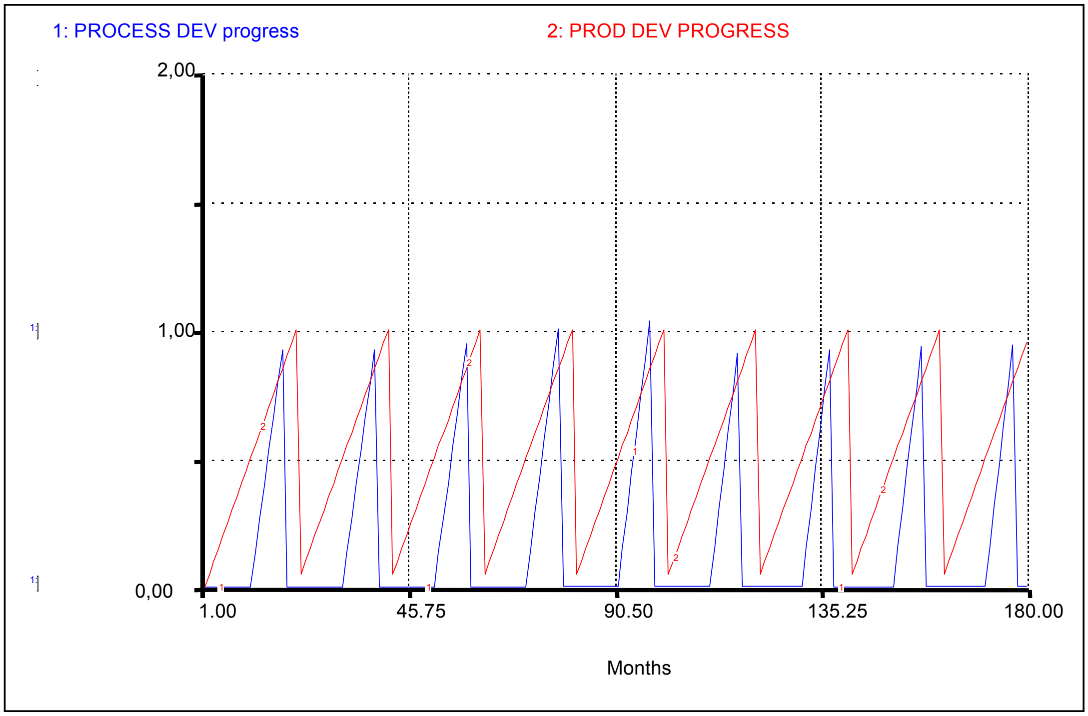
The results of the first set of experiments show that for an early start strategy (when 40% of product development is completed), there is acceleration, which is significant when learning capability in R&D is high (a 10% rate learning curve). Although the learning capability within the process R&D function does not appear to be critical, as in all cases process development ends before product development, this is not the case. If the lead-time for the plant construction is taken into account (in the model it is 10 months), then process R&D learning attains a greater significance.

Thus, the demand for acceleration is still substantial since the primary objective is not to converge the two development processes at a single point in time, but to be able to operate the new production process within a specific time span. Issues such as product-specificity of the production process and product-process modularity could be further explored in this direction. Also, while the impact of process R&D on the cost of production capacity has been considered, the impact on the lead-time of plant delivery and ramp-up has not.

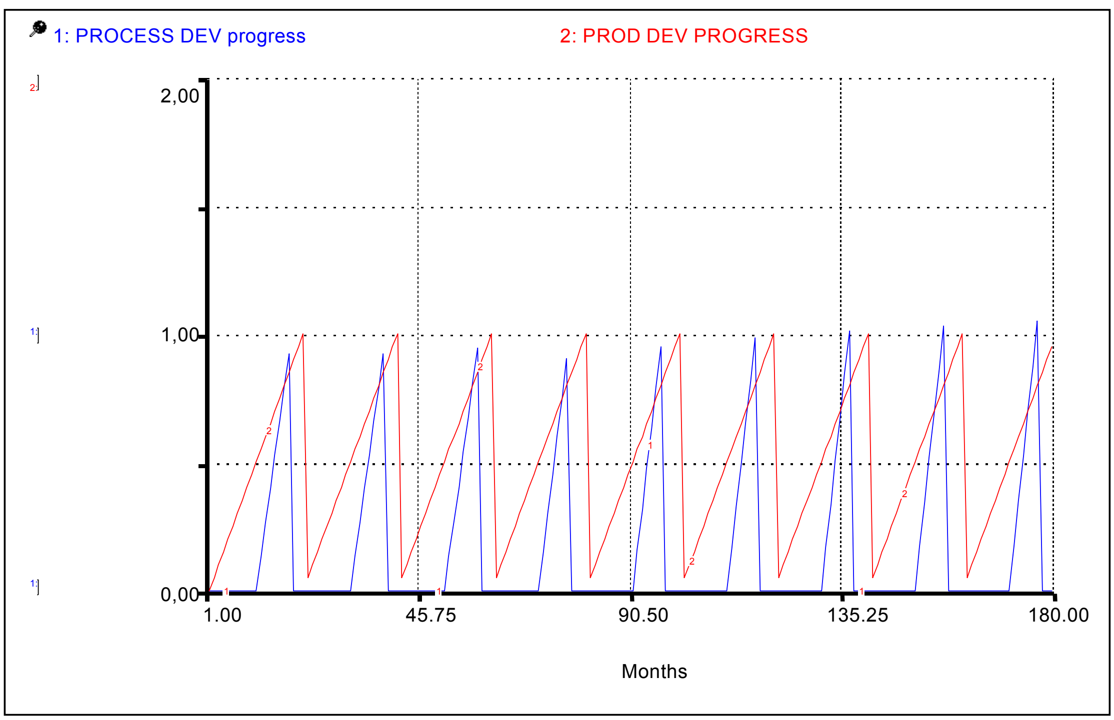
When a late process development strategy is adopted (Figures 5a-d), then for process R&D to catch up with product development, a combination of accelerated learning (at a rate of 20%) and a compromise in process development achieved should be made (Figure 5d). Such a strategy would be viable only if there is limited ability to exploit fully the achievements of R&D at the shop floor, where additional learning by doing should be required. However, even more accelerated learning in R&D and a relatively earlier start of process development might deliver greater economic benefits if the ability to materialise R&D achievements in actual production would be substantial.

