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A Multi-Stage Data Envelopment Analysis Framework to Assess New Product Development Proficiency and Performance

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Abstract

This paper proposes a framework for benchmarking the new product development process of individual companies. The company's market environment and the internal capabilities (resources) it allocates in order to maximise the effectiveness of new product development are factors affecting the multi-stage process of new product development. The ultimate success is measured by means of product performance, which includes aspects of product positioning, market power, and profitability. This paper proposes a multi-stage optimisation framework based on data envelopment analysis through which new product development (NPD) benchmarking measures are gauged at various stages of its development. The empirical part of the research draws on qualitative information obtained from the product managers of 110 manufacturing companies in Greece.

Keywords

New Product Development, Data Envelopment Analysis, Optimization

1. Introduction

Several years after the first systematic efforts by BAH consulting [1] [2] and the subsequent series of surveys by the Product Development and Management Association (PDMA), some of the problems identified at the early stages of research seem to persist. For instance, about 1/3 of all new product projects commercialised by companies were led to failure either due to wrong ideas and/or wrong timing. Nowadays, new product development is considered the most important operational capability of the firm, with profound implications on firm performance [3].

The literature on new product development (NPD) reports numerous research efforts concerning the identification of new product success drivers. In these pursuits for new product success determinants, authors have investigated the effect of market conditions [4], competitive intensity [5], internal company capabilities [6], organisational learning [7], and product innovativeness [8]. This research led to a statistical endeavour for the identification of the effect of antecedent factors on new product development performance (NPD performance). It is noteworthy that the statistical linkages between factors yield information from new product development elements' *average* behaviour and do not address the fundamental question raised by product managers who seek to compare the process mix of their activities with a similar-sized product development group.

Product development is a complex function that involves the use of various types of resources in order to deliver new products. The identification of best practices should be considered an issue of primary attention since most new product development managers would ideally like to know their competitive standing when compared to the best in class and not to the sample average. Existing literature on new product development provides a multitude of information on the synergistic effects of intrinsic and extrinsic factors of product performance. On the other hand, existing literature does not provide information on the benchmark comparison of the full extent of the process companies follow when developing new products. Obtaining such a benchmark comparison is feasible via a systemic formulation through which all input resources brought into the process are jointly considered in their effort to augment the new product performance results. This conceptualisation draws primarily on the understanding that the new product development process is a problem consisting of many objectives, while it is not possible to simultaneously satisfy all resource requirements and, thus, resource allocation decisions are imperative in order to maximise different aspects of new product development performance.

New product development is currently recognized [9] as a complex process involving a number of elements:

- The importance of the new product development process and its components.
- The organisational management of new product development programs.
- The company climate and internal culture toward the development of new products.
- The involvement of senior management in the new product development process.
- The existence of a new product development strategy that is in line with the company's overall strategy.
- The market environment surrounding the new product's launch.

The following parts of the paper are organised as follows: Section 2 contains information about the conceptual framework of the proposed research, followed by research hypotheses; Section 3 describes the optimisation model regarding the benchmarking of the new product development teams; Section 4 contains the empirical part of the study; Section 5 concludes the paper.

2. Conceptual Framework and Research Hypotheses

Our model is grounded in strategic management theory. Following the resource-based view (RBV), we treat marketing and technical capabilities as firm-specific resources that are difficult to imitate and thus serve as sources of competitive advantage. These capabilities enable firms to execute the new product development (NPD) process more proficiently, consistent with stage-based theories (e.g., Cooper's stage-gate model) that link systematic execution of each NPD phase to greater product success. In this way, we conceptualize NPD proficiency as a mediator: firms' capabilities (and related resources) feed into more effective NPD processes, which in turn yield better new product outcomes. We also incorporate contingency theory by noting that external market conditions moderate these relationships. For example, highly munificent (resource-rich, predictable) market environments help firms leverage their capabilities, whereas hostile, turbulent markets (characterized by intense competition and unpredictability) can disrupt systematic NPD efforts. Thus, our framework articulates a resource-process-performance chain, extending beyond a simple input-output model to reflect both the mediating role of NPD processes and the moderating role of the market context.

Griffin [10], in a thorough review of the matter of most major surveys regarding product development practices among professionals, emphasizes the identification of best practices among the respondents of each survey. Griffin undertook a major quest for the definition and operationalization of what falls under the term *best practices* and how such practices can be the outcome of survey research.

A two-phase framework necessary for the identification of the market and organisational correlates of NPD performance has an eminent place in new product development literature. The division into two stages comes as a consequence of the existence of two concepts of performance that need to be accounted for: new product development success and then new product success. Langerak, Hultink, and Robben [11], in an attempt to assess the impact of company market orientation on specific dimensions of NPD, recognised and empirically tested this multi-stage performance quest encountered in NPD research. In a relevant study, discrete stages such as proficiency in NPD product launch, product advantage, and organisational performance are measured and tested in order to identify their direct and indirect association with the company's market orientation.

These two types of performance are not always tantamount and thus require separate assessment. The pictorial representation in **Figure 1** summarizes the conceptual framework of factors driving new product development performance as it has appeared in recent research.

The conceptual framework in **Figure 1** has significant similarities to what Song and Parry [12] have proposed, through which new product performance is statistically linked to skills, synergy, and design sensitivity that constitute company resources and capabilities. Song, Souder, and Dyer [13] as well as Song and Parry [14] have also proposed similar conceptual frameworks. The conceptual model in **Figure 1** constitutes the foundation for exploring the structure of the relationships advocated in the proposed framework via a series of research propositions. Such propositions will then be tested for their statistical foundations, and they will be used subsequently to feed the optimisation framework that will be developed to benchmark the new product development process.

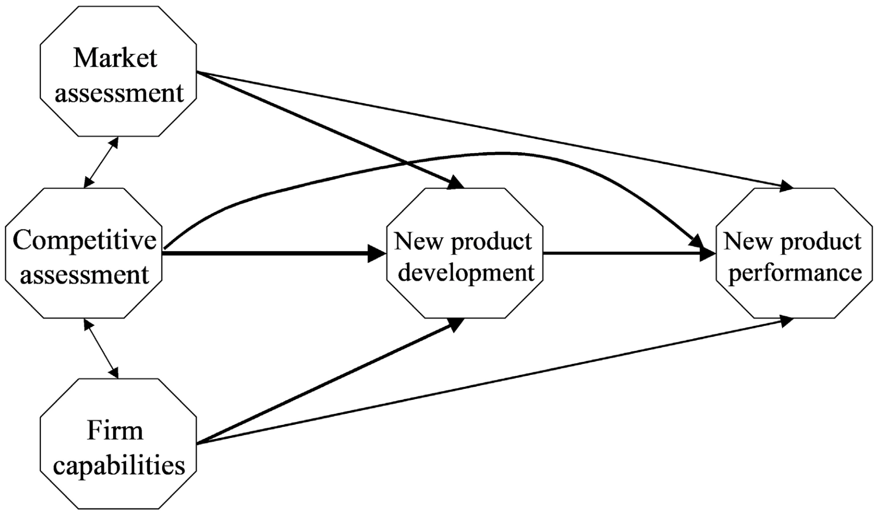

Figure 1. Market environment, company capabilities, new product proficiency & new product performance (ME, CC, NPDP, NPP).

2.1. Generic Company Capabilities

Research focusing on organisation theory and strategic management has opened the debate concerning company competencies and capabilities, as noted by Wernerfelt [15], Barney [16], and Prahalad and Hamel [17]. The key characteristic of organisational capabilities is that they are difficult to obtain and to copy, are accumulated through continuous learning, and can be used as the basis for the company's long-term competitive advantage. Aside from the role played by resources and capabilities in company performance, their definition, operationalisation, and measurement are key issues. In 1998, Kusunoki *et al.* [6] proposed an empirical framework with the understanding that capabilities should be seen along the lines of *local*, *architectural*, and *process* dimensions. They also advocated the role of organisational capabilities as a facilitator of the new product development process, as well as being a product advantage through better positioning.

In view of the paradox between core capabilities and core rigidities, Leonard-Barton [18] also appreciated the role of core capabilities in new product development. That is, existing core capabilities, the necessities for new product development, may hamper the freshness that is vital for proceeding with new products. Atuahene-Gima [19] added further evidence to the capability-rigidity paradox regarding the interaction between existing product innovation competencies and new competencies required by the company in order to address new market challenges. Market knowledge and inter-functional coordination are seen as moderators that prevent companies from becoming operationally efficient but strategically inefficient.

