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By

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Abstract

The purpose of this study is to examine how the exploration/exploitation continuum is applied by decision-makers in new product gate decision-making. Specifically, we analyze at gate decision-points how the evaluation of a new product project is affected by the information source exploitation/exploration search behavior of decision-makers. In addition, overexploitation and overexploration in new product development decision-making is investigated through mediating effects of perceived information usefulness and applied performance criteria by decision-makers at gates. To this end a conceptual model of gate decision-making and information sources was developed across five generic stages (idea, concept, design, test, and commercialization). Our data was generated with a participatory agent-based simulation of NPD gate decision-points in the development process. The sample consists of 134 managers from different Scandinavian companies. Data was analyzed using hierarchical regression models across decision criteria dimensions and NPD stages as well as analyzing the combination of selected information sources.

Rather than forwarding one optimal search behavior for the entire NPD process, we find optimal search behavior to be contingent on NPD stage. The simulation demonstrates that decision-makers at gates shift between information source exploitation and information source exploration (punctuated equilibrium). We find that the effect on gate decisions is negative if decision-makers apply a specialized information search behavior at either end of the exploitation/exploration continuum. Additionally, we find that overexploitation and overexploration is caused by managerial bias. This creates managerial misbehavior at gate decision-points of the NPD process.

Introduction

Research has shown an on-going interest for new product development (NPD) gate decision-making. Empirical studies have investigated the ability of various models, techniques and software tools to aid decision-makers in their new product screening (Baker and Albaum, 1986; Rochford, 1991; Calantone, Benedetto and Schmidt, 1999; Ozer, 1999). Other studies have found that gate decision-making is disconnected from in-stage and strategic decision-making levels of NPD (Jespersen, 2008b). Still, research and managerial agreement states that gate decision points are the weakest link of the development process (Cooper, 2008).

Gate decision-points of the new product development process contain three problem solving activities for decision-makers to handle adequately if they wish to ensure effective decision-making for new products in an organization. The three activities are information search, performance criteria judgment, and new product decisions (Krishnan and Ulrich, 2001; McCarthy, et al., 2006; Cooper, 2008; Jespersen, 2008b). In innovation literature there is a high level of descriptive knowledge concerning these elements, but little empirical evidence exists of their interplay at gate decision-points (Hart, et al., 2003). Recent research on performance criteria, against which a new product is judged at gates, was motivated by this (Hart, et al., 2003; Carbomell, Escudero and Aleman, 2004; Antioco, Moenaert and Lindgreen, 2008). This body of empirical studies has identified five performance criteria for NPD gates: technical, financial, strategic, customer and market related criteria. The aim of this paper is to extend this body of research by addressing the role of information search behavior at gate decision-points. Hereby we aim to make clear whether decision-makers are able to manage the dualities of information source exploitation and exploration at NPD gates or whether they are specialized in one of them. This is significant as information source exploitation and exploration give different attention patterns of decision-makers in their NPD gate decision-making (March, 1991; Danneels, 2002; Gupta, Smith and Shalley, 2006; Greve, 2008). In addition, decision-makers' search processes for information (exploitation or exploration) may either be a rigidity or capability in the NPD process (Leonard-Barton, 1992; Atuahene-Gima, 2005). Information source exploitation is defined in our study as a local/internal search for information. Information source exploration is defined as a distant/external search for information in the NPD process (March, 1991; Wang and Li, 2008).

Internal information sources applied for the generation of information in the NPD process are for example company databases (e.g. sales forecasts, complaints records, production analyses), company experts (e.g. sales, engineering, production, customer support), literature (e.g. trade magazines, technological updates) and/or secondary information (e.g. previous market analyses, previous product tests, new product project records) (Aguilar, 1967; Hart, Tzokas and Saren, 1999a; Crawford and Di Benedetto, 2008). External information sources for NPD activities have traditionally been limited to conventional information sources such as surveys, experiments, focus groups, interviews, product tests and cultural probes. However, technological progress has created a new set of information sources for NPD activities (see (Dahan and Hauser, 2002; Jespersen, 2008a; Jespersen and Buck, 2009). Many of these information sources incorporate information and communication technology (ICT) tools such as 3D technology, Web 2.0 applications, simulations, on-line communities and mobile phone technology. These information sources let insights evolve from subject interaction in an NPD activity. Movements in market and technology can more readily be detected when the degrees of freedom are not predetermined as is the case with conventional information methods (Danneels, 2004; Garcia, 2005; Henderson, 2006).

On the exploitation/exploration continuum this leads to a differentiation of three groups of information sources applicable to the NPD process. Pure exploitation is the selection of internal information sources, whereas pure exploration is the use of ICT incorporated information sources. Conventional information sources can be viewed as both exploitation and exploration. Though conventional information sources remain external, they have to a large extent become part of companies search routines (Barczak, Griffin and Kahn, 2009). The information space generated with conventional information sources is not unfamiliar to decision-makers (Katila and Ahuja, 2002).

The purpose of this study is to examine how the exploration/exploitation continuum is applied by decision-makers in new product gate decision-making. Specifically, we analyze at gate decision-points how the evaluation of a new product project is affected by the information source exploitation/exploration search behavior of decision-makers. In addition, overexploitation and overexploration in new product development decision-making is investigated through mediating effects of perceived information usefulness and applied performance criteria by decision-makers at gates. To this end a conceptual model of gate decision-making and information sources was developed across five generic stages (idea, concept, design, test, and commercialization) (figure 1). Our data was generated with a participatory agent-based simulation. The simulation of NPD gates was chosen so as to maintain focus on the decision-making behavior at gates rather than on a description of gate content throughout the NPD process. The investigated NPD process simulates the development of a new, consumer product with a high level of innovativeness. Product technology is new to the industry, and the added functionalities through the technology are new on the market, but the core concept of the product is known.