The economic performance of the hypothetical firm was also investigated for a set of combinations of different R&D learning rates and process development policies. Two metrics were considered: production unit cost, which represents the impact of learning on the variable production factors cost per product unit, and profit which is the difference between revenue and costs – without taking into account the cost of product development. The results of these experiments are illustrated in Figure 6 (a and b) and Figure 7 (a and b) respectively.

Figure 4: Early process development strategy choices (Product Development 40%)

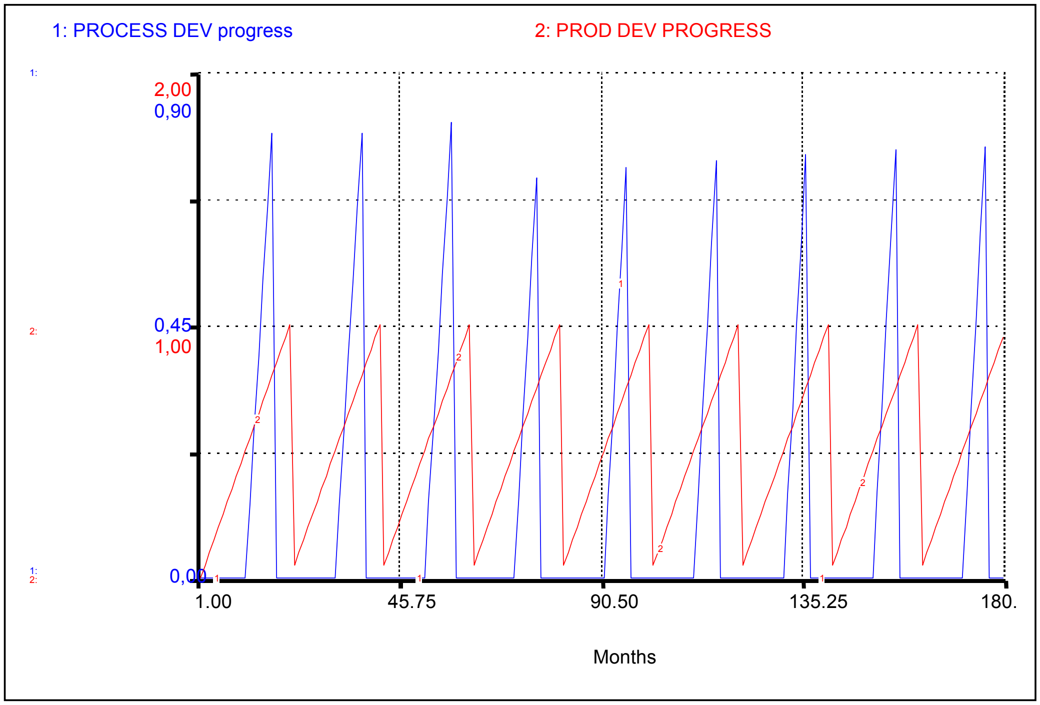


(a) ***Process Development Policy: 90%, Process R&D learning rate: 5%***

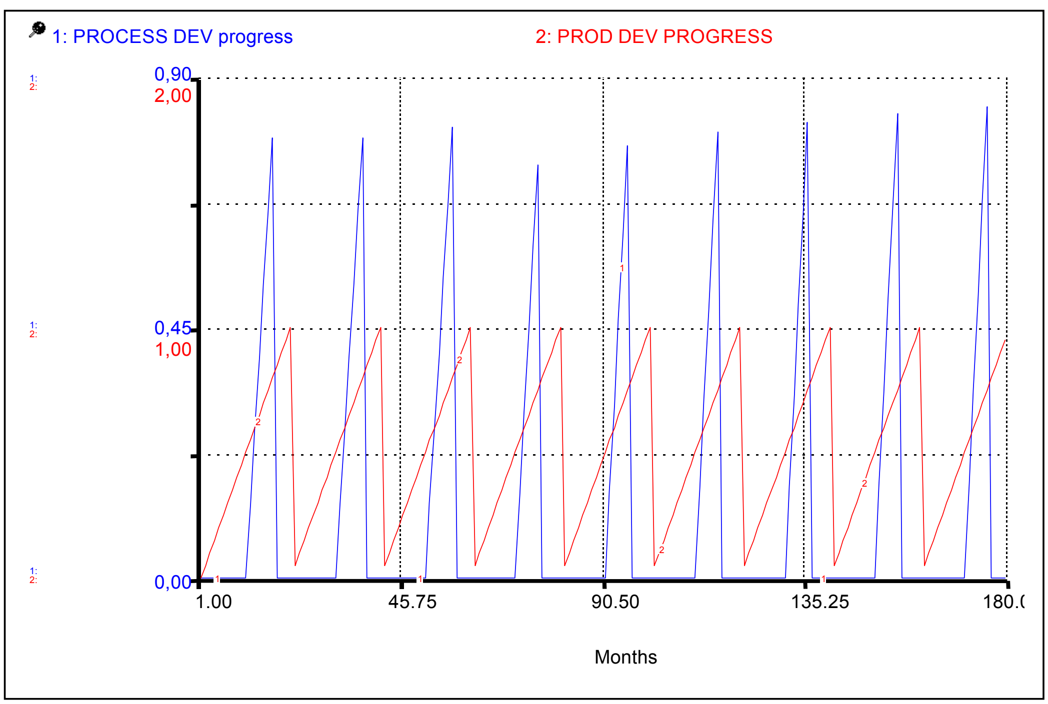


(b) ***Process Development Policy: 90%, Process R&D learning rate: 10%***

Figure 4 (cont'd): Early process development strategy choices (Product Development 40%)

