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Modelling Product Development Productivity with System Dynamics

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Abstract
This paper analyses the performance of product development as an input-delayed partial productivity. Firstly, the total productivity concept is introduced in the framework of firm-level performance measurement. Some recent literature related to new product development is reviewed and three related system dynamics models are reviewed. Based on the analysis we suggest that productivity measurement of product development requires knowledge in project and resource structure. Finally, the preliminary results related to product development are concluded and the practical applicability of the productivity framework is discussed for further research in the area.

1 Introduction

The financial performance of a contemporary company depends much on its ability to introduce new products and apply new technologies. Product life cycles of many products have decreased in many industries, which forces companies to seek more efficient ways to make applications for new and existing markets. For instance, electronics, telecommunications and software industries are highly depending on product development performance.

Performance of product development of a company is a widely discussed topic in management of research and development. Traditionally, proposed measures for product development are often either lists of success factors, found out in qualitative analyses. R&D performance measures have been used at more general level; for example, in econometric models, which elaborate the relationship between investment and gained revenue. Direct linkages to company-level financial performance has not been studied in great extent in terms of the relationship between R&D and new product development.

Productivity measurement is a well-known approach for assessing the financial performance of a company. This approach origins from Davis (1955) who proposed a model that could be used to analyse the performance of a company by using a measure for total productivity. He defined the total productivity as ratio between total tangible outputs and total tangible inputs used to make the outputs. The traditional definition of productivity has a variety of different interpretations. Productivity has often been associated with productivity of labour, but according to total productivity models, labour is not the only one input parameter. Other input items are most often tied with profit and loss calculation and/or cost accounting principles (see Davis 1955). Traditionally, the total productivity models tend not to deal the total output as units sold, but the units produced – productivity is about converting efficiently inputs to outputs (Craig & Harris 1973: 16; Sumanth 1979: 6.5). Craig et al. (1973) completed one of the first implementations of total productivity measurement at the firm level. Also Sumanth (1979) described same kind total productivity formula as Craig et al. (1973), but excluded from *Q* energy expenses. The general expression of the productivity can be stated as follows:

$$\text{Total Productivity} = \frac{\text{Total Tangible Output}}{\text{Total Tangible Input}}$$

$$\text{Total Productivity} = \frac{O_1 + O_2 + O_3 + O_4 + O_5}{H + M + FC + WC + E + X}$$

where O_n is output, *H* human input, *M* materials input, *FC* fixed capital input, *WC* working capital input, *E* energy input, *X* other expenses input. As shown in the formula above, the total productivity can be divided into partial components, which have direct link to operations.

Productivity measurement been successfully used to analyse partial productivities such as material productivity, human productivity, energy productivity etc. (e.g. Craig & Harris 1973, Sumanth 1997). However, productivity of product development has not been used. This is probably due to two reasons: firstly, this information has not been available for financial statements until recently; and secondly, there is a long delay between cost accumulation and the revenue.

2 Dynamics of R&D and productivity

Many performance measures has been proposed for assessing R&D productivity. Werner and Souder (1997a) made an extensive literature review in R&D performance measurement. By comparing the measurement approaches they identified three main categories of frameworks, namely: (1) quantitative-objective, (2) quantitative-subjective, and (3) qualitative metrics. According to them (1997a), the following factors should be taken into account when selecting an appropriate measure set for a company: user needs, the data available, amount of efforts needed. Werner and Souder (1997a) concluded that integrated measures, which combine several types of measures, are the most effective. On the other hand, they are also the most complex and expensive to use too. Later Werner and Souder (1997b) reported that there are big cultural differences in use of R&D measures. Despite the similar general management practices, companies in Germany and US used very different frameworks.

Productivity measurement is a quantitative-objective method, regarded in terms of its relevance for the internal control of a company (Nachum 1999). According to Werner and Souder (1997a) productivity related metrics reported frequently in the literature include the following types: (1) effectiveness index, which is defined as a ration between revenue generated from products introduced last years and the total R&D costs; (2) innovation index, which is the percentage of revenues generated from new products; (3) quality indexes; and (4) various patent indexes Werner and Souder (1997a).