This study contributes to the existing literature in three ways. First, most NPD gate studies are focused on models and techniques that aid decision-makers in their decision-making. Our study presents an empirical investigation of gate decision-making through analysis of the interplay between information search, performance criteria judgment and decision outcomes across five NPD stages. Hereby it extends our knowledge base of this troubled part of the NPD process. Second, research in the area has led to ‘best practices’ of the NPD process. Yet, when reviewing a new-product project, knowledge is lacking with regard to the use of in-stage generated information. The present study addresses this gap through analysis of decision-maker information search behavior at gates. To our knowledge, the combined effect of information sources (NPD activities) on new product decisions have not been analyzed in previous studies. Third, the present study takes a micro level focus on exploitation and exploration. Single domains studies exploration and exploitation are scarce (Gupta, Smith and Shalley, 2006). To our knowledge, no study has investigated information source exploitation/exploration by decision-makers and the effects of these on their NPD gate decisions. Through this study we hope to fill a part of this gap in extant knowledge.

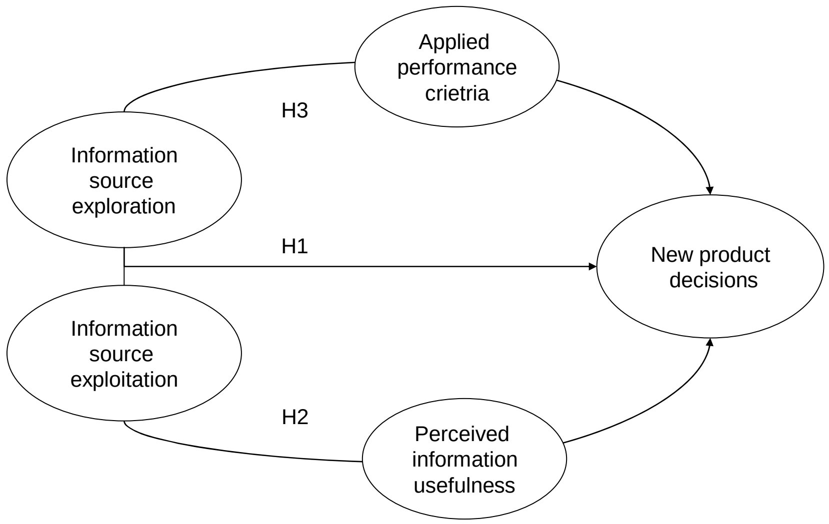
The paper is organized as follows. First, literature is reviewed and the hypotheses are developed. Thereafter follows a description of the participatory simulation, sample characteristics and variable measurement. After a presentation of results, these are discussed and conclusions are given along with managerial implications.

Literature review and hypothesis development

This paper takes its point of departure in the attention of decision-makers as this is central in decision-making processes (Cohen and Levinthal, 1990; Cho and Hambrick, 2006; Levinthal and Rerup, 2006; Todorava and Durisin, 2007; Yadav, Prabhu and Chandy, 2007). Our general proposition is that information source exploitation and information source exploration are distinct dimensions of information search within the NPD process. The choice to pursue one of these dimensions or to balance them has affects on a decision-maker’s new product decisions at gates. In the following hypotheses, information source exploitation is defined as the collection of information from internal sources and/or a combination of internal and conventional sources. Information source exploitation is defined as the collection of information from ICT incorporated sources and/or a combination of ICT incorporated and conventional sources. Balanced information generation is defined as the collection of information from a combination of internal and ICT incorporated sources or the collection of information from conventional sources only.

Figure 1 depicts the conceptual model analyzed in this paper. The model contains the direct link of information source exploitation and exploration on new product decisions. It also shows two indirect links of exploitation and exploration through perceived information usefulness and/or applied performance criteria. These indirect links signify overexploitation and overexploration at gates by decision-makers. The hypotheses in the model for both direct and indirect effects on new product decisions are developed in the following.

Figure 1. Conceptual model



Information source exploitation/exploration and new product decisions

Since their formal introduction by March (1991), exploitation and exploration have been and are still widely discussed in research. The discussion in new product development and innovation management literature has focused on the benefits of exploration. Studies of market orientation and new product performance have provided sound empirical evidence of the positive link between market orientation and new product performance as well as product innovativeness (Atuahene-Gima, 1996; Hurley and Hult, 1998; Lukas and Ferrell, 2000; Narver, Slater and MacLachlan, 2000; Baker and Sinkula, 2002). Information processing researchers have provided insights on the challenges organizations face when obtaining actual market information use (Ottum and Moore, 1997; Hart, Tzokas and Saren, 1999b; Raju and Roy, 2000; Veldhuizen, Hultink and Griffin, 2006). The capability view of new product innovation states that exploration is a needed capability if new products are to act as vehicles of learning in organizations (Danneels, 2002). Yet research also finds that too much exploration can damage new product development (Ahn, Lee and Lee, 2006; Wang and Li, 2008). Exploration may enhance the number of new product, but explorative knowledge is also difficult to use due to its more heterogeneous elements (Luca and Atuahene-Gima, 2007). Though the knowledge pool is enriched, exploration demands a highly developed information capability to respond correctly to new information (Danneels, 2002; Katila and Ahuja, 2002).

This progression of insights on exploration and new product development has changed the view on exploitation. The initial view as a short sighted approach to knowledge, learning and innovation is replaced by a necessary partner facilitating exploration (Katila and Ahuja, 2002; Gupta, Smith and Shalley, 2006). Exploiting information sources in the NPD process limits the ability to be innovative. The information window applied for new product development is narrowly defined (Leonard-Barton, 1992; Levinthal, 1997). Yet information source exploitation also builds capabilities. Sound exploitation is a necessary condition for exploration to be successful (Danneels, 2002). Through use and reuse of information sources, decision-makers become more capable of understanding information from theses sources. They also become better equipped to transform their information input into relevant knowledge for new product development (Zahra and George, 2002). To a certain degree, exploitation can therefore benefit new product development (Gupta, Smith and Shalley, 2006; Wang and Li, 2008).