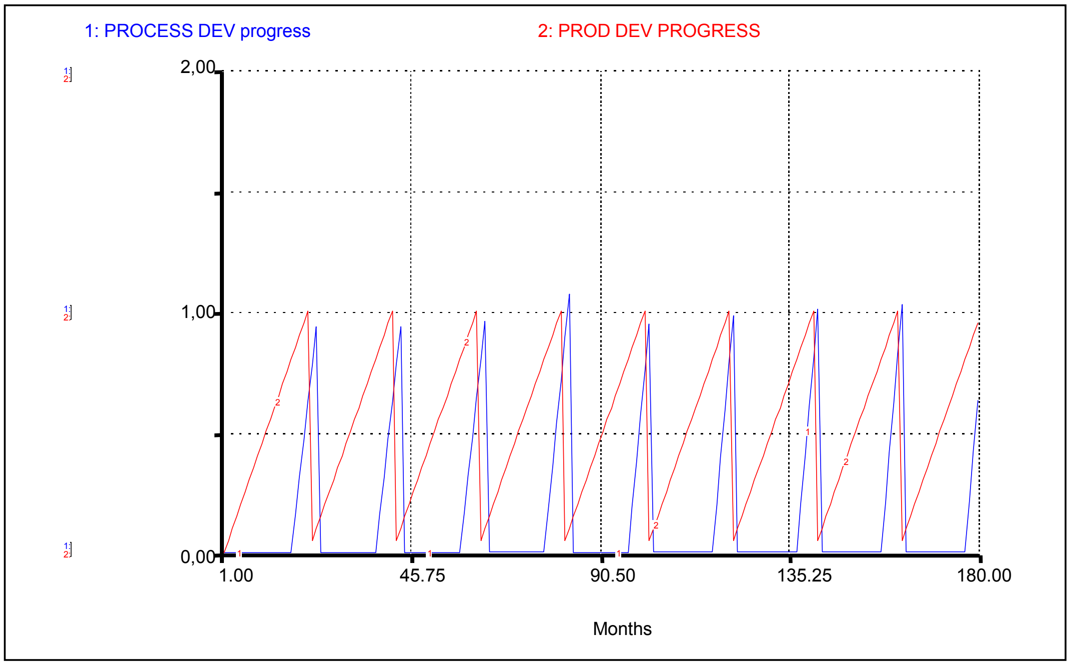


(c) ***Process Development Policy: 70%, Process R&D learning rate: 5%***

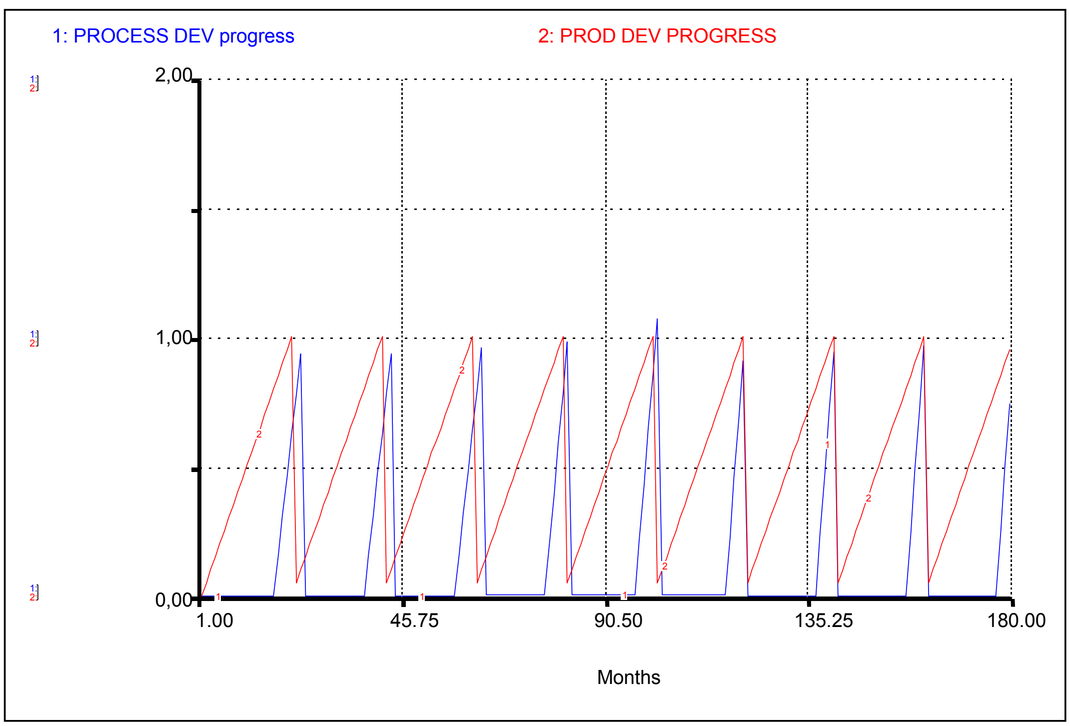


(d) ***Process Development Policy: 70%, Process R&D learning rate: 10%***

Figure 5: Late process development strategy choices (Product Development 70%)