Calantone and di Benedetto [20], Cooper [21], Montoya-Weiss and Calantone [22], and Song *et al.* [14] attempted to bridge the gap between the generic company capabilities and the specific needs emerging from the development of new products. In a more recent study, Harmancioglu, Droge, and Calantone [23] made the distinction between the company's internal resources and the new product development execution proficiencies necessary for product success. They identified five factors as key success drivers of new product development: *process skills*, *project management*, *alignment skills with needs*, *team skills*, and *design sensitivity*. Then, they used the above five factors as the basic features for the definition of Marketing and Technical proficiencies as key determinants of new product performance. Kleinschmidt, De Brentani, and Salomo [24] also pursued similar research focusing on the interaction between 1) organisational NPD resources, 2) NPD process capabilities or routines for identifying and exploiting new product opportunities, and 3) global NPD program performance. The ability to generate and market creative ideas in new products (NPs) and related marketing programs (MPs) in response to changing market needs is part of the organisational capabilities equation. Im and Workman [25] showed that new products and marketing product creativity do affect new product success.

H1a. *Company resources and capabilities associated with the new product development process are differentiated into marketing and technical elements*.

H1b. *Marketing capabilities have positive effects on every dimension of new product performance*.

H1c. *Technical capabilities have positive effects on the intrinsic characteristics of new product development performance*.

2.2. Market Knowledge (Competitive Assessment)

Li and Calantone [4] used the role of market knowledge on new product advantage as a primary source of investigation. In their research, they empirically defined the concept of market knowledge and quantified its impact on product performance. Day [26], Glazer [27], and Prahalad and Hamel [28] also recognized the role of market knowledge on producer advantage and, consequently, on new product performance. Linking further this argument with Narver and Slater's [29] definition of market knowledge along the lines of competitor and customer orientation, it becomes clearer that information gathering and analysis mechanisms differ in each customer and competitor knowledge case. In the study by Li and Calantone [4], market knowledge was represented via a three-dimensional construct including customer knowledge process, competitor knowledge process, and the marketing, research, and development interface, providing empirical evidence of positive effects concerning each one of the above dimensions on new product advantage. The results also reveal a positive association between new product advantage and product market performance. The findings regarding the antecedents indicate that the perceived importance of market knowledge by top management has the greatest impact on the processes of market knowledge competence. In a more recent study, Frishammar and Åke Hörte [30] tested market orientation and its effects on new product development performance, with positive effects being tested in a sample of manufacturing companies.

Market knowledge is gradually gaining recognition in many recent studies concerning its impacts on both product development process effectiveness and product performance.

H2a. *Market knowledge has positive effects on the marketing performance of new products*.

H2b. *Market knowledge does not statistically affect short-term performance indicators such as profitability*.

2.3. Market Conditions

Market knowledge, as addressed earlier, conveys a message concerning the market orientation of individual companies engaged in new product development activities. Such orientation, though necessary, does not convey any information about the market conditions upon which a new product is about to be positioned. Market conditions should affect both the new product development process and new product performance in the market. Calantone *et al*. [5] recognized and elaborated further on this dual role of environmental conditions, since the new product development process may be subject to acceleration or delay due to intense market hostility, and thus it is not straightforward to assume that environmental hostility may lead to adverse product performance. Furthermore, Souza *et al*. [31] have found that industry clockspeed and time to market from the company's point of view are closely related, showing the close ties between industry conditions and new product development fit-strategy.

Cooper and Kleinschmidt [32] have shown that there is scope for adopting a multi-stage process of new product development with direct effects on new product success. When systematic steps for new product development are linked with environmental hostility, such a process may prove cumbersome or safeguard. Calantone *et al*. [5] and Calantone *et al*. [33] posed similar questions since they sought to address the complementary or competing relationship between the systematic way for new product development and the quest for *speed-to-market*, especially in market environments characterised by discontinuous changes. The empirical results of their study indicate that environmental hostility should not be used as an excuse for eliminating steps from the NPD process.

There are reasons to believe, however, that technological turbulence and competitive intensity may moderate the entrepreneurial orientation-NPD-performance relationship. Smart and Vertinsky [34] and Miles and Arnold [35] argued that an entrepreneurial orientation provides the foundation for appropriate strategic responses caused by environmental turbulence. The findings of Covin and Slevin [36] also validated this argument. Covin and Slevin [36] found that performance among smaller manufacturing companies—like the ones used in this paper's research—has positive links with an entrepreneurial orientation posture in hostile environments. In their view, hostile environments are, among other things, characterized by intense competition and lack of predictability.

For measuring technological turbulence and competitive intensity, this paper draws on Jaworski and Kohli [37]. All in all, this paper uses four items in order to capture the dimension of technological turbulence and six items to measure competitive intensity.

H3a. *Companies functioning within highly hostile market conditions violate the steps necessary for new product development*.

H3b. *Market hostility has negative effects on new product performance*, *at least regarding the short-term dimensions*.

H3c. *Complementary market conditions play a mediating role in new product development performance*.

2.4. New Product Development Process Steps

NPD research identifies execution proficiencies associated with different NPD stages as important determinants of success [14] [38]-[42]. This paper focuses on execution proficiencies in marketing versus technical NPD activities [14] [20] [43]. These two proficiency constructs mirror the two resource fit constructs. When it comes to a particular new product project, a differentiation appears regarding the following two main constructs: 1) marketing execution proficiency as competence in initial screening, preliminary market assessment, detailed market study, customer tests of the product, and market launch; and 2) technical execution proficiency as competence in preliminary technical assessment, prototype development, pilot production, and production start-up. Thus, the domain of the two execution proficiency constructs spans development activities as well as launch activities.

Empirical evidence from different industries and cultures has shown that having strong market orientation, marketing, and technical capabilities and following systematic steps in the pre-development activities increases the likelihood of success for individual new products, as Cooper [21], Cooper and Kleinschmidt [44] [45], de Brentani [46], and Maidique and Zirger [47] stress in their works. The conceptualisation of new product development in this paper is along the lines of Calantone and Cooper [48] [49] and Song and Parry [14] and is approached as a five-stage process: idea development and screening, business and market opportunity analysis, technical development, product testing, and product commercialisation. Such product development dimensions, despite their logical appeal, find empirical verification in previous research by Song and Parry [14]. This paper proceeds with a re-examination of their dimensionality.

H4a. *Each stage of the new product development process retains its distinct effect on the ultimate performance of the new product attempt.*

The dimensions of new product development are supplementary with reference to specific company capabilities during the implementation of the new product development process. In Maidique and Zirger [47] [50], the effect of such items on the performance of NPD teams was the subject of their research, while Song and Parry [14] managed its successful application. Also, Olson, Walker, and Ruekert [51] recognized the effect of organizational structure and coordination on new product development without, however, addressing the dimensions of market knowledge in full. Troy *et al.* (2008) [52] posited on the role of inter-functional coordination on new product development performance. In their findings, they indicated that, though integration seems to affect new product success directly, the combination of integration with other key factors may be of greater importance to consider. It is noteworthy that most of the variables that significantly affect the integration—success relationship in Troy *et al.* [52]—are either under managerial control or context-specific. In a similar vein, a recent study by Haon, Gotteland, and Fornerino [53] recognized the effects of cross-functional integration and cooperation on NPD success. Particular interest in cross-functional coordination is being given to the marketing-manufacturing integration that Swink and Song [54] demonstrated, as its strength has direct implications for NPD success.

H4b. *Cross-functional integration plays a significant role in new product development success.*

2.5. Performance Measurement

Most researchers in Product Design and Development (PD&D) strive continually to improve the process for the transformation of a *market need* or *market opportunity* into a successful product. However, these are very general elements of performance that are difficult to measure objectively, and their relation to new tools and methods is frequently ill-defined. Griffin and Page [55] sought to investigate the case of product success measurement from the point of view of each product's individual strategy and, consequently, the level of strategy attainment. In their empirical results, they found that managers customarily use project-specific and business-specific strategic goals for assessing new product performance. Rijsdijk *et al.* [56] propose the distinction between two product advantage components: product meaningfulness and product superiority as two different components of new product performance assessment.