Exploration and exploitation have been defined as orthogonal or two ends of a continuum. Originally, the combination of exploitation and exploration was forwarded as the most beneficial approach (March 1991). Recent research has returned to this focus and theorizes that a balance of exploitation and exploration is most productive for NPD. These studies argue that the important issue is the type and amount of learning rather than the presence or absence of learning (Gupta, Smith and Shalley, 2006; Wang and Li, 2008). Information source exploration gives new information to the NPD process, and information source exploitation facilitates the absorption of new information at decision points in the NPD process, i.e., NPD gates. Balancing information source exploitation and exploration should create an information space more prone to opportunities with new products than an information space build solely on either information source exploitation or exploration. The combination of exploration and exploitation is more likely to generate innovative outcomes. (Katila and Ahuja, 2002). This leaves two competing hypotheses for effective new product decision-making at gates in the development process.

Hypothesis 1a: Explorative information sources have a positive influence on decision-makers' go-decisions at gates in the NPD process relative to exploitative information sources.

Hypothesis 1b: A combination of information source exploration and exploitation has a positive influence on decision-makers' go-decisions at gates in the NPD process relative to a specialization in either exploitation or exploration.

Overexploration/overexploitaiton at NPD gates

The above NPD literature holds the premises that new product performance hurts from too much exploitation or exploration (March, 1991; Gupta, Smith and Shalley, 2006). Overexploitation (overexploration) is defined as internal (external) information source domination in gate decision-making and represents deviations from optimal search behavior. Overexploitation and overexploration can be caused by either managerial bias or managerial misbehavior (Wang and Li, 2008). Managerial bias at gate decision-points that pertains to information search and would create a deviation has been conceptualized in literature as perceived information usefulness (Wilton and Myers, 1986; Menon and Varadarajan, 1992). Information usefulness has to be high for decision-makers to rely on information from a given information source (Arnold, et al., 2004). Managerial misbehavior at gates stems from an agency conflict of the applied performance criteria and information search (Ahn, Lee and Lee, 2006). New product decisions are contingent on the applied performance criteria in the new product development process (Hart, et al., 2003; Greve, 2008).

Perceived information usefulness

Information usefulness is contingent upon information summarization, information homogeneity and information source familiarity (Arnold, et al., 2004; Luca and Atuahene-Gima, 2007). Information sources may be classified according to information summarization and homogeneity (Aguilar, 1967; Ross and Robertson, 1990; Ashill and Jobber, 1999). Information summarization refers to the aggregation of information delivered to a decision-maker as input to decision-making (Ashill and Jobber, 1999). The level of summarization depends on the information sources used for the execution of NPD activities (Aguilar, 1967; Ross and Robertson, 1990; Hart, Tzokas and Saren, 1999a). According to this classification framework, internal information sources provide information input with a high level of summarization. At the other end, ICT incorporated information sources provide very detailed information input to new product decisions. The more summarized the information is, the more homogeneous are the elements given by an information source. When information heterogeneity increases, its employment to NPD gate decision-making becomes more difficult (Kaplan, Reneau and Whitecotton, 2001; Luca and Atuahene-Gima, 2007). This leads the decision-maker to rely on highly summarized information. According to Leonard-Barton, decision-makers are trapped by their familiarity with aggregated information input and therefore less sensitive to detailed input from other information sources (Leonard-Barton, 1992). This argument is supported by research which investigates the ability of decision-makers to integrate various information sources into the NPD process. Decision-makers find it difficult to act on collected information (Zahay, Griffin and Fredericks, 2004; Haas and Hansen, 2005). Furthermore, research posits that information input from information sources which are familiar to the decision-makers will exert influence on decision-making irrespective of the range of selected information sources (Menon and Varadarajan, 1992; Arnold, et al., 2004; Luca and Atuahene-Gima, 2007). Based on this, a managerial bias toward information source exploitation can be expected for new product decisions at gates in the development process.

Hypothesis 2: Overexploitation will more likely take place at NPD gates due to higher perceived information usefulness from internal and conventional sources by decision-makers relative to ICT incorporated sources.

The applied performance criteria

Information source exploitation/exploration depends on the priority given to the five performance criteria by decision-makers (Danneels, 2002; Ahn, Lee and Lee, 2006). Empirical studies have proven the existence of five overall performance criteria against which new products are judged at gates in the new product development process. These dimensions are technical, financial, strategic, customer and market-related criteria (Tidd and Bodley, 2002; Hart, et al., 2003; Carbomell, Escudero and Aleman, 2004). Technical and financial related performance criteria utilizes decision-makers' knowledge base from internal information sources (Ahn, Lee and Lee, 2006; Greve, 2008). Strategic performance criteria also favour the selection of internal information sources as this behavior emphasizes leverage of current strategy (atuahenme-gima capability/rigidity). The external orientation of customer and/or market criteria builds on market orientation theory (Hart, et al., 2003; Atuahene-Gima, 2005). Research on market orientation and innovation builds on the premises that market orientation increases the generation, dissemination and use of external information sources to gain insights on market and customers (Narver and Slater, 1990; Kohli and Jaworski, 1993). At new product gates this represents a potential conflict as managers, depending on the priority given to the performance criteria dimensions, can misbehave in terms of information search. An orientation toward technical, financial and strategic performance criteria would lead to information source overexploitation. Opposite information source overexploration can stem from an increased weight given to customer and market criteria.

Hypothesis 3a: Overexploitation will more likely take place at gates due to higher priority given to technical, financial and strategic performance criteria by decision-makers in their new product decisions.

Hypothesis 3b: Overexploration will more likely take place at gates due to higher priority given to customer and market performance criteria by decision-makers in their new product decisions.

Methodology

Innovation management literature argues that NPD knowledge can benefit positively from studies applying agent-based simulations (Bhuiyan, Gewin and Thomson, 2004; Garcia, 2005; Ma and Nakamori, 2005). The present research findings are based on a participatory agent-based simulation (ABS). Though participatory ABS has become closely tied to experimental economics, the methodology is broader in a significant way, it can be used to model non-economic aspects of agent behavior (Jespersen, 2006; North and Macal, 2007). Participatory ABS was chosen because it is simpler than agent-based simulation and can provide more clear results of complex situations like NPD gate decision-making. It is a methodology building on the synergy of human actors and artificial agents. Participatory ABS employs people to play the role of agents (North and Macal, 2007).