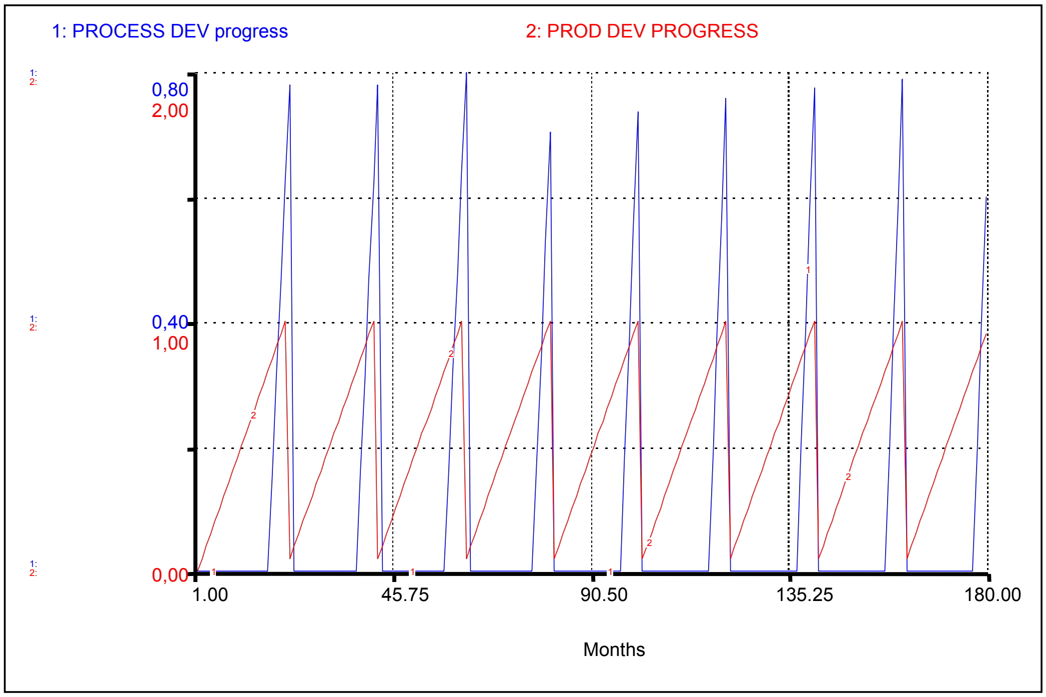


(a) ***Process Development Policy: 90%, Process R&D learning rate: 10%***

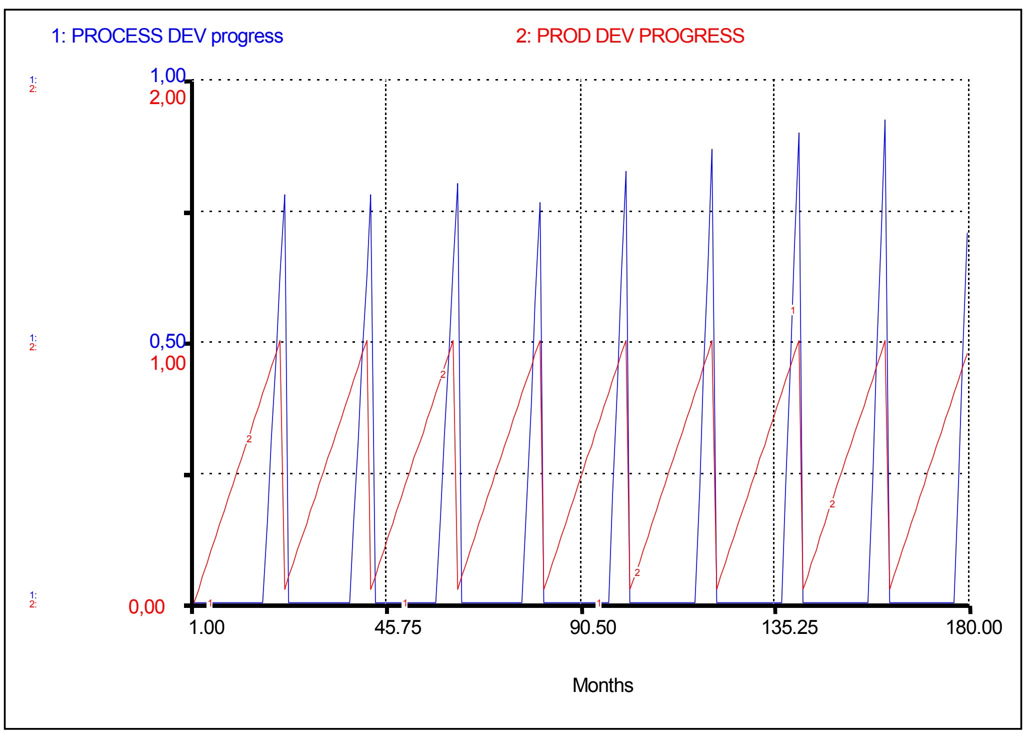


(b) ***Process Development Policy: 90%, Process R&D learning rate: 10%***

Figure 5 (cont'd): Late process development strategy choices (Product Development 70%)