As shown in Werner and Souder's review, companies use several measures simultaneously. The reason behind this may be that the current productivity of the firm is depending from the decisions and investments made in the past. Especially in case of development investment, the time delay between inputs and the outcomes is quite long. The methodology of system dynamics allows using time delays in modelling. The lag between investments and R&D revenues can be described with delayed stocks. Figure 2 illustrates a simple model of a company investing on R&D. In this model, the total productivity of a firm consists of revenue inflow, expenses outflow and profit, the stock between these flows. The revenues is depending from the revenues.

*profit(t) = profit(t - dt) + (revenues - expenses - RnD_investment) * dt*
INIT profit = 20
*revenues = 9+RnD_outcome*3*
expenses = 10

Certain amount of current profit is invested into research and development periodically. This capital investment accumulates the delayed stock, R&D in process.

*RnD_investment = profit*0.20*
*RnD_in_process(t) = RnD_in_process(t - dt) + (RnD_investment - RnD_outcome) * dt*
INIT RnD_in_process = 0.05 - TRANSIT TIME = 3

In practical terms, delay means the time between starting the project to selling the new product. Some percentage of R&D outcome will affect sales efficiently. R&D productivity is a ratio between total tangible outputs (revenues) and R&D outcome coming from the delayed stock. Otherwise the measure is considered to be similar to other partial productivities.

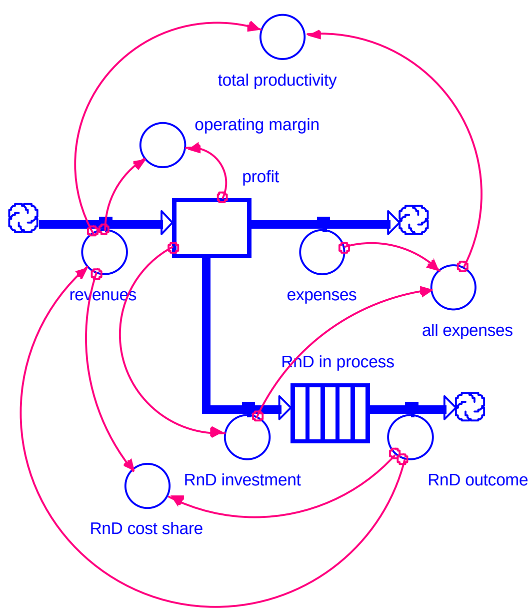

Figure 2. A general infrastructure of delayed effect of R&D investment.

Running this hypothetical model shows how the revenues are depending from the R&D investments. Because certain amount of value-added is allocated to R&D the future investments are depending on current performance (Figure 3). The time delay presented in variable *"RnD in Process"* determines how the fast the investment can be utilised in sales.

Managing this time-to-market factor is very critical. In the given example the performance of the product development is constant (*revenues = 9+RnD_outcome*3)*. In practice this economic efficiency is what most of the productivity measures related to product development are trying to capture. The business impact of new product is the main output, whereas the R&D costs are the input.