The design and use of a participatory ABS make it possible to model NPD gates as described by NPD research. In the model, artificial agents act as NPD activities, NPD team members, CEO and board of directors. With the participatory ABS research, focus could shift from defining NPD gates to analysis of micro rules employed by NPD managers for each element of the NPD gate decision-making system (deliverables, decision criteria and go-decisions) across NPD stages.

Data collection process

The simulation was made available to NPD managers through invitation. Placed on the Web, it was accessible at all times from any location[1]. Before entering the simulation part of the data collection process, participants filled in a questionnaire with measures of individual characteristics, measures of NPD (Siguaw, Simpson and Enz, 2006; Salomo, Talke and Strecker, 2008) and information processing (Kasdan, Rose and Fincham, 2004; Atuahene-Gima, 2005).

The aim of the simulation was to have NPD practitioners go through the interactive process of collecting information input from NPD activities, distributing decision criteria weights and evaluating a new product's potential from idea to launch.

The basic structure of the simulation was as follows. The NPD practitioners were asked to initiate NPD activities (see table 2) for the purpose of evaluating a new-product project as it evolved through the NPD process. They were to collect information within the frame of a

[1] Simulation homepage: www.pandan.dk. Contact the author for log-in code. The simulation is in Danish, but the concept and the structure can be understood regardless.

budget. At each stage NPD practitioners were given a short description of the latest progress followed by a list of NPD activities for that specific stage. Participants rated these and decided which NPD activities to perform. A list of the selected NPD activities then appeared, and the participants accessed the information input from each. Based on their newly gathered information, participants were asked to distribute weights to decision criteria and evaluate the new-product project for its potential (go-decisions). The simulation was concluded with the decision of whether to launch the new product or not. For a full account of the data collection process consult (Jespersen, 2006).

Sample

The sample consisted of large international companies whose NPD units were located in Denmark. The sample was drawn from the national register of business in Denmark. Targeted industries included food, textile, electronics, machinery, wood, and information technology. The selection criteria of the targeted companies were reasonable size, consumer products and NPD in Denmark. Participants were invited to participate because they were their companys' NPD gate keepers. They were identified through organizational charts and company interviews. Data was collected in the fall of 2007. All potential participants were pre-notified and then sent a personal log-in code to the simulation home-page. Preliminary notification by phone was used to solicit cooperation, check the relevance of the study for the identified person, and increase the number of participants. Of 600 contacted NPD managers 189 participated and of these 131 finished the whole simulation. As an incentive and a way to indicate the relevance of the study to participants, these were asked to indicate whether they wanted to receive a report of the preliminary research findings from the simulation. Over 96% did.

To evaluate the extent of possible bias, the participants were tested across groups for differences in their behavior caused by industry, functional background (e.g marketing, engineering, IT, R&D), and early vs. late participation. No significant differences emerged from these tests. This suggests that these biases were not an issue in the simulation. The sample characteristics are displayed in table 1.

Table 1: Sample characteristics

Decision-maker background (%)		Industry (%)	
Engineering	25.58	Food	22.3
Sales/marketing	21.70	Textile	7.1
IT	11.63	Electronics	16.3
Economics	20.16	Machinery	9.6
Communication	4.65	Wood	13.9
Design	8.53	Information technology	26.2
Other	7.75	Other	4.6
Sum	100	Sum	100

Simulation validity

Despite the many benefits derived from the designed participatory ABS, respondents nonetheless enter a constructed and simplified reality. This constrains the analysis results and introduces the risk that nothing but the behavior in the simulation in question is explained. To counter this, the external validity of the virtual NPD process was addressed *explicitly*. Particular efforts were made to prevent information items from obscuring the participants' decision-making.

The price (resources/cost) of each information item was based on details given in interviews with market research companies in Denmark. We also took into account the genuine comprehension that explorative activities are more resource demanding than exploitative activities (March, 1991). The match between importance of an information item and its average acquisition percentage shows no outliers to demonstrate a price effect on the importance/buy relationship in the simulation.

The collection of information input was tested for front-end and back-end imbalance. These tests were not significant which means that participants were not found to collect significantly more information input at the front-end. Neither did the tests show that participants collected significantly more information at the back-end in order to use their given budget.

The appropriateness of decision criteria dimensions was cross-analyzed with data from the introductory questionnaire in which the participants were asked to rank 10 different decision criteria (Carbomell, Escudero and Aleman, 2004). This pre-ranking of decision criteria gave a top five that matched the five generic dimensions from previous research. Thereby the appropriateness of the chosen criteria in the simulation was confirmed.

Variable measurement

As the participants entered the simulation and began the development of the new product in the simulation, the NPD gate decision-making was measured for each of the five generic stages in the simulated NPD process (idea, concept, design, test, launch). Hence each variable was measured at five different gates.

In each stage, six NPD activities were available, from which the participant could chose to perform and collect information input. The six information sources were distributed evenly among internal, conventional and ICT incorporated types of information sources (table 2). All 30 NPD activities were drawn from research of NPD best Practices (Cooper, Edgett and Kleinschmidt, 2004c, b, a; Crawford and Di Benedetto, 2008). The collection of information input to NPD gate-decision-making from an information source (NPD activity) or from a pair of information sources was measured as a binary variable (not-collected/ collected).

Table 2: Information source descriptives from the simulation

NPD Stage	Information sources: Internal		Conventional		ICT incorporated	
Idea	1: Opinion of sales force	.371*	2: Idea screening focus group	.636	3: Comments from user community	.530
	4: Engineering evaluation	.512	5: Study from Department of Future Studies	.667	6: Idea screening in Second Life	.508
Concept	1: Comments from the development team	.629	2: Focus group on the concept	.606	3: Lead user and expert input on the concept	.364
	4: Economic calculation	.568	5: Patent investigation	.712	6: Lead user and technology expert on the concept	.636
Design	1: Update from chief of sales	.644	2: Technical prototype test	.447	3: Prototype test in second life	.955
	4: Distribution up-date	.220	5: Market prototype test	.644	6: RFID tagging analysis	.280
Test	1: Production control	.682	2: Survey of buying intentions	.705	3: Product test of functional limits	.576
	4: Technology evaluation	.576	5: Price analysis in market	.735	6: Simulating product use at users	.689
Launch	1: Sales prognostics	.720	2: Focus group test of adds and packaging	.773	3: Communities on potential Internet sales output.	.492
	4: Distribution channel overview	.727	5: Expert interview	.621	6: Testing RFID communication	.348

* Each number indicates the selection percentage of each information input from the information sources in the simulation.