Tan *et al.* [3] found a statistical association between the company's operational capability and its performance. Operational capability is conveyed via the product development performance of the company, while performance measures utilize company-specific dimensions (profitability, customer service, and market share). That is, the study focuses on new product capability for its overall performance effects, and not solely on the performance of specific products. Many researchers in the Resource-Based View innovation and marketing literature focus on the financial outcome, such as the extent to which the new product achieved its sales and profit objectives [19] [22] [55] [57]-[59].

Harmancioglu *et al.* [23] measured NPD performance at the company level. Although some authors favor measuring this concept at the project level, this paper aims for the company level for three reasons. Firstly, since the companies investigated are fairly small, there is no reason to believe that substantial differences exist in NPD performance among different units of the same company. Secondly, ceteris paribus, since small companies undertake fewer NPD projects than large ones, considerable variations in the nature and performance of new product projects are less likely to occur in comparison with large companies. Operationally, this research used the four items suggested by Atuahene-Gima and Ko [60]. This scale measures the extent to which new products meet their market share, sales and customer use, sales growth, and profit objectives.

Relative performance was assessed as a qualitative metric concerning the perceptions of new product development teams regarding their initial expectations. This disconfirmation approach, frequently met in the customer satisfaction literature, addresses the difficult problem of defining a *common* base of assessment. To assess new product performance, a three-dimensional construct—relative profitability, relative market share, and relative sales—was devised with similar use as that in Song and Parry [14]. The empirical results of the study did not provide verification of such clear-cut dimensions, and three different performance dimensions emerged—tangible effects, intangible effects, and indirect corporate effects.

H5. *Performance of new product development involves the differentiation into direct "accounting" effects, indirect business effects, and strategic company-level effects.*

3. An Optimization Framework of Market Conditions, Company Capabilities, and New Product Proficiency and Performance

New product development proficiency, apart from being an input in the assessment of performance, is also the direct outcome of the resources' commitment to each new product development team effort, as described in **Figure 1**. **Figure 2** is a graphical illustration of the mechanism of this two-stage process of assessing the effectiveness of new product development. Recent research in data envelopment analysis has appreciated the presence of multiple performance dimensions when the efficiency of operating units is assessed, Paradi *et al.* [61]. A series of research studies have adopted multi-stage efficiency assessments whereby the output of one stage then becomes the input to another stage, and in such a way, the dynamics of multi-level and sequential production of activity systems are captured, Soteriou and Zenios [62], Athanassopoulos [63], Golany *et al.* [64], Yu and Lin [65], Tone and Tsutsui [66], and Chen *et al.* [67]. Furthermore, Flores *et al.* [68] [69] made explicit connection between new product development and DEA methodologies, opening a series of other studies that followed thereafter.

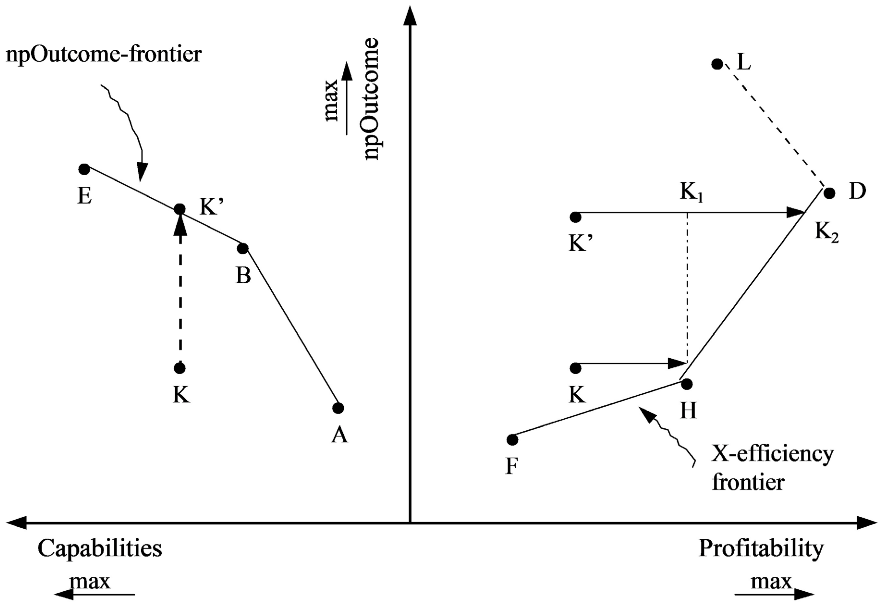

Figure 2. Embodying NPD proficiency into new product performance.

3.1. Focus on New Product Development Team Proficiency

The left part of the illustration in Figure 2 involves information concerning the extent to which an NPD team utilises its resources and capabilities by means of the successful outcome of the stages required for the successful development of new products. Such an issue is by no means related to the success or failure of a new product, but is actually related to the level of new product development process proficiency while meeting set procedures effectively.

Let us consider, for example, the case of NPD team K, which utilizes a set level of capabilities (e.g., market knowledge, coordination between product teams) in order to respond to the needs of the various stages of the new product development process. NPD teams A, B, and E constitute the best practice's optimum frontier concerning new product development proficiency. Such a frontier is undoubtedly of an empirical nature and can be used to project team K in terms of improved levels of proficiency. Such proficiency may be, for instance, the successful undertaking of market research and/or market testing while the development of the new product is still in progress. Point K' is a linear combination between teams E and B and yields information on the extent to which higher levels of project proficiency should be achievable for a given level of team competences. New product team proficiency is seen as an intermediate output, where its maximization increases the likelihood of new product development success in the market. The causal loop of new product proficiency has the obvious implication that an increase in internal company capabilities would lead to higher levels of team proficiency as far as the core activity of product development is concerned.

The link between company capabilities and new product proficiency constitutes a resource allocation problem regarding both resource volume and resource-mix level. In the first case, the issue of resource level commitment arises, as the acquisition and/or development of resources and capabilities depends on an overall allocation of resources concerning these resources (e.g., overall budget for training). On the other hand, in the second case, there is the issue of optimum resource mix, which draws upon the setting of priorities concerning the emphasis that needs to be assigned to certain aspects of the internal company capabilities. Bearing in mind that company capabilities constitute intangible assets, the choice over specific elements of said capabilities should be discernible during the benchmarking process so that no excess *capability* capacity will be stored if not needed during the new product development process. The methodology used for benchmarking enables the development of the prioritization scenarios concerning both the quantitative aspects of resources and capabilities, but also the aspect of their optimum mix.

3.2. Focus on New Product Performance

The second stage in the benchmarking process concerns product performance, which is the end result of the development process. This process has been set aside from new product development sufficiency since the success of a new product does not necessarily rely on the quality of its development. For instance, considering the case of team K and its efficiency comparisons on the right part of the illustration in **Figure 2**, *input* is considered the NP team's proficiency and *output* is the NP performance. As demonstrated in **Figure 2**, the output of the first stage of benchmarking assessment is used as the input of the second stage. The assumption in this case is that the final performance of the new product is a function of the new product team proficiency[1].

The assessment of NP proficiency of team K is by means of projecting it on the EB segment of the proficiency frontier (under variable returns to scale). The efficient position K' shows the proficiency score of branch K in case it had utilized its corresponding capabilities in full. The efficient level K' is used as an input in the benchmarking of team K, as illustrated on the right part of the frontier. The new product performance of team K is estimated by means of its projection at point K_2 of the segment HD.

Clearly, the improvement potential of the performance of team K would have been underestimated by an amount of K_1K_2, without the *proficiency* level adjustment made in the first stage of the assessment. The K_1K_2 quantity constitutes a gap (unrecognised capacity) between the realised and the unrealised potential of individual teams in the form of outcome generation.

The analysis concerning the assessment of new product performance in the case of observed and maximum proficiency levels also leads to the conclusion that the

[1]No doubt, in reality, the assessment of new product performance is a function of more factors included in a multi-input, multi-output production technology.

performance expectations under the scenario of maximum proficiency levels will be higher than the corresponding performance levels that correspond to observed proficiency levels. With reference to **Figure 2**, that is K'K1 ≤ K'K2. The latter relation draws upon a fundamental assumption of isotonicity that drives DEA, under which, for efficiency in operations, higher levels of resources will lead to higher or the same level of output. In addition, the current DEA framework adopted in this research induces a strong output disposability assumption and, thus, the observation at point L should not be considered an efficient observation.