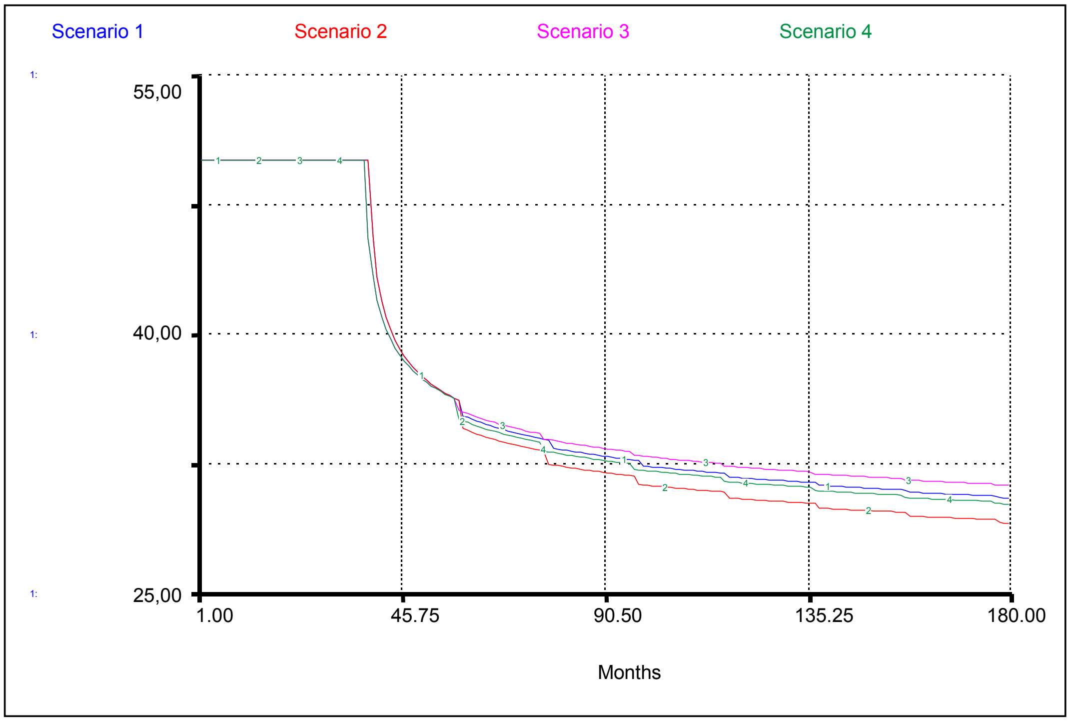


(c) ***Process Development Policy: 70%, Process R&D learning rate: 10%***

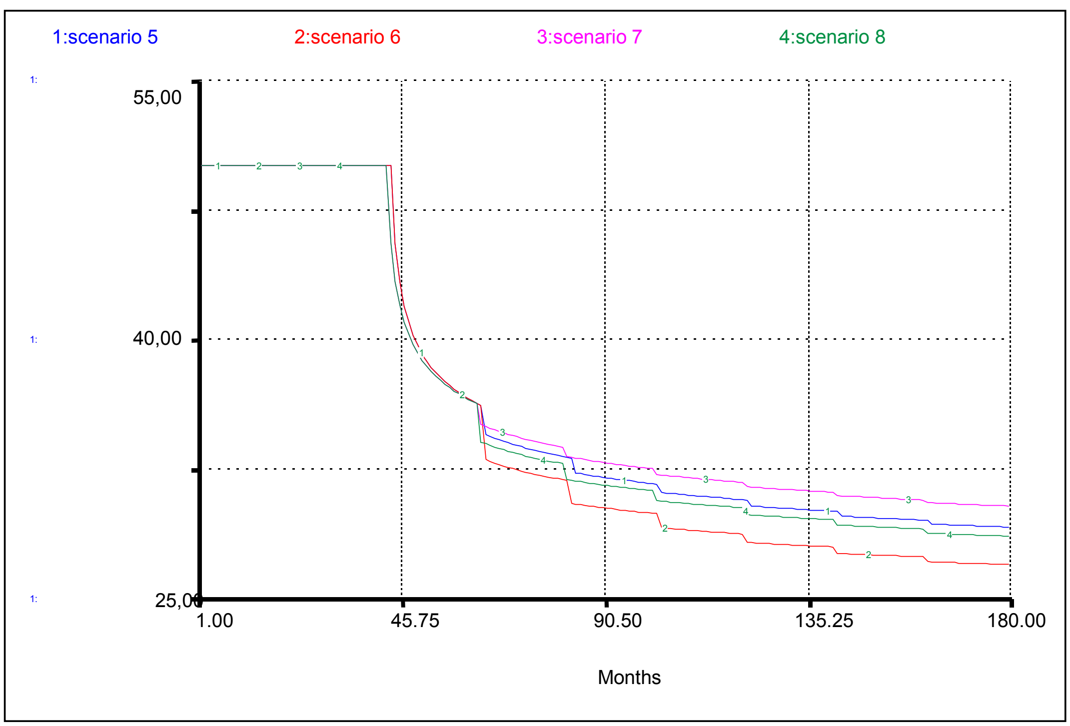


(d) ***Process Development Policy: 70%, Process R&D learning rate: 20%***

Figure 6: Production unit cost sensitivity analysis

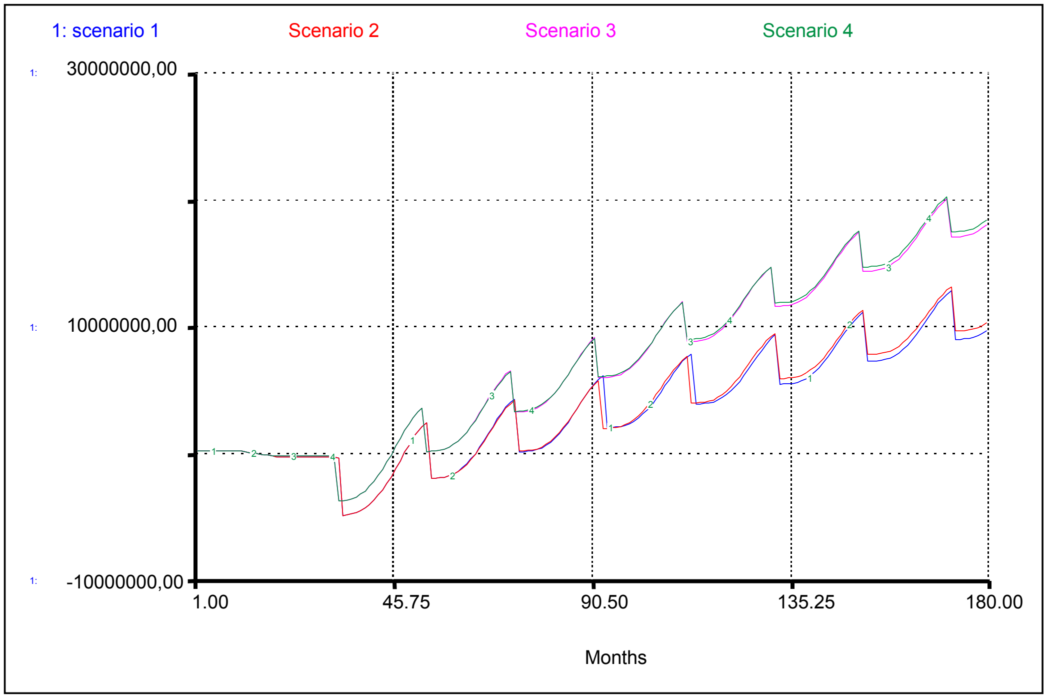


(a) Early process development (40% of product development completed)

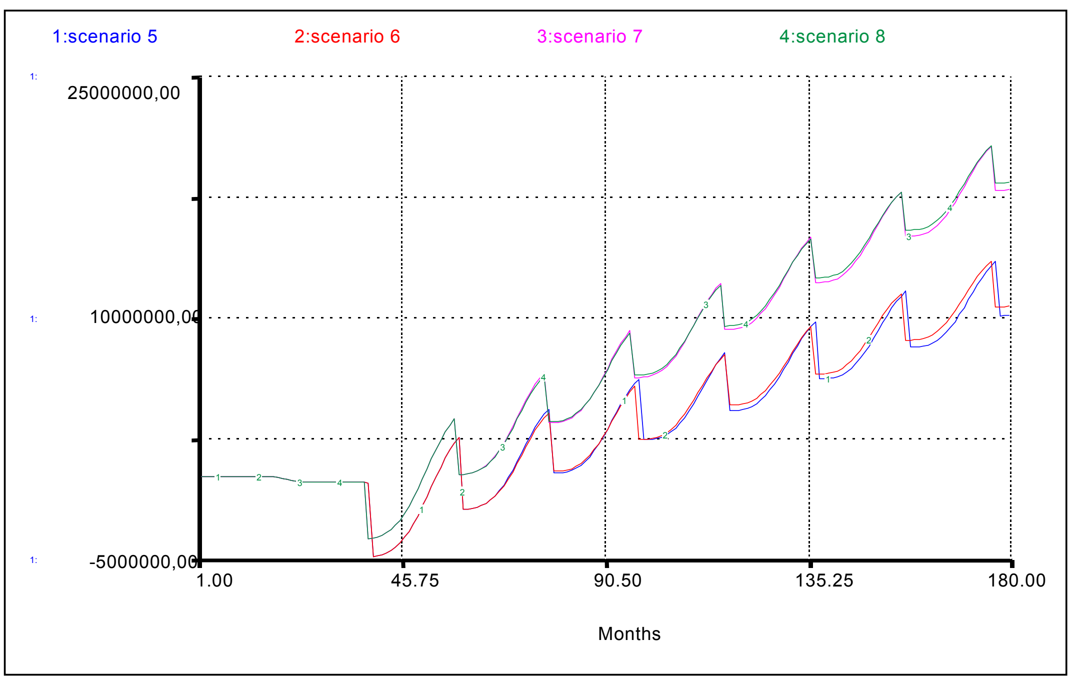


(b) Late process development (70% of product development completed)

Figure 7: Profit sensitivity analysis



(a) Early process development (40% of product development completed)



(b) Late process development (70% of product development completed)

At a first glance one might argue that the results obtained contradict Pisano's argument about the long-term effectiveness of aggressive R&D strategies. However, in order to conclude so, one should take into account the specific conditions, which apply to the circumstances upon which the results depend:

- The degree of R&D and capital intensity and
- The degree of technology tacitness.

A more careful look shows that the better strategies with respect to production unit cost do not always prove to be the best for overall performance. Hence, while scenarios 4 and 8 rank poorly in terms of production unit cost, they are optimal when overall profitability is considered. The point we seek to demonstrate here is that the non-linearity that characterises systems with emergent behaviour is also evident in the case of product development management, where cause and effect appear in different contexts of place and time.

Our experiments confirm the fact that although local impact may be less significant, the long term, system-wide effect is quite impressive. While the impact on the scheduling of R&D tasks may be - in some cases - negligible, the corresponding economic effect appears to be substantial. Thus, while scenario 8 exhibits an impressive economic performance, the corresponding benefit in terms of project scheduling did not appear to be that significant (Figure 5d).