The perceived usefulness of information sources and their input to new product decision-making at gates was measured on a five-point Likert smiley scale (1 = very unhappy; 5 = very happy). On this scale participants rated their overall satisfaction (perceived usefulness) with inputs from all their selected information sources in a given stage of the simulation.

The performance criteria in the simulation followed the five dimensions identified by research: technical, strategic, customer related, financial, market. Each dimension was exemplified with criteria in accordance with the literature on the topic (Hart, et al., 2003; Carbomell, Escudero and Aleman, 2004), e.g., the customer related decision criteria were customer satisfaction and product quality. For each of the gates in the simulation, participants were asked to allocate 100 points among the five dimensions according to their relative importance for the go-decision (Carbomell, Escudero and Aleman, 2004).

New product decisions were measured using a two-dimensional construct of product evaluation and likelihood of continuance (go/no-go) of the project. After the distribution of decision criteria weights, the participants were asked to evaluate the potential success of the new product on a scale from 0 to 100. Afterwards, they were asked whether they would recommend go or no-go (binary variables). Tests of the correlation between evaluation and go were significant (range of r = [0.505;0.655]) showing that the evaluation of product potential can act as proxy for new product decisions in the simulation.

Analyses and results

In this section the analyses of data from the participatory simulation is presented and the formulated hypotheses tested. The indirect and direct effects of information source exploitation/exploration at NPD gates are analyzed using hierarchical regression models that capture the proposed relations of the hypotheses. One set of the regression models held performance criteria weights or perceived information usefulness as the dependent variable and information sources and pairs of information sources as independent variables. As five dimensions are simulated for each of the five stages, the analysis of performance criteria amounted to 25 different regression models. For perceived usefulness, the number of regression models is five which corresponds to the number of NPD stages in the simulation. The other set of regression models held go-decisions as the dependent variable and information sources, perceived information usefulness, and applied performance criteria weights as the independent variables.

Table 3, 4 and the appendix show the regression results. Both the individual information sources and information source pairs have been analyzed for their influence on new product decision-making. The listed numbers for information sources corresponds to the numbers in table 2. In each regression table, model 1 contains the main effect of information sources. Model 2 investigates the effect of information source pairs and model 3 shows the full regression model of information sources. The hierarchical models demonstrate the gains from analyzing the effect of pairs of information sources on new product decisions.

The section consists of three parts in accordance with the conceptual model in figure 1. First, the information source exploitation/exploration in relation to new product decisions is evaluated. Then focus is turned to the phenomena of overexploitation caused by managerial bias. Finally, an evaluation is presented of whether overexploitation/overexploration pertains to applied performance criteria at gates.

Table 3. Regression coefficients for new product evaluations at gate decision-points

		New product evaluations														
		Idea			Concept			Design			Test			Launch		
Information source		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Exploi-tation	1	-1,843		-5,415	5,161		1,657	8,692*		6,920	11,463*		9,659	2,296		-8,037
	4	2,377		-7,892	,675		20,795	-7,259		-10,792	-		33,116**	12,212**		7,459
Balance	2	3,014		-5,892	-1,343		-27,203	4,419		-	-		-18,432	9,867^{a}		-2,677
	5	-,952		-17,843	5,805		-16,806	-3,676		12,457	-		-17,301	-6,050		-30,875^{a}
Explo-ration	3	5,566		-,828	-2,324		-7,980	-11,156		-18,065	-		-11,207	-4,022		15,579
	6	1,935		-11,805	-6,002		-26,810	5,653		,701	-		-10,697	-3,044		-16,963
Pairs of information sources																
Exploi-tation	1_2		2,397	2,862		10,936	16,200		1,937	-4,172		-	-6,026		3,017	5,343
	1_4		,934	2,141		2,048	-11,408		-3,570	-3,980		10,383	-		9,268	5,804
	1_5		9,300	16,355		-6,108	-5,236		6,866	1,452		5,575	7,874		-2,087	12,420
	2_4		9,406	11,983		-2,276	-5,089		16,251	15,733		7,444	-		,637	-4,207
	4_5		,071	6,606		3,897	-6,799		-4,550	-4,333		-18,379**	-27,132*		-,789	5,354
Balance	1_3		-7,895	-9,043		5,083	4,401		-2,485	-		-	-		-9,417	-11,747
	1_6		-12,111	-12,803		-1,601	1,548		17,113^{a}	10,630		-	-		-1,413	2,573
	2_5		-3,147	1,360		9,098	25,346*		-5,130	-8,265		12,980^{a}	27,697*		8,810	20,030^{a}
	3_4		-6,404	-8,088		5,744	3,931		-,849	10,969		-	-		9,745	3,025
	4_6		,333	3,884		-10,575	-11,167		-14,723	-15,262		-	-16,546		-6,992	-10,558
Explo-ration	2_3		9,663	9,555		-18,846*	-15,089		8,467	15,621		-8,370	-		-9,101	-20,357^{a}
	2_6		-8,138	-5,356		-4,091	12,564		-20,326^{a}	-20,646^{a}		-10,639^{a}	-		16,916^{a}	26,466*
	3_5		-2,046	1,269		-2,493	2,044		-3,705	-10,697		-	-		-,733	,533
	3_6		15,153*	15,830^{a}		5,631	14,818		2,347	6,742		9,070	16,094		8,636	8,053
	5_6		6,180	16,472^{a}		5,324	17,238		2,769	2,633		-	10,392		-21,897**	-9,355
Information usefulness		7,309**	7,175**	7,360**	8,858**	8,658**	9,453**	4,368^{a}	3,372	4,022	8,467*	8,016*	8,134*	10,246**	11,228**	12,269**
Decision criteria																
Technical		-	,384	,327	,518*	,325	,490*	-	-	-	2,010	1,708	,053	-	-	-
Financial		-,250	,084	,005	-	-	-	-,644**	-,692**	-,690**	2,067	1,688	-	-,028	-,030	-,088
Strategic		-,239	,103	,148	,417^{a}	,281	,332	-,071	,075	,050	2,094	1,725	,189	-,014	,031	-,003
Customer		-,302	-	-	,765**	,591*	,599*	-,182	-,244	-,228	1,975	1,577	-	-1,55	-,061	-,116
Market		,569*	,895**	,887**	,800**	,740**	,720**	,403^{a}	,465^{a}	,450^{a}	2,201	1,798	,167	,294	,337^{a}	,240
R^2		,240	,319	,337	,263	,314	,366	,252	,292	,308	,108	,182	,211	,261	,323	,370