In summary, the underlying principle behind the pre-estimation of maximum attainable levels of NP team proficiency consists of two parts. The primary target is to estimate the maximum attainable level of NP proficiency after controlling for the internal characteristics of each team, while the second stage of the assessment focuses on the performance of individual products, having controlled for the maximum level of product proficiency that should be provided in the first place. The latter can be used as the basis for modifying the form of the equation in (2) by (3), as presented in **Table 1**.

$$\text{Performance} = \text{F}\left(\text{Max}\left[\text{NPDproficiency}\right], \text{Market conditions}, \text{Company capabilities}\right) \quad (1)$$

The substitution of team proficiency with the corresponding maximum feasible level is used as the basis for assessing the impacts of new product proficiency on performance [(2), **Table 1**] and the opportunity cost from not providing appropriate levels of service quality [(3), **Table 1**].

3.3. Mathematical Formulation of NPD Benchmarking

As part of this paper's methodology, a set of $j = 1, \cdots, n$ new product teams is used, which exploit company resources and capabilities $C \in \Re_+^m$, with x_{ij}^c being the capability *i* of product-team *j*; each team also operates in a market environment that can be described by a set of characteristics that have positive effects on its tasks $I_p \in \Re_+^p$, with t_{ij}^p being the market characteristic I^p of product team *j*, along with a set of characteristics that have negative effects on its tasks $I_n \in \Re_+^n$, with t_{ij}^n being the market characteristic I^n of product team *j*. The NPD team also has an outcome $Q \in \Re_+^a$, with q_{rj} being the outcome *r* of team *j*, yielding product performance quantities $O \in \Re_+^s$, with y_{rj} being the performance-dimension *r* of product *j*. The notation framework is developed in order to accommodate input characteristics that have differential effects, some negative and some positive, on the output performance of the NPD teams. The two-stage benchmarking assessment of the products follows the optimisation models (2) and (3).

The use of the linear programming formulations in (2) and (3) in **Table 1** takes place in order to obtain estimates of the maximum level of team proficiency and its ensuing implications on product performance. The models (2) and (3) in **Table 1** represent an instance of the assessment for branch k under variable returns to scale assumptions. The two formulations in (2) and (3) in **Table 1** belong to the family of non-radial efficiency models (see [70]). That is, the optimum solution in

(2) and (3) in Table 1 yields improvement rates for individual inputs and outputs according to their representation in the objective functions. An assessed branch k is relatively efficient if $\theta^*_{rk} = 1 \quad \forall r \in Q$ in (2) and $\phi^*_{rk} = 1 \quad \forall r \in O$ and $v^*_{ik} = 1$ $\forall i \in D$ [2] in (3), in Table 1. The objective functions of (2) and (3) in Table 1 contain preferences P_r, ω_r, ω_i over inputs and outputs, respectively, regarding decision-makers' priorities on the rate of improvement of inputs/outputs. Setting these priorities at unity, the assessment does not inherit any preferential treatment over individual inputs/outputs. In the current empirical study, the priority levels were set either at the level of 1 or 0 simply to indicate the preference over controllable and non-controllable inputs and outputs. At a second stage of the solution process, specific preference weights concerning the NPD team preferences over NPD performance are introduced.

Table 1. Foundational DEA models used.

First Stage: NPD Proficiency	(2)	Second Stage: NP Performance	(3)
		$\underset{\phi_{ri},\lambda_j}{\text{Max}} \sum_r \omega_r \phi_r$	
$\underset{\theta_r,\kappa_j}{\text{Max}} \sum_r P_r \theta_{rk}$		$\sum_{j=1}^{n} \mu_j t_{ij} \le t_{ik} \quad i \in I_P$	(3.0)
$\sum_{j=1}^{n} \mu_j t_{ij} \le t_{ik} \quad i \in I_P$		$\sum_{j=1}^{n} \mu_j t_{ij} \ge t_{ik} \quad i \in I_n$	(3.1)
$\sum_{j=1}^{n} \mu_j t_{ij} \ge t_{ik} \quad i \in I_n$		$\sum_{j=1}^{n} \lambda_j \theta_{rj} q_{rj} \le \theta'_{rk} q_{rk} \quad r \in Q$	(3.2)
$\sum_{j=1}^{n} \mu_j q_{rj} = \theta_{rk} q_{rk} \quad r \in Q$		$\sum_{j=1}^{n} \lambda_j y_{rj} - \phi_r y_{rk} = 0 \quad r \in O$	(3.3)
$\sum_{j=1}^{n} \mu_j = 1$		$\sum_{j=1}^{n} \lambda_j = 1$	(3.4)
$\theta_{rk} \ge 1, \mu_j \ge 0$		$\varphi_r \ge 1, \lambda_j \ge 0$	

The first stage of the assessment of (2) in Table 1 yields the efficient team proficiency level ($\theta^*_{rk} q_{rk} \quad \forall (r,k)$) for each branch. Team proficiency is given to a multi-dimensional nature and, thus, the model in (2) has a non-radial nature so that targets are estimated for all team proficiency dimensions. The second phase of the assessment yields performance targets for controllable inputs and outputs of the NPD teams [(3.1) and (3.2) in Table 1]. Additionally, the model incorporates control variables [(3.3) in Table 1] that correspond to production attributes such as market characteristics, which are not treated as controllable factors in the context of the current study.

And finally, the equations in (3.4) in Table 1 reflect factors that represent the team proficiency attributes included in the model. In the context of the present empirical application, team proficiency is given an explicit input behavior in the

[2]The optimum solutions of the two models are by no means related, and, thus, branches may be efficient in terms of quality maximization and inefficient in terms of X-efficiency, or vice versa.

formulation of model (3.4), and thus, as illustrated in **Figure 1**, higher levels of team proficiency should lead to higher levels of output performance.

In the current formulation in (3) in **Table 1**, team proficiency is represented by its maximum feasible levels as estimated in (2) in **Table 1**. Different results will be obtained in case team proficiency is represented using observed and not estimated NPD proficiency. Also, the optimisation framework in (3) in **Table 1** does not include any priori assumptions as to whether team proficiency should be considered to have a positive, neutral, or negative effect on branch performance. The lack of such an assumption is facilitated via the equality constraints in (3.4) in **Table 1**, where team proficiency is given a weakly disposable character. This option was found necessary as there seem to be different theoretical arguments as well as empirical findings regarding the effect of team proficiency on the generation of company outputs. This paper also explores more elaborate model formulations so that the presence of underutilised capacity and input-output value constraints is incorporated into the assessment.

3.4. Opportunity Gap Due to Lack of NDP Proficiency

Important by-products of the two-stage assessment of (2) and (3) in **Table 1** are the measurable effects obtained from the under-provision of team proficiency on the outcomes of individual products. Deriving an estimate from this x-efficiency gap, one will have to re-estimate the outcome targets of (3) in **Table 1**, using the observed levels of team proficiency of (3.4) in **Table 1** instead of using their maximum obtainable amounts. Assuming that the rate of improvement of controllable output r of team k is estimated as ϕ_{rk}^{*}, a similar, but different in magnitude, rate of improvement ($\hat{\phi}_{rk}^{*}$) will be obtained if the model in (3) is resolved by using the observed and not efficient levels of team proficiency. It can be shown that the rate of improvement as obtained from (3) in **Table 1** for output r will always be greater than or equal to the corresponding value obtained from the revised solution[3] ($\phi_{rk}^{*} \geq \hat{\phi}_{rk}^{*} \geq 1$). The relation between the two types of efficiency indices holds due to the isotonicity and strong output disposability assumptions that hold in model (3) in **Table 1**.

The team proficiency gap (TPG) on the performance targets of output r of branch k is then estimated by $TPG_{rk} = \phi_{rk}^{*} / \hat{\phi}_{rk}^{*}$, which takes values greater than one in the case of team proficiency under-provision, and one if the team proficiency has no incremental impact on the branch outcomes.