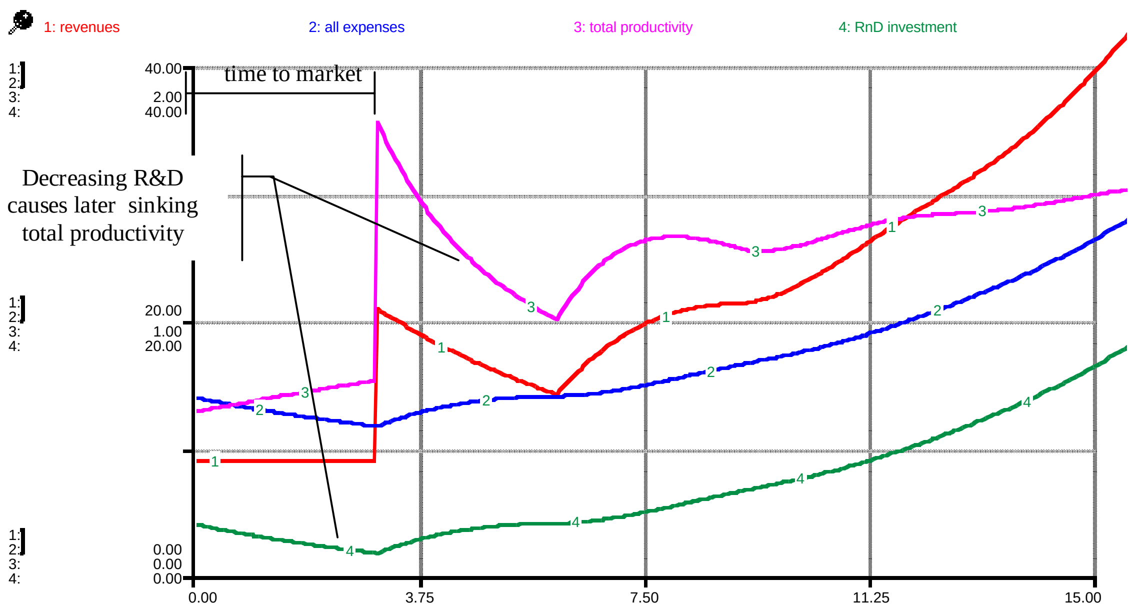

Figure 3. A hypothetical example - the revenues are depending from R&D investments.

3 Resource allocation - an approach on project level

According to Nachum (1999) introducing a time delay between outputs and inputs, as proposed in the model, may provide only partial solution to problem. The key issue in addition to pure economic performance and time factor is how the resource allocation is done in project level. Hansen, Weiss and Kwak (1999) demonstrated the allocation problem of R&D resources by illustrating and quantifying the situation with system dynamics. According to this model, product development projects can be in three different stages during their way from concepts to ready products. These stages present the micro-mechanism of *"RnD in Process"* in the last model. In the first stage (*Phase 1*), a number of ideas are generated a function of resources. Some of the projects die in initial stages (*exit_p1*), but some continue to next stage (*Phase 2*). There is a time lag between phase shifts (*Phase 1 Inventory*). The flows moving projects from stage to another are functions depending from resources. In every phase shift, the resource requirements, project dieing rate and success rates vary. The general rule is that the better commercial readiness, the more expensive is moving to next stage. On the other hand, initial concepts are cancelled more frequently than ready products. Figure 4 illustrates a Stella replication of the model structure.

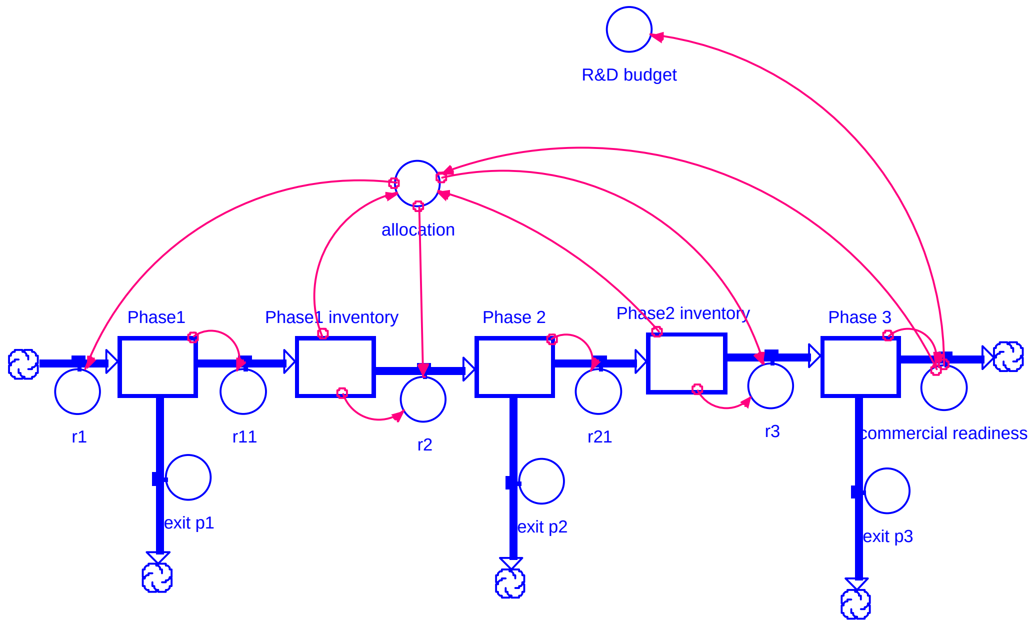

Figure 4. R&D allocation, reconstructed from Hansen, Weiss and Kwak (1999).