Sig. (2-tailed) $^{**}p < 0,01$ $^{*}p < 0,05$ $^{a}p < 0,10$

Table 4. Regression coefficients for perceived information usefulness

		Information usefulness														
		Idea			Concept			Design			Test			Launch		
Information source		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Exploitation	1	-		-,141	-		-,550[a]	-		-	-		-	-,049		-,461
	4	-		,007	-		,380[a]	-		1,516	,172		,598**	,251[a]		,715
Balance	2	,382*		-,808[a]	-		-	-		-,175	,060		-	,439**		-,321
	5	,090		1,146*	-		-,763*	-		-2,156[a]	-,246*		-	,035		,166
Exploration	3	-		,346	-		,979*	-		,257	-		,246	,058		-,090
	6	-,177		-1,032*	-		-	-		-	-		-	-,181		,262
Pairs of information sources																
Exploitation	1_2		,463[a]	,710[a]		-	-		-,487[a]	-,390		-,238[a]	-		,449*	,975**
	1_4		,551[a]	,583[a]		-	-		-	-,375		-	-		-,095	-,286
	1_5		-,437[a]	-,699[a]		-	,496		,160	,491*		-	-		-,265	-,173
	2_4		-	,433		-	-		-	-,141		,279*	-		,080	-,173
	4_5		-,122	-,668[a]		-	-		-	-		-	-,334*		,273	,000
Balance	1_3		-,309	-,142		-	-		,191	-		-	-		-,753**	-,547*
	1_6		-	,153		-	-		,439[a]	,436		,235[a]	-		,266	,252
	2_5		,397	,245		-	-		,351	,665*		-	-		-,042	-,045
	3_4		,255	,028		-	-,429		,266	-,911		-	-,352		-,314	-,481[a]
	4_6		-,375	,015		-	-		-	-,112		-	-		,354	,131
Exploration	2_3		-,147	-,018		-	-		,417	,358		-	-		,689**	,798**
	2_6		,207	,847*		-	-		-,211	-,220		-	-		-,850**	-,906**
	3_5		-,143	-,762*		-	-		-,239	1,530		-	-		,204	,139
	3_6		,270	,586[a]		-	-,884*		-	-		-	-		,452[a]	,529*
	5_6		-,210	-,210		-	,552**		-	,096		-,271*	-,065		-,176	-,214
R^2		,065	,171	,278	-	-	,118	-	,132	,199	,060	,075	,090	,114	,329	,363

Sig. (2-tailed): ** p < 0,01; * p < 0,05; [a] p < 0,10

Information source exploitation/exploration and new product decisions

The study held two competing hypotheses for information source exploitation/exploration at NPD gate decision-points. Hypothesis 1 concerned whether exploration or a combination of exploitation/exploration has a positive effect on new product decisions. Table 3 presents the regression results from the simulation concerning these hypotheses. Hypotheses 1a and 1b are supported by the results from the simulation at different stages of the development process. Explorative information sources affect positively new product evaluations in the idea phase ($\beta 3\_6$ = 15.153; $\beta 5\_6$ = 16. 472) and at launch ($\beta 2\_6$ = 26.466). Differently, the positive influence on new product evaluations in the concept, design and test stages is created by a balance of information source exploitation/exploration ($\beta 2\_3$/design = 25.346, $\beta 1\_6$/design = 17.113, $\beta 2\_5$/test = 27.697). The partnership of exploration and exploitation is stressed in these stages by negative coefficients by specializations in either end of the continuum on new product decisions ($\beta 2\_5$/concept = -18.846, $\beta 2\_6$/design = -20.646, $\beta 4\_5$/design = -27.132, $\beta 2\_6$/test = -10.639). Rather than forwarding one optimal search behavior for the entire NPD process, we find optimal search behavior to be contingent on NPD stage.

Overexploitation: managerial bias

The study hypothesized that information source overexploitation at gate decision-points could be caused by higher perceived information usefulness of internal sources, i.e., a managerial bias at gates. Table 4 shows the regression results of the information sources in the simulation affecting decision-makers perception of information usefulness. The continuous positive effect of internal information sources through the simulated product development process renders support for hypothesis 2 on overexploitation at gates caused by managerial bias. Managerial bias is a relevant issue at gate decision-points. This is especially so because of the direct high positive effect of perceived information usefulness on new product decisions at all gates (table 3).

Through the five stages of the NPD process, the decision-makers perceive different information sources to be useful. A balance of sources is appreciated at idea ($\beta 2\_6$ = 0.847, $\beta 5$ = 1.146, $\beta 1\_2$ = 0.710, $\beta 1\_4$ 0 0.583, $\beta 3\_6$ = 0.586) and launch stages ($\beta 1\_2$ = 0.975, $\beta 2\_3$ = 0.798, $\beta 3\_6$ = 0.529). Information source exploration is perceived as a more useful input in the concept stage ($\beta 3$ = 0.979, $\beta 5\_6$ = 0.552). Exploitation is satisfying at design ($\beta 1\_5$ = 0.491, $\beta 2\_5$ = 0.665) and test stages ($\beta 4$ = 0.598). These findings depict an information search rhythm in the NPD process that resembles punctuated equilibrium. Punctuated equilibrium is an adaptation mechanism that individuals may adhere to in order to gain a balance of the need for both exploitation and exploration (Gupta, Smith and Shalley, 2006). This will be elaborated on in the discussion.