Conclusion

The medium- to long-term performance of a firm is still a subject of controversy. While substantial progress has been made towards a synthesis of theoretical perspectives, the arguments are still far from convincing. The case explored in this paper has shown that a system dynamics modelling approach may provide substantial insight into the dynamics of performance in more than one way. First, it highlights the causality of phenomena vis-à-vis decisions made. Second, it provides a tool for insight into the behaviour of complex, counter-intuitive systems. Third, it may be used for the development of user-friendly decision support tools.

The task of modelling the complexity of the development and production products and knowledge has not been a simple exercise. The need to integrate in a single model the dynamic processes occurring within the firm with the introduction of discrete events has increased the danger of losing consistency and the difficulty of the task.

The present exercise shows that a more comprehensive model that would include similar processes in product R&D and their interaction with the rest of the system might be a fruitful attempt. However, the complexity and magnitude of the task should not be underestimated.

Finally, the model has highlighted the significance of the fact that when a firm chooses to develop dynamic capabilities of a 'higher order', i.e. learning by doing in R&D, their effects are significant in the medium and long term. This brings us back on the issues of resource commitment and structure (with respect to the development of dynamic capabilities within and between functions). The use of system dynamics may help in directing behaviour, by educating managers holding different worldviews about their operational environment, on the holistic and long-term perspective of the strategy process and its outcomes.

Appendix: System Dynamics Equation Formulation

```
cumulative_REVENUES(t) = cumulative_REVENUES(t - dt) +
(sales_revenues) * dt
INIT cumulative_REVENUES = 0
sales_revenues = price*PRODUCTION
TOTAL_COST(t) = TOTAL_COST(t - dt) + (PROC_R&D_EXPEND + CAP_EXPEND +
PROD_EXPEND) * dt
INIT TOTAL_COST = 1
PROC_R&D_EXPEND = PROC_DEV__ACTIVTITY*R&D_COST
CAP_EXPEND = CAP_COST*cap_deployment
PROD_EXPEND = UNIT_COST*PRODUCTION
AVG_COST = IF (PRODUCTION=0 OR Cumulative_Production=0) THEN 0 ELSE
TOTAL_COST/Cumulative_Production
CAP_COST = IF cap_deployment=1 THEN
PROCESS_DEV_policy*5000000/(R&D_CAPAB*cap_deployment) ELSE 0
NET_REVENUES = sales_revenues-PROC_R&D_EXPEND-CAP_EXPEND-PROD_EXPEND
price = UNIT_COST*1.2
PROC_DEV__ACTIVTITY = IF PROCESS_DEV_RATE=0 THEN 0 ELSE 1
PROFIT = cumulative_REVENUES-TOTAL_COST
R&D_COST = 50000
PROCESS_DEV_progress(t) = PROCESS_DEV_progress(t - dt) +
(PROCESS_DEV_RATE - NEW_PROCESS) * dt
INIT PROCESS_DEV_progress = 0
PROCESS_DEV_RATE = IF (PROJECT_IN_DEV=1) THEN
(0.1*R&D_CAPAB*prod_proc) ELSE 0
NEW_PROCESS = IF (PROCESS_DEV_progress>= PROCESS_DEV_policy) THEN
PROCESS_DEV_progress+PROCESS_DEV_RATE ELSE 0
PROJECT_IN_DEV(t) = PROJECT_IN_DEV(t - dt) + (proj_for_dev - proj_out)
* dt
INIT PROJECT_IN_DEV = 0
proj_for_dev = IF PROJECT_IN_DEV=0 AND PROJ_IN_Q>0 THEN 1 ELSE 0
proj_out = IF NEW_PROCESS>0 THEN 1 ELSE 0
PROJ_IN_Q(t) = PROJ_IN_Q(t - dt) + (proj_in - proj_for_dev) * dt
INIT PROJ_IN_Q = 0
proj_in = INT(COS(ABS(PROD_DEV_PROGRESS-PROD_PROCES_POLICY)))
proj_for_dev = IF PROJECT_IN_DEV=0 AND PROJ_IN_Q>0 THEN 1 ELSE 0
R&D_CAPAB(t) = R&D_CAPAB(t - dt) + (R&D_LEARNING) * dt
INIT R&D_CAPAB = 1
R&D_LEARNING = IF total_projects<2 THEN 0 ELSE
(learning_by_doing*ProdR&D_link+NEW_PROCESS*((total_projects-1)^(-
R&D_learning_rate)-(total_projects^(-R&D_learning_rate))))
total_projects(t) = total_projects(t - dt) + (proj_out) * dt
INIT total_projects = 0
proj_out = IF NEW_PROCESS>0 THEN 1 ELSE 0
PROCESS_DEV_policy = 0.7
ProdR&D_link = 0.1
prod_proc = 0.8*PROD_PROCES_POLICY+1
PROD_PROCES_POLICY = 0.7
R&D_learning_rate = 0.3220
NEW_PRODUCTS(t) = NEW_PRODUCTS(t - dt) + (NPD) * dt
```

```
INIT NEW_PRODUCTS = 0
NPD = IF PROD_DEV_PROGRESS>=1 THEN 1 ELSE 0
PROD_DEV_PROGRESS(t) = PROD_DEV_PROGRESS(t - dt) + (PROD_DEV_EFFORT -
NPD) * dt
INIT PROD_DEV_PROGRESS = 0
PROD_DEV_EFFORT = 0.05
NPD = IF PROD_DEV_PROGRESS>=1 THEN 1 ELSE 0
Capacity(t) = Capacity(t - dt) + (cap_deployment - cap_rejection) * dt
INIT Capacity = 0
cap_deployment = DELAY(proj_out,15)
cap_rejection = IF Capacity=1 THEN cap_deployment ELSE 0
Cumulative_Production(t) = Cumulative_Production(t - dt) + (Products)
* dt
INIT Cumulative_Production = 0
Products = IF share_of_prod_runs_completed>=PROD_RUN_SIZE THEN
PROD_RUN_SIZE ELSE 0
production_tech_capab(t) = production_tech_capab(t - dt) +
(learning_by_doing + LEARNING_BEFORE_DOING) * dt
INIT production_tech_capab = 1
learning_by_doing = IF TOTAL_NO_OF_PROD_RUNS<2 THEN 0 ELSE
PRODUCT_RUNS*((TOTAL_NO_OF_PROD_RUNS-1)^(-rate_of_learning)-
(TOTAL_NO_OF_PROD_RUNS^(-rate_of_learning)))
LEARNING_BEFORE_DOING = IF R&D_LEARNING>0 THEN
PROCESS_DEV_policy*transferability*r&d_production_link*R&D_LEARNING
ELSE 0
share_of_prod_runs_completed(t) = share_of_prod_runs_completed(t - dt)
+ (PRODUCTION - Products) * dt
INIT share_of_prod_runs_completed = 0
PRODUCTION = Adoption_Rate_AR
Products = IF share_of_prod_runs_completed>=PROD_RUN_SIZE THEN
PROD_RUN_SIZE ELSE 0
TOTAL_NO_OF_PROD_RUNS(t) = TOTAL_NO_OF_PROD_RUNS(t - dt) +
(PRODUCT_RUNS) * dt
INIT TOTAL_NO_OF_PROD_RUNS = 0
PRODUCT_RUNS = IF PROD_RUN_SIZE=Products THEN 1 ELSE 0
initial_unit_cost = 50
PROD_RUN_SIZE = 10000
r&d_production_link = 0.8
rate_of_learning = 0.1520
transferability = 0.8
UNIT_COST = initial_unit_cost/production_tech_capab
Adopters_A(t) = Adopters_A(t - dt) + (Adoption_Rate_AR - Discard_Rate)
* dt
INIT Adopters_A = 0
Adoption_Rate_AR = IF cap_deployment=1 OR Capacity=0 THEN 0 ELSE
Adoption_from_Advertising+Adoption_from_Word_of_Mouth
Discard_Rate = IF cap_deployment=1 THEN Adopters_A ELSE
Adopters_A/Average_Product_Life_I
Potential_Adopters_P(t) = Potential_Adopters_P(t - dt) + (Discard_Rate
- Adoption_Rate_AR) * dt
INIT Potential_Adopters_P = Total_Population_N - Adopters_A
Discard_Rate = IF cap_deployment=1 THEN Adopters_A ELSE
Adopters_A/Average_Product_Life_I
Adoption_Rate_AR = IF cap_deployment=1 OR Capacity=0 THEN 0 ELSE
Adoption_from_Advertising+Adoption_from_Word_of_Mouth
Adoption_Fraction_i = .0125
Adoption_from_Advertising =
Advertising_Effectiveness_a*Potential_Adopters_P
```

```
Adoption_from_Word_of_Mouth =
Contact_Rate_c*Adoption_Fraction_i*Potential_Adopters_P*Adopters_A/Tot
al_Population_N
Advertising_Effectiveness_a = 0.00916
Average_Product_Life_I = 50
Contact_Rate_c = 25
Total_Population_N = 1000000
```