4 Conclusions

Delayed processes may present problems for traditional productivity measurement for an organisation, which has a great proportion of newly introduced products. There are some references in academic R&D studies that product development productivity as a ratio between sales and R&D expenses is a driver for business success. For instance, Loch et *al.* [9] concluded their study in electronics industry *"the clearest result of this analysis is that development productivity, measured by expense intensity, stands out as a critical driver of business success …"*. The longer time to market parameter is, the more difficult is to approximate the actual productivity of product development. Another problem with product development productivity may emerge with different kinds of projects. There are several types of product development projects. These differ in terms of cost requirements, market impact and time to market. Some projects are technology related while some are related to customisation of existing products. We have identified from the literature four types of projects, these are:

- *Advanced research*, which is a highly cost intensive project and the direct applications or revenues are unlikely to emerge in near future. Research of a new technology is an example of this kind of project.
- *Advanced development* projects are aiming to develop new products, which differ from the old ones in terms of technology selection or design. The cost intensity in this category is high, and the payback time relatively long.
- *Platform development* projects are those projects aiming to renew product design in large extent or to build new product families. Compared to advanced research or development projects, platform projects should have shorter payback time.

- *Derivative development* are projects aiming to customise existing designs for customer requirements. Cost effect is typically rather low compared to gained revenues. Also time to market in this kind of projects is very high.

Product development organisations need to launch each types of projects time to time. In short period, derivative projects may be most productive and value-adding for customers. On the other hand, if the product families are not renewed frequently or the company is not paying attention to new technologies, the overall performance will collapse. The right mix of projects in every stage is a challenging task.

One basic premise is that productivity measurement is based on periodical assumptions. Often we can find examples of productivity trends reported on annual or biannual basis. Firm level accounting practices are also integrated by this cyclical and periodical nature of evaluation. It is not really an issue to debate that whether the issue of product development productivity is really comparable with more generic business dynamics like annual business performance, demand and time-to-market challenges. Our point is that Product development productivity is in a way a partial productivity factor, analysed against the firm level total productivity. Like the role of manufacturing performance is a part of the firm's overall business performance. Usually such partial productivities may have been analysed through labour, materials, energy and capital inputs. Our discussion has here referred to some examples where product development productivity is really deeply associated to the level of resource allocation in product development projects, and the progressive nature of product development costs in general. This is the underlying lesson we may have also learned in this process. There are some specific kinds of cost dynamics embedded in product development. But the difficulty is that, like in other forms of product development performance evaluations, the nature of periodical bases or cycles necessary for productivity measurement are easily lost in the overall cost accumulation of R&D and product development work.

Our solution to this problem is that we can use the concept of product development portfolio as a kind of integrated proxy for the characterization of the inputs in product development. It is also recommendable that such kind of product development portfolio models can be linked to firm level product development processes (Cooper, Edgett and Kleinschmidt 1997). We can illustrate this thinking with a hypothetical example. A firm carries out different kind of R&D and product development activities. A development project portfolio of that firm may simultaneously include different kinds of projects: advanced research, advanced development, platform development and derivative projects (see e.g. Wheelwright and Clark 1992). Development projects are future oriented, so it would be natural to expect that firm has demands for various kinds of utilities to be gained through these projects. And the expectations for these development results (utilities) are also driven by strategies for time-to-market etc. In average, we could draw a development portfolio model by analysing the different kinds of projects being pursued, see table below.