4. Empirical Results

The empirical results of the paper were accrued from a total of 110 manufacturing companies in Greece. The companies were selected following their participation in a large-scale project concerning the promotion of innovation management techniques in small and medium-sized enterprises (SMEs) in Greece. The project

[3]Under the assumption that the priorities are kept unchanged in the objective function of (4).

team selected an initial sample of 300 SMEs during the initial screening for participation in the project. A total of 110 SMEs agreed to participate and spent the time necessary to fulfill the data enquiry. In return, those companies that participated in the study received free of charge benchmarking data and, thus, support based on the study findings. From that perspective, the companies involved in the study may be considered as a convenience sample, while one should bear in mind that the companies participating in the study were willing to contribute considerable time to a wider project regarding the implementation of new management practices.

Data selection was carried out by means of appointments with the top management of each SME, involving the solicitation of responses to the various questions set by the research instrument. It should be noted that the responses were accrued by averaging the replies obtained from individual informants of each company. These key informants were selected to respond to strategic issues concerning their company (Chief Executive Officer, General Manager, Financial Manager, Marketing Manager, and Production Manager).

Companies were contacted via mail and telephone, explaining the project's cause and inviting them to an open workshop where the project's objectives and content would be explained. The companies that participated in the study received 10 days of consulting services from the consortium of management experts. This package of services comprised a 2-day diagnostic study for each company, followed by four 2-day workshops held on the premises of each company regarding the implementation of a management tool deemed appropriate during the diagnostic phase of the project. Descriptive statistics regarding the identity of the participants can be found in Table 2.

Table 2. Descriptive statistics of participating company.

Industry Participation	Sample Composition	Average Company Turnover (Thous. in €)	% Employees with a University Degree	Years in Operation	% of Sales from Products Launched during the Last 3 Years
Food	23%	1500	12	17	25
Textiles	11%	800	6	26	70
Chemicals	22%	1800	9	11	35
Wood	9%	400	8	19	25
Ceramic	5%	550	16	11	45
Electronic	12%	450	25	7	80
Other	14%	650	11	12	35
Total	**100%**	**1079**	**11**	**14**	**40**

The size characteristics of the companies in the sample indicate that they belong in the segment of SMEs, with size characteristics that enable the presence of minimum managerial characteristics, as new product development would be expected to fulfill systematic procedures. The life stage of the companies participating in the sample indicates a level of maturity and, thus, new product development would be part of a long life stage process and not part of the starting-up process.

4.1. Empirical Specification

Having described the conceptual basis of assessing the performance of new product development, the proposed operational framework is summarized in Figure 3.

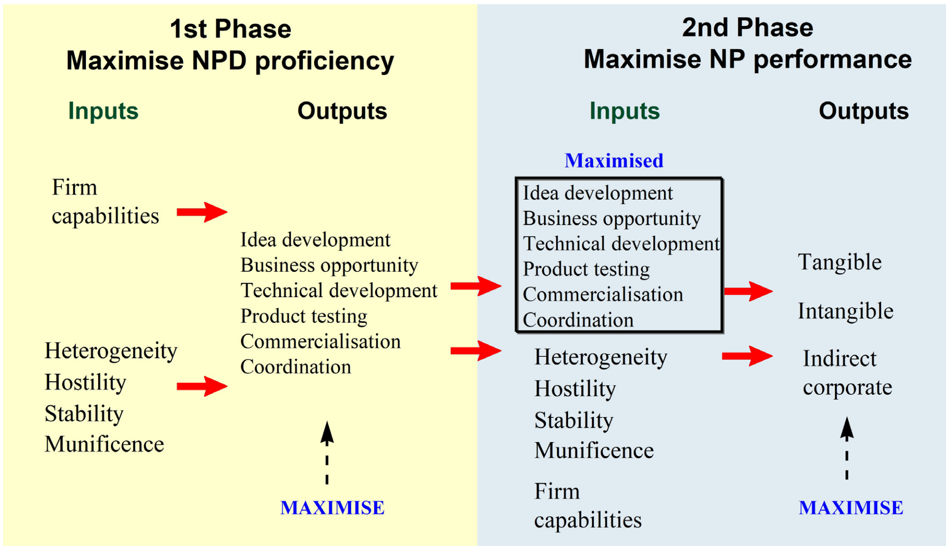

Figure 3. Netput framework for new product development benchmarking.

The benchmarking framework of new product development involves two interlinked stages. In the first stage, we seek to assess the proficiency of new product development teams, while in the second stage, we focus on the assessment of new product performance. In the first stage, we use inputs reflecting the company's capabilities and the market environment characteristics. The second stage includes as inputs the outputs of the first stage, as well as other relevant inputs that affect new product performance, which is the output of this stage. In the second stage of the assessment, the use of new product proficiency indices can be implemented in two separate steps. During the first step, the observed scores of NPD proficiency can be used, while during the second step, the target scores of NPD proficiency can be used to assess the differential effect of the NPD proficiency on NP performance.

4.2. Construct Development—Antecedents

The development of the research constructs of the study draws upon recent research literature from the fields of strategy and marketing. The discussion that follows is based on confirmatory factor analysis results concerning the variables selected for the optimisation model and each variable's assumed direction of influence on the performance of NPD teams.

4.2.1. Company Capabilities

The *company capabilities* construct consists of two key factors—marketing capabilities and technical capabilities—composed as multi-dimensional constructs. Company capabilities were measured using 10 question items that were allocated to the two latent factors via confirmatory factor analysis modelling. Details concerning the composition of the factors associated with the factors of company capabilities can be found in **Table 3**.

Table 3. Standardized factor loadings concerning the assessment of company capabilities.

Company Capabilities ($\chi^2 = 39.3$, p = 0.23, CFI = 0.968)	Marketing	Technical
Market knowledge	0.637	
Sales dynamism and capabilities	0.769	
Positive company image for its customers	0.680	
Extensive distribution network	0.656	
Relationships with suppliers and customers	0.706	
Database marketing capabilities	0.858	
Effective production capabilities		0.706
Exploitation of economies of scale		0.680
Technological infrastructure		0.604
Patents and innovations		0.490

It is worth observing that new product development teams recognized two fundamental dimensions regarding the NPD process: technical-related capabilities and market-related capabilities. Both dimensions are included in the optimization framework, playing a positive role in the performance of NPD teams. That is, the higher the capabilities, the higher the expectations from the NPD team. At a later stage in the research, the study also focused on the potential presence of input congestion, which would indicate opportunity costs from non-utilized capability stocks.

4.2.2. Market Environment Assessment

The market environment has also been considered an important factor in view of the assessment of its effects on the performance of both NPD proficiency and NP performance. Of course, the definition of market characteristics and the exact structure of its constituent parts have been an issue of significance since there is ample empirical evidence concerning alternative definitions of the market characteristics upon which new products are positioned. **Table 4** contains information concerning three general views on market conditions, with subsequent factor dimensions associated with each one of the three market condition views.

Table 4. Standardized factor loadings concerning the assessment of the market environment.

Market Environment Assessment (χ^2 = 36.3, p = 0.28, CFI = 0.981)	Munificence	Investment Requirements	Predictability
Safe with little threat to our company	0.603		
Rich in investment opportunities	0.875		
Rich in product development opportunities	0.729		
There are ample tangible and intangible resources	0.809		
It is relatively easy for our company to affect the market	0.771		
Very demanding in R&D		0.66	
Demanding in technology		0.77	
Demanding in issues of customer service		0.61	
It is easy to predict competitors' actions			0.76
It is easy to predict customer preferences			0.94
Frequency of Market Changes (χ^2 = 7.153, p = 0.53, CFI = 1.00)	Market Changes	Product Changes	
Changing competitor strategies	0.535		
Competitive new product introduction	0.804		
Changing customer preferences	0.699		
Changing product technology		0.688	
Changing cost of production		0.678	
Rate of product obsolescence		0.689	
Market Segment Heterogeneity (χ^2 = 1.93, p = 0.32, CFI = 0.96)			
Customer preferences	0.79		
Type and competitive intensity	0.68		
Prospects and business opportunities	0.73		

Three broad dimensions characterize the market environment of individual new product development teams—market assessment, frequency of changes, and market segment heterogeneity—further differentiated into more detailed construct dimensions. That is, based on the study's empirical results, the market environment is characterized alongside six dimensions—*munificence*^{P}, *investment requirements*^{N}, *predictability*^{P}, *market changes*^{N}, *product changes*^{N}, and *segment heterogeneity*^{N}. For an optimization-based assessment of performance, decisions must be reached bearing in mind the causal link between such market characteristics and new product development team outcomes. This is the reason why each component of the market environment was characterized as expected to have a negative (N) or positive (P) effect on the performance of a new product development team[4].