Overexploitation/overexploration: a conflict of applied performance criteria

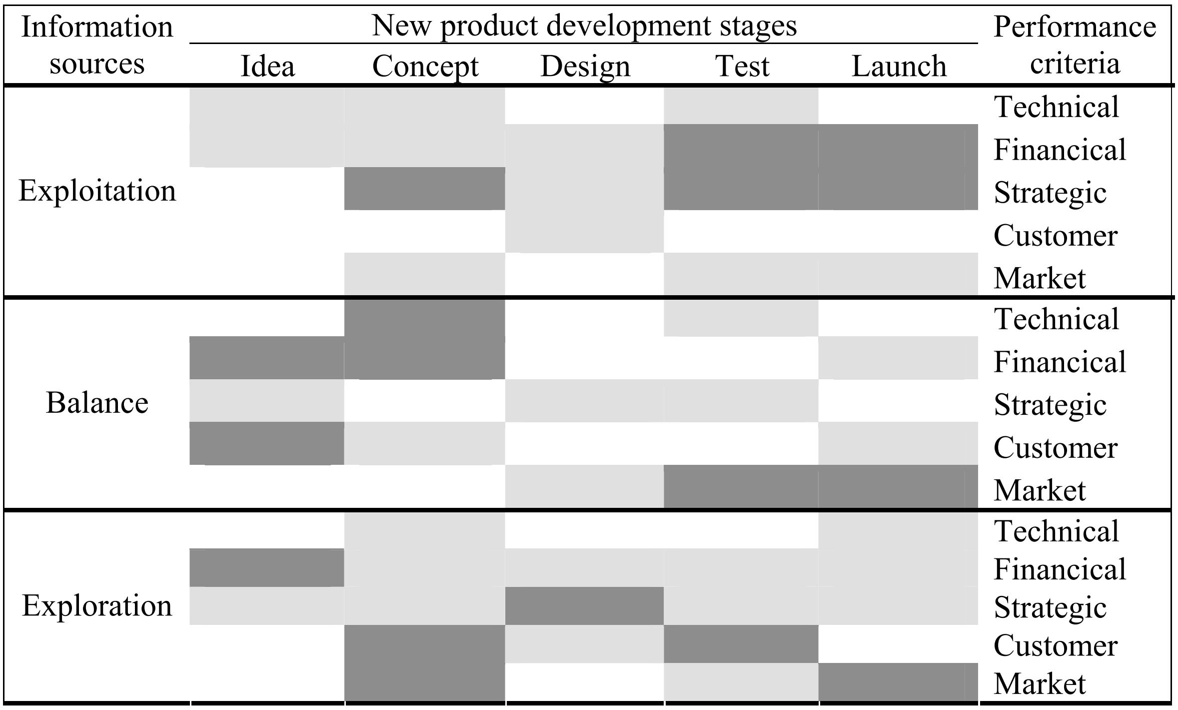
Figure 2 summarizes the results of the 25 regression models of each performance criteria dimension as a function of information search behavior from idea-to-launch in the simulated NPD process. An overview of significant regression coefficients is available in the appendix. The shaded areas of figure 2 represent links between information source exploitation/exploration and performance criteria weights at gates. The light grey areas in figure 2 signify support for the hypothesized relationship between information search behavior and performance criteria. The dark grey areas depict a not-hypothesized relationship. Information source exploitation increases weights on technical, financial and strategic performance dimensions and decreases weights on customer and market criteria if hypothesis

3a is supported. For exploration in hypothesis 3b, weights are increased on customer and market criteria and decreased for technical, financial and strategic criteria.

Interestingly an overweight of information sources from both ends of the exploitation/exploration continuum affects technical, financial and strategic performance criteria (figure 2). As hypothesized, information source exploitation increases weights on technical, financial and strategic criteria while decreasing weights on customer and market performance criteria. Therefore hypothesis 3a is supported by the simulation findings. Differently, figure 2 shows that information source exploration decreases weights on technical, financial and strategic criteria, but does not increase customer and market weights. Information source exploration seems to be used more as moderator of inputs from internal information sources than as generator of external openness at gate decision-points. Though information exploration takes place, hypothesis 3b is not supported.

These findings report an interesting managerial misbehaviour at gate-decision points. Irrespective of search behavior, information is applied to evaluate technical, financial and strategic performance criteria. This is a finding that emphasizes a potential conflict between organizational performance measures and new product performance measures. The simulation findings on the effect of applied performance criteria and new product decisions support this. In table 3, the regression results demonstrate that only market related performance criteria have a continuous positive effect on new product decisions. Information search determines the weight given to technical, financial and strategic performance criteria, but market criteria determine new product decisions at gates. The latter is not new in the literature on new product success factors, but the former is an undisclosed conflict at new product gates.

Figure 2. Summary of significant regression coefficients for applied performance criteria.



Discussion

It is widely agreed upon in NPD literature that NPD gate decisions are essential for new product outcomes of the NPD process. However, there is equal concurrence that NPD gates are the weakest link of NPD processes in companies. Yet research knowledge of NPD gate decision-making is mostly descriptive. Through analysis of information source exploitation and exploration at gates, the present study aimed to fill a part of this gap in extant knowledge. Our analyses of NPD gate decision-making in a participatory agent-based simulation showed that decision-makers information search plays a significant role in decision-making misbehavior at NPD gates.