References

Burgelman R.A., A. Madique and S.C. Wheelright (1996) Strategic Management of Technology and Innovation, 2nd ed, Irwin: Chicago

Dierickx, I. and K. Cool 1989. Asset stock accumulation and sustainability of competitive advantage Management Science 35:. 1504-1511.

Fawcett, S.E. and Myers, M. B. 2001. Product and Employee development in advanced manufacturing: Implementation and Impact. International Journal of production research 39(1): 65-79

Ghemawat P.and Pisano G. (2001) 'Building and Sustaining Success', in P. Ghemawat (ed) *Strategy and the Business Landscape: core concepts*, pp. 111-134, Prentice Hall, New Jersey

Morecroft, J.D.W. 1999. Management Attitudes, Learning and Scale in Successful Diversification: a Dynamic and Behavioural Resource System View, Journal of the Operational Research Society 50: 315-336

Murmann, P. and M. Tushman, 1997, Organization Responsiveness to Environmental Shock as an Indicator of Organizational Foresight and Oversight: The Role of Executive Team Characteristics and Organization Context. In Technological Innovation: Foresights and Oversights, R. Garud, P. Nayyar, and Z. Shapira (Eds.): Cambridge University Press, New York

Pisano, Gary P. 1996. The development factory: Unlocking the potential of process innovation. Harvard Business School Press: Boston, MA

Porter, M. 1996. What is Strategy. Harvard Business Review, November-December: 61-78

Sterman, John D., 2000: Business dynamics: systems thinking and modelling for a complex world: McGraw-Hill: Boston

Teece, D., G. Pisano and A. Schuen al. 1997 Dynamic Capabilities and Strategic Management. In Resources, Firms and Strategies: A Reader in the Resource-Based Perspective, N. Foss (ed): Oxford University Press, Oxford: 268-285

Warren, K.D. 1996. The Dynamics of Building Resources for Competitive Advantage, Financial Times, "Mastering Management" 17: March

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