In the optimisation framework in (2) in Table 1, the market characteristics were characterised as product components that were not deemed to be maximised and/or minimised. On the other hand, they were allowed to have slack variable effects on the optimum solution of (2). For those market factors considered as having positive effects on the outcomes of the NPD process, the slack variables were considered as having negative effects on observed inputs used. On the contrary, for the market factors with negative effects on outcomes, the slack variables were considered as having positive effects on the observed levels of resources. Therefore, the study allowed for positive slacks on the munificence (s_m) and predictability (s_p), and negative slacks on investment requirements (s_{ir}), market changes (s_{mc}), product changes (s_{pc}), and segment heterogeneity (s_{sh}).

4.3. Construct Development—NPD Proficiency

New product development proficiency is geared towards the assessment of the performance of the NPD teams at each stage of NP development. The constructs of new product development were quantified via appropriate scale items that correspond to each dimension of new product development. Table 5 consists of the details concerning the exact structure of the six dimensions of new product development proficiency.

Table 5. Scale development of new product development proficiency.

	Standardised Factor Loadings	
Idea Development and Screening (χ^2 = 1.88, p = 0.29, CFI = 0.93)		
Product screening	0.79	
New idea formulation	0.74	
Assessment of business prospects	0.64	
Business and Market Opportunity Analysis (χ^2 = 8.971, p = 0.344, CFI = 0.993)	Extrinsic	Intrinsic
Desired product characteristics		0.65
Assessment of market trends		0.87
Feasibility assessment regarding the development of the product		0.58
Assessment of resource requirements and business risks involved		0.71
Conducting detailed market research	0.73	
Assessment of competitive environment	0.94	
Product attributes leading to differentiation	0.68	

[4]The assumption made here is that the study ignores the current competitive stance of each company, since a company that has a dominant position in the market should not worry about entrance costs to the market compared to a new entrant. All companies in the study have had similar life cycles concerning their focus on the market and also their number of years in operation.

Continued

Technical Development of New Product (χ^2 = 6.71, p = 0.144, CFI = 0.953)	Design	Feasibility
Initial assessment of technical and product needs	0.83	
Product development according to technical specifications	0.81	
Determination of a detailed production plan	0.58	
Benchmarking specifications concerning the assessment of product positioning in the market		0.74
Evaluation of current production infrastructure to support new product requirements		0.59
New Product Testing (χ^2 = 1.38, p = 0.16, CFI = 0.99)		
Sample selection of customers and conducting of tests	0.92	
Evaluation of results from market testing and product introduction to the market	0.93	
Commercial Exploitation of a New Product (χ^2 = 6.71, p = 0.144, CFI = 0.953)	Entrance	
Integration of the production plan	0.74	
Integration of the marketing plan	0.67	
Role and task allocation in the management of the program	0.62	
Entrance of the new product into the market	0.84	
Assessment of market response to the new product introduction	0.82	
Administrative Support and Internal Cooperation (χ^2 = 1.58, p = 0.24, CFI = 0.95)		
Full support from the management of the company.	0.64	
Clear allocation of values and tasks among the members of the NPD team	0.89	
Full cooperation among the team members of NPD and prospective customers of the proposed product	0.47	

The operationalisation of the stages of new product development proficiency has verified the presence of six distinct dimensions via the testing of exploratory and confirmatory factor analysis results. That is, the rejection of the null hypothesis that the process is a single dimensional construct (CFI = 0.78) as opposed to (CFI = 0.95) in the six-dimensional approach[5]. The items tested as components of the six dimensions of the NPD process have been proposed in various research works by Cooper [21], and Cooper and Kleinschmidt [32], while they have been later used by Calantone and Cooper [49], Cooper and Kleinschmidt [71], and Parry and Song [14] [72].

[5]The full testing concerning the dimensionality of the construct involved exploration of all possible combinations of combined constructs via the confirmatory factor analysis results. All such models yielded inferior fit indices compared to the six-dimension solution presented here. Full results from these tests can be obtained from the author upon request.

The statistical verification of the construct has also yielded two-dimensional solutions for some of the constructs that constitute the new product development proficiency construct. These were the *business and market opportunity analysis* (*extrinsic and intrinsic analysis*), and *technical development of new product* (*design and feasibility*). This analysis enabled us to better understand the drivers of NPD proficiency and thus improve the subsequent benchmarking formulation.

4.4. Construct Development—NPD Performance

A multi-item construct was used to measure new product performance, comprising three factors consisting of the measurement model results listed in **Table 6**. The measurement model yielded a three-factor solution reflecting *tangible effects*, *non-tangible effects*, and finally *the indirect effects of new products on other aspects of company performance*.

Table 6. Dimensions of new product performance.

New Product Performance (χ^2 = 6.71, p = 0.144, CFI = 0.953)	Tangible	Intangible	Indirect Benefits
Sales volume	0.65		
Growth in sales volume	0.59		
Profit margin	0.82		
Profit contribution	0.73		
Market share	0.76		
Growth in market share	0.56		
Brand image building	0.48		
Perceived quality		0.58	
Cost reduction		0.53	
Enhanced relationships with suppliers		0.67	
Implementation of investment plans		0.68	
New growth opportunities in the company		0.61	
Growth in sales of other products			0.60
Growth in the profit of other products			0.55
Entrance into new markets			0.78

These results do not comply with the results reported in previous studies concerning the dimensions of new product performance. Song and Parry [14], for instance, reported factors concerning *profitability*, *relative sales*, and *relative market share*. Cooper and Kleinschmidt [9] reported different views among academics and practitioners concerning the assessment of new product performance. Cooper [73] [74] reported measures of new product performance associated with objective and subjective information. One part of the assessment corresponded to the role and relative weight of the new products in each company's overall portfolio. Additionally, the use of measures associated with individual new product projects was applied, reflecting upon *profitability*, *technical success*, *impact on sales and sales objectives*, *impact on profit and profit objectives*, and finally, *relative success of the project as compared to the competition.* Song and Parry [14] conceptualised new product performance with four items comprising *commercial expectations' achievement*, *technical expectations' achievement*, *market positioning*, and finally *product quality*. And finally, Atuahene-Gima [57] used a four-item scale concerning the market performance of new products and a six-item scale concerning the project performance of new products.

4.5. Exploratory Assessment of Market, Capabilities, and NPD-Proficiency Effects on NP Performance

This section includes statistical results concerning the research hypotheses that followed the conceptual framework of the research. These research hypotheses, without being the primary objective of the research, are essential for building the benchmarking framework that enabled the research to draw relative comparisons concerning the effectiveness of the new product development teams. The study of these research hypotheses evolved in two stages, as presented in **Table 7** and **Table 8** below.

Table 7. Assessing the marginal effects of company capabilities and market conditions on NPD proficiency.

	Idea Development	Extrinsic Market Analysis	Intrinsic Business Analysis	Design of New Products	Feasibility of a New Product	New Product Testing	Commercial Exploitation	Administrative Support
Marketing Capabilities	0.25**	0.09	0.11*	0.21*	0.04	0.16	0.19*	0.01
Technical Capabilities	−0.01	0.17*	0.22*	0.19*	0.35**	0.13	−0.08	0.13
Munificence	0.34**	0.32**	0.19*	−0.06	0.10	0.33**	0.34**	0.16*
Investment Requirements	−0.21*	−0.19*	−0.02	0.12	0.19*	−0.05	−0.31**	0.22*
Predictability	0.11	0.10	0.28**	−0.02	0.18*	0.01	0.14	0.14
Market Changes	0.29**	0.12	0.31**	0.06	0.14	0.029	0.26*	0.06
Product Changes	−0.05	−0.09	−0.09	0.15	−0.25**	−0.03	−0.18*	0.13
Market Heterogeneity	0.05	0.26**	−0.008	−0.11	−0.089	0.06	0.16*	−0.08
R^2-adjust.	0.40	0.42	0.37	0.15	0.20	0.26	0.49	0.30

** indicates 1% significance level and * indicates 5% sign confidence level.

This research explored the effectiveness of new product development stages via a series of independent regression analyses seeking to identify patterns of association between NPD proficiency, company resources and capabilities, and market characteristics. All regression results gave acceptable model fits, with the most notable among them being the case of commercial exploitation. Company capabilities seem to play a significant role in NPD proficiency in terms of *marketing* and *technical capabilities*. The two types of company capabilities are spread across the stages of NP development, playing a significant and positive role. The market characteristics have shifting effects on NPD proficiency. Market munificence affects positively the proficiency of NPD teams in completing the stages of NPD effectively. On the contrary, the extent to which the market environment is considered as resource-demanding affects negatively the effectiveness of the NPD teams. It seems that in market environments where there is a high degree of investment requirements, NPD teams find it difficult to be proficient in developing new products. Finally, the extent to which the market can be predictable affects positively the company's capability to get organized internally and, thus, to assess the feasibility of the new product. NPD teams seem to enjoy operating within markets with frequent changes, which also has a positive effect on their performance in developing new products. On the other hand, when the frequency of changes concerns the products per se, such development has negative effects on certain NPD dimensions. Frequent market changes, indeed, affect negatively the team's ability to assess the feasibility of the new product and its commercial exploitation. To conclude, market heterogeneity, which indicates the presence of market niches within the positioning of the new product, has a positive effect on the assessment of NPD market characteristics and on the commercial exploitation of the new product.