Table 1. Development project category types

Strategic goal for Time-to-market	Project Unit cost	Ratio of R&D value	Ratio of NPD value	Project category
36 months	500 000 FIM	70 %	30 %	Advanced research
30 months	5000 000 FIM	60 %	40 %	Advanced development
48 months	20 000 000 FIM	40 %	60 %	Platform development
15 months	2000 000 FIM	10 %	90 %	Derivative development

This previous table illustrates how product development costs may be allocated to different kinds of projects that are being conducted under different time frames. This kind of data is usually only available for firm's internal operations. External evaluation of development productivity is to be done with development intensity measures. But we can find some possibilities to link these two different worlds together. Analysing the development intensity as a measure of average spending expense put into development work within a given time frame can do this. See example below:

$$Development\_productivity = \frac{\text{Business Impact}}{\mathrm{ArC(t)} + \mathrm{AdC(t)} + \mathrm{PdC(t)} + \mathrm{DdC(t)}},$$

where t = average development cost within a specified evaluation period, *ArC(t)* = Advanced research project unit costs (expense flow/t), *AdC(t)* = Advanced development project unit costs (expense flow/t), *PdC(t)* = Platform development project unit costs (expense flow/t), *DdC(t)* = Derivative development project unit costs (expense flow/t). Moreover, we need also some generic time variables in order to model this kind of things with system dynamics principles. We decided to adopt a time-to-market based time frame for a base variable in our model. This can be illustrated with a sort of characteristic curve where various form of project-based unit costs (integrated into overall expense flows) can be modelled against to strategic goals for time to market. (See figure 5)

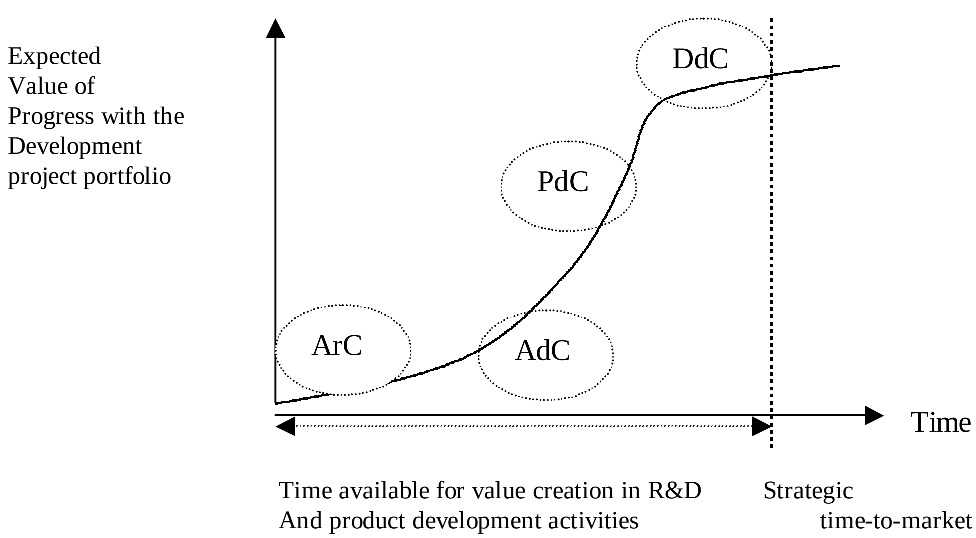

Figure 5. Accumulated expectation for business impacts from the development inputs.

Our philosophy with this kind of model is that it may be possible to collect field data from different firms for the description of their development portfolio strategies used in R&D and product development. Similarly, by basing this model on the firm level analysis of total productivity it may be possible for us to analyse product development productivity with firm level data. Such kind of presentation of the R&D strategy may also be used in the communication of various R&D goals for the top management of the firm.

Based on the system dynamics model presented, we can conclude that productivity of product development is a highly dynamic measure. For this reason we would propose that in addition to product development productivity managers should use predictive measures as well. The purpose of these measures would be supporting the resource allocation and investment justification. These measures could include for instance the following ones:

- *New product intensity = Sales of those products introduced in last three years / Total sales [%]*. This measure tells how critical the product development function is for the company.
- *Average time to market* is a time delay parameter that determines requirement for cash flow.
- *Proportion of direct product development work and proportion of indirect work* as well as
- *Intensity of product development project types* [$ / type] show how the allocation is made between different kind of projects.

The research challenge is to build models for deeper understanding of the impact of new product introduction and strategic planning for time-to-market issues. One major question is that firms should know both the profitability and productivity impacts of new product introduction capabilities in order to market appropriate plans for time-to-market goals. Also the relation to productivity measurement is important because in many industries the long term competitiveness of a modern company is based on productivity improvement. Traditional total productivity approach does not acknowledge the delayed investments for R&D even if they were highly important for the company.

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