Table 8. Assessing the marginal effects of company capabilities, market conditions, and NPD proficiency on NPD performance.

	Tangible	Intangible	Indirect Corporate
Marketing Capabilities	0.52**	0.20*	0.37**
Technical Capabilities	−0.07	0.32**	0.14
Munificence	−0.06	0.21*	−0.06
Investment Requirements	−0.25*	0.02	−0.09
Predictability	0.09	−0.02	−0.10
Market Changes	−0.19*	0.21*	0.06
Product Changes	0.24*	0.05	0.10
Market Heterogeneity	0.08	−0.06	0.08
Idea Development	−0.19*	−0.21*	−0.26**
Extrinsic Market Analysis	0.23*	0.05	0.30**
Intrinsic Business Analysis	−0.09	−0.22*	−0.14
Design of New Product	0.08	0.01	−0.09
Feasibility of New Product	0.28**	0.07	0.23**
New Product Testing	−0.04	0.1	−0.08
Commercial Exploitation	0.29**	0.39**	0.25*
Administrative Support	0.08	0.09	0.22*
R^2-adj.	0.49	0.58	0.35

** indicates 1% significance level and * indicates 5% sign confidence level.

The attempt to provide a statistical framework regarding the relations among market conditions, company capabilities, and NPD proficiency about the performance of new products has gauged the regression equations in **Table 8**. Simple observation of such results indicates a relatively good fit between the explanatory variables and new product performance dimensions. The tangible aspects of new product performance seem to depend upon the marketing capabilities of the company, are affected negatively by the investment requirements of the company (since it is a short-term resource requirement), and, last but not least, are affected negatively by market changes since they cannot be absorbed in the short run by the company. Idea development seems to affect NP performance negatively, which may indicate either the resources consumed for such activities and/or the time delays for completing such an important task. On the contrary, external market assessment and commercial exploitation seem to affect the performance of NPs positively.

Looking at the intangible effects, better explanatory power of the model with emphasis on the positive effects of both aspects of capabilities should be noted, as well as the positive effects of munificence and market changes (reflecting operations within a promising market environment) and the negative effects during the stages of NPD related to idea development and intrinsic business analysis, and, finally, the positive effects from the assessment of the commercial exploitation of the new products.

The case of the company's indirect corporate benefits as an NP-performance dimension seems to be affected by factors similar to those of the other two dimensions, with the exception of administrative support, which appears to have a substantial positive effect on the performance of NPs.

The absence of noticeable effects from some of the stages of NPD should not be seen as evidence of their lack of importance, but rather as a case in which company responses did not differ substantially from each other, and therefore such variables cannot be used to explain variation in NPD performance.

Table 9 below presents these statistics. All scales meet the usual thresholds: Cronbach's $\alpha \geq 0.70$ and CR ≥ 0.70. Most constructs also have AVE ≥ 0.50 (e.g., marketing capabilities AVE = 0.544, munificence AVE = 0.582), supporting convergent validity. For constructs with AVE slightly below 0.50 (e.g., Intangible NPD Performance AVE = 0.378), the CR is still above 0.70, which is acceptable per Fornell and Larcker's criterion. These results substantiate the CFA measurement model.

Table 9. Reliability and convergent validity statistics for all multi-item constructs.

Construct	# Items	Cronbach's α	Composite Reliability (CR)	AVE
Marketing capabilities	5	0.83	0.855	0.544
Technical capabilities	4	0.77	0.716	0.391
Munificence	5	0.84	0.873	0.582
Investment requirements	3	0.71	0.722	0.467

Continued

Predictability	2	0.75	0.843	0.731
Market changes	6	0.80	0.841	0.471
Segment heterogeneity	3	0.74	0.778	0.540
NPD proficiency				
Idea dev.	3	0.72	0.768	0.527
Extrinsic analysis	6	0.85	0.890	0.579
Design	3	0.72	0.789	0.560
Feasibility	2	0.61	0.616	0.448
Testing	2	0.90	0.922	0.856
Commercial expl.	5	0.81	0.859	0.552
Admin. support	3	0.71	0.717	0.474
NPD performance				
Tangible	6	0.82	0.844	0.478
Intangible	9	0.80	0.843	0.378
Indirect	6	0.79	0.815	0.426

From the findings listed in **Table 10**, it is evident that not all hypotheses were validated without that having any detrimental effect on the benchmarking exercise, since the important element has been the correct sign of inputs and outputs and also the multi-stage assessment of the comparative benchmarks had all product development teams performed on their efficient frontier.

4.6. Benchmarking the New Product Development Process

Having defined the overall theoretical and empirical framework that can be used as a vehicle for understanding the new product development process, its antecedents, and its effects on performance, the following step includes the actual benchmarking of such a process. This activity was carried out utilising the data envelopment framework proposed for the two-stage evaluation process.

In Stage 1, *we include eight input variables*: *two controllable* (*internal capabilities*) *and six non-controllable market-related factors*. *We follow the approach of Banker and Morey* [75] *by* treating *these six market inputs*—1) *market munificence*, 2) *investment requirements*, 3) *market predictability*, 4) *market changes*, 5) *product changes*, *and* 6) *segment heterogeneity—as exogenously fixed* (non-discretionary) factors. These reflect external conditions that the NPD team cannot change. In the DEA model, such inputs are included with slack variables but are not subject to optimization in the same way as controllable inputs.

Furthermore, each environmental input is assigned a *sign convention* based on its expected effect on NPD outcomes. If a factor is thought to *facilitate* NPD processes (a "good" factor), we allow *positive* slack (treating higher levels as desirable). Conversely, if a factor is expected to *impede* NPD (a "bad" factor), we assign *negative* slack (reflecting that higher observed levels represent a disadvantage). For example, market munificence and predictability were hypothesized to aid NPD efficiency (so slacks on these inputs are positively oriented), whereas high investment requirements, rapid market changes, frequent product changes, and segment heterogeneity were hypothesized to impose burdens on NPD teams (so slacks on these inputs are negatively oriented). In practical terms, this means the DEA model is specified so that "good" environmental factors can only enter with positive improvement slack, whereas "bad" factors enter with negative slack, consistent with their theorized impact on team performance.

Table 10. Summary of hypothesis testing.

Hypothesis	Empirical Test (Analysis)	Outcome
H1a. Resources/capabilities differentiate into Marketing vs. Technical.	Confirmed via CFA of capabilities (Table 3 shows distinct Marketing and Technical factors).	*Supported* (*distinct factors found*)
H1b. Marketing capabilities → positive effect on all NPD performance dimensions.	Regression of NPD performance on Marketing capabilities (Table 8): Positive and significant coefficients for Tangible (β = 0.52**), Intangible (β = 0.20*), and Indirect (β = 0.37**).	*Supported*
H1c. Technical capabilities → positive effect on intrinsic (non-tangible) NPD performance.	Regression (Table 8): Technical capabilities had a positive effect on Intangible performance (β = 0.32**) but not on Tangible/Indirect.	*Partially supported* (*significant only on Intangible*)
H2a. Market knowledge → positive effect on marketing performance of new products.	Regression analysis (market performance as DV)—market knowledge showed non-significant effects.	*Not supported*
H2b. Market knowledge → no effect on short-term profitability.	No evidence of market knowledge influence on NPD performance.	*Not supported*
H3a. High market hostility → violation of NPD steps (negative effect on NPD proficiency).	Regression (NPD proficiency on market hostility): No clear evidence.	*Not supported*
H3b. Market hostility → negative effect on short-term NPD outcomes.	Regression (NPD performance on Market Changes): Significant negative effect on Tangible performance (β = −0.19*).	*Supported* (*for tangible outcomes*)
H3c. Complementary market conditions mediate NPD performance.	Not directly tested (no three-way interaction analysis).	*Not supported*
H4a. Each NPD process stage has a distinct effect on new product performance.	Regression (Table 8): Different stages show different significant effects (e.g., Extrinsic Market Analysis positive on Tangible/Indirect; Idea Development and Intrinsic Analysis generally negative).	*Supported* (*distinct effects observed*)
H4b. Cross-functional integration (coordination) → positive effect on NPD success.		*Not supported*
H5. NPD performance is multi-dimensional (direct, indirect, strategic).	CFA of NPD performance measures (Table 6): Three factors (Tangible, Intangible, Indirect) emerged.	*Supported* (*3-factor solution confirmed*)

** indicates 1% significance level and * indicates 5% sign confidence level.

Table 11. NPD—three-stage efficiency assessment.

		(1) Maximize NPD Effectiveness	(2) Maximise NPD Performance with Observed Inputs	(3) Maximise NPD Performance with Optimum Level Inputs	
Inputs—Stage 1	Observed	**Max** θ_{rk}^{*}			
Marketing capabilities	44	42 (95%)			
Technical capabilities	53	47 (88%)			
Munificence (F)	77	77			
Investment requirements	74	74			
Predictability (F)	63	63			
Market changes (F)	79	79			
Product changes (F)	44	44			
Market heterogeneity (F)	43	43			
Outputs—$NPD_{proficiency}$			**Max** $\hat{\phi}_{rk}^{*}$	**Max** ϕ_{rk}^{*}	**Team Proficiency Gap** $TPG_{rk} = \phi_{rk}^{*} / \hat{\phi}_{rk}^{*}$
Idea development	74	**98 (75%)**	71 (95%)	**90 (91%)**	**104%**
Extrinsic market analysis	71	**80 (88%)**	71	**80**	**100%**
Intrinsic business analysis	78	**93 (83%)**	69 (88%)	**88 (94%)**	**94%**
Design of new product	70	**94 (74%)**	70	**90 (96%)**	**104%**
Feasibility of new product	59	**76 (77%)**	59	**76**	**100%**
New product testing	66	**84 (78%)**	66	**84**	**100%**
Commercial exploitation	59	**98 (60%)**	59	**92 (94%)**	**106%**
Administrative support	66	**72 (91%)**	61 (92%)	**62 (86%)**	**107%**
Outputs—$NPD_{performance}$	Observed		**Target Stage 2**	**Target Stage 3**	
Tangible	55		66 (83%)	64 (85%)	102%
Intangible	61		67 (89%)	73 (83%)	96%
Indirect corporate	53		59 (89%)	68 (77%)	86%

F: Exogenously fixed inputs outside the control of management.

Table 11 presents the efficiency framework of a particular NPD team in three stages. In stage 1 in Table 11, an input-output model is tested by means of the team capabilities (inputs) versus the new product proficiency of the team (output). The input improvements at various stages are extra gains obtained from the optimisation model in (2) and (3) in Table 11 for inputs that have an optional nature. The outputs of each stage, though controllable, have been assessed in a non-radial DEA efficiency model and, thus, there is a distinct improvement gain for each output.

- **At stage one** (Maximise NPD effectiveness), the NPD team was assessed for its comparative efficiency in developing new products. With the use of an eight-input and eight-output data envelopment model, with six out of eight inputs treated as non-controllable, no slack improvements were provided for. A minimum output improvement of 9% was obtained for the output administrative support, while the maximum non-radial improvement was in the design of new product output (16%). Improvement scope was also obtained on both marketing and technical capabilities controllable inputs by 5% and 12%, respectively.

- **At stage two**, the study proceeded with the assessment of NPD performance using eight input variables (the outputs of stage one) and three output factors. At this stage, the study aimed to assess the comparative efficiency of the 110 product development teams using the observed input and output values for each team. The maximum pro rata output improvement was found to be 11%, while for the tangible outcome, there was a 17% improvement. For three of the observed inputs, there was some allowance for reduction as a result of the optimum solution to the mathematical model [(2), **Table 11**].
- **At stage three**, NPD performance was assessed using the inputs and outputs from stage two, with the notable difference that the inputs are the optimum levels obtained from the solution of stage one. That is to say, the inputs were stressed at their maximum level when considered as outputs. In such a way, the result was an efficiency assessment after the removal of any possible inefficiency in the new product development process. Such a yardstick goes beyond the simple assessment of effort among the NPD teams and provides insight as to their talent, the ultimate customer perception about the product, and the product promotion/advertising acceptance. In the event that such inefficiencies would not occur, then all companies following the NPD processes in an efficient manner would end up with products that would look and perform the same way in the market.

In this illustrative case study, the particular NPD team has unrealised potential to improve its performance by at least 15% (85% being the maximum pro rata level of efficiency), as for the other two performance dimensions, there was additional improvement scope from the model (17% and 23%, respectively). Such findings indicate that other teams with the same $NPD_{proficiency}$ scores were able to achieve higher end results beyond the $NPD_{process}$ effort.

The assessment of two versions of NPD performance, one with observed and the other with optimum levels of input factors, gives the opportunity to compute the ratio between the two efficiency indicators for each output. The *team proficiency gap* TPG_{rk} is calculated for all outputs and it yields an assessment of the gap between.

The overall assessment of the efficiency across the NPD teams is listed in **Table 12**. In the top left quadrant, there are 21 teams listed that were found to be relatively efficient in both the NPD proficiency and performance dimensions. These 21 teams can be considered role models for the remaining teams, and in particular for those teams that were found to be inefficient in both dimensions.

Table 12. Summary results regarding the performance of the 110 new product development teams.

		New Product Development Proficiency	
		Efficient	Inefficient
New Product Development Performance	Efficient	#17 *Businesses*	#9 *Businesses* Mean efficiency $NPD_{proficiency}$ = 75%
	Inefficient	#15 *Businesses* Mean efficiency $NPD_{performance}$ = 82%	#69 *Businesses* Mean efficiency $NPD_{proficiency}$ = 65% Mean efficiency $NPD_{performance}$ = 72%

From the efficiency results obtained, it appears that the two inefficiency dimensions are correlated (Spearman rank correlation coefficient 0.62), which means that NPD teams being inefficient in the processes undertaken to develop the product are more likely to be inefficient in the end result of the product. NPD teams that are partially efficient in one or the other dimension demonstrate scope for partial improvements. Improvements across the NPD proficiency front seem to be more controllable at a company level as a result of internal investments to enhance the new product development process.

5. Conclusions

The study sought to demonstrate the benefits of combining the mainstream methodology with the statistical method of exploring the NPD process regarding the antecedents of NPD success with the optimisation models of DEA. The analysis, despite its complications, has shed light on how such combinations can be achieved, but most importantly, what kind of conclusions can be drawn.

The new product development framework has been tested for its components, which have already been described in the relevant literature. The importance of market scanning and market environment, combined with organisational capabilities, has been tested with verified dimensions also found in previous studies. The process of new product development is a multi-dimensional construct, and the statistical evidence obtained testifies to the distinct stages of new product development. Such multi-stage recognition increases the likelihood of failure since these components are interlinked and, thus, a failure at an early stage may be transferred across the whole project. The concept of new product performance, apart from its qualitative measurement, is clearly differentiated into short-term and long-term perspectives. Indeed, the launch of a new product may have profound effects on the company's corporate image.

The present study is based on a sample of small- and medium-sized enterprises (SMEs) operating in Greece. As such, the findings may not generalize directly to larger firms, different industry sectors, or other national/institutional environments. Greek SMEs have particular resource constraints and market conditions, so we advise caution in applying our results to very different contexts. Future research should test this multi-stage DEA framework using larger, randomly sampled populations and in other countries or industries to establish broader validity.

It is notable however that these kinds of data-rich studies find it difficult to have large data sets across countries and industries.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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