The first issue emerging from our study pertains to a conflict in NPD literature. NPD research has stressed that organizations are struggling with the implementation of NPD activities (Hauser, Tellis and Griffin, 2006). Parallel with this, best practice studies continue to find information source exploration as a characteristic of high performing companies (Barczak, Griffin and Kahn, 2009). Our finding that optimal search behavior is contingent upon NPD stages provides a possible explanation for this conflict. In the concept, design and test stages, decision-makers use information source exploitation to facilitate information source exploration. Explorative learning builds on a capability to exploit existing learning resources (March, 1991; Danneels, 2002; Katila and Ahuja, 2002). Also in line with previous research (Wang and Li, 2008), we find that the effect on gate decisions is negative if decision-makers apply a specialized information search behavior at either end of the exploitation/exploration continuum. As decision-makers and their organisations design NPD activities according to best practice, the facilitating element of information source exploitation becomes absent in the NPD process. Internal information sources are regarded as building blocks to failure (Von Hippel, 2005; Veldhuizen, Hultink and Griffin, 2006; Luca and Atuahene-Gima, 2007). We agree that this is the case if information source exploitation stands alone, but decision-makers and their organizations will struggle with the implementation of NPD activities if information source exploitation is not considered a viable partner.

A second finding in our study stresses the above point further. As the unit of analysis of NPD decision-making at gates is the individual decision-maker, the viable balancing mechanism of exploitation/exploration is found by research to be punctuated equilibrium (Gupta, Smith and Shalley, 2006). The simulation demonstrates that decision-makers at gates shift between information source exploitation and information source exploration. Though this mechanism is viable, it is in conflict with best practice recommendations and makes organizations struggle with the implementation of NPD activities in the NPD process. As shown in table 4, information source exploitation is appreciated at design and test stages, which illustrates a lacking usefulness of NPD activities such as prototype and product test (information source exploration). One explanation could be the heterogeneity of information from test activities in the NPD process. These are difficult for decision-makers to transform into relevant knowledge (Kaplan, Reneau and Whitecotton, 2001; Todorava and Durisin, 2007). The heterogeneity of information input can lead to the mistaken impression by decision-makers that the NPD process is opened again. This negative cost-benefit analysis of information input like test results leads decision-makers to information source exploitation.

The results here support the notion of overexploitation at NPD gates. This has been predicted by prior research on learning and competency traps (Levinthal, 1997; Ahuja and Lampert, 2001; Henderson, 2006; Todorava and Durisin, 2007) The appearance of overexploitation at gate decision-points hampers the abilities of organizations to improve along a technological trajectory (Danneels, 2004). As decision-makers overexploit information sources, the NPD in companies runs the risk of being a rigidity rather than a capability (Atuahene-Gima, 2005). Decision-makers and their organizations do not perform on the knowledge dimension of new product success factors as overexploitation gives a low learning level (Danneels, 2002). The positive effect of overexploitation on new product decisions found in the simulation stresses the seriousness of the challenges faced by decision-makers and their organizations at gate decision-points.

A third emerging issue from the simulation findings is a conflict of organizational performance criteria and new product performance criteria that results in managerial misbehavior at gates. Market proficiency is a success factor of new products. Market orientation advocates in favor of customer and market performance criteria in NPD. Best practice studies show that explorative information sources foster success (Barczak, Griffin and Kahn, 2009). Yet our findings from the simulated NPD gate decision-points show that internal performance criteria (technical, financial and strategic) state the innovative direction that decision-makers must adhere to in organizations. This, despite the fact that decision-makers know the importance of market performance as these criteria positively affects new product decisions in the simulation. One explanation for the conflict can be that organizations have build up routines for technical, financial and strategic performance criteria that lead to a self-attribution of actions by decision-makers at gates (Greve, 2008). Information source exploitation/exploration is devoted to state pros and cons for these performance criteria which leaves customer and market performance criteria as passive partners at gates. This routinization of innovative direction is a potential entrapment of NPD decision-making at gates (Greve, 2008).

Conclusion and implications

The aim of our study was to investigate decision-markers' abilities to manage the dualities of exploration and exploitation. Our findings lead to the conclusion that NPD gates are affected by decision-makers information source exploitation and exploration. The managerial (mis)behavior is caused by a combination of underdeveloped individual information competences and organizational routinization of internal innovation performance criteria. Insights of NPD gate decision-making also aid the understanding of the troubled NPD activity implementation in companies as reported by research. These results may provide useful guidelines for assessing and improving NPD gates in companies. The present study holds three recommendations for managers in NPD (gate) decision-making.

First, we recommend that managers assess routines for performance criteria application in their NPD process. In this process it is, as suggested earlier, central that knowledge performance is established as an organizational performance measure. Such a reflection would help managers avoid managerial misbehavior at gates and ensure high learning levels as well as high performance levels.

Second, we recommend that decision-makers create more interaction with markets and customers in the NPD gates. This can be accomplished by increasing the experience with ICT-incorporated information sources in NPD. For this to provide positive returns of future NPD, it is important to let information source exploitation facilitate this implementation. Of equal importance is it not to let information source exploitation hamper the information input from these sources.

Third, it was interesting to find that the information capability to transform information input into relevant information for NPD was untrained by decision-makers. Therefore, we recommend that decision-makers include information competence development in their work. This can be accomplished through formal individual education, but should be extended to the organizational level as part of the resource optimization of NPD. Through information competence enhancement, the appreciation of information source exploration would increase in

NPD gate decision-making. This would allow decision-makers to secure the innovativeness of new products and a higher performance on markets as ‘the needs of users’ are transferred into NPD decision-making.

Limitations and further research

This study has contributed new insights on NPD gate decision-making by analyzing decision-makers information source exploitation and exploration across the NPD process. However, as with all research, the study has technical limitations which leave opportunities for further research on NPD decision-making.

First, a participatory agent-based simulation is a constructed and simplified version of reality. This methodology has many advantages when it comes to the exploration of research topics. Yet the inherent limitations of the methodology leave room for further research to build on the presented findings.

Second, the similar findings across environmental uncertainties and product innovativeness also indicate a limitation of this study. It would be natural to expect differences in information search pertaining to the two constructs. We suggest that an analysis of the combination of information sources for different degrees of innovativeness of new products and/or under different environmental conditions may produce additional insights on NPD gate decisions.

Third, information source exploitation and exploration may reflect true managerial attention at NPD gates. A link between absorptive capacity and NPD decision-making can be expected. Research examining this link could give significant contributions to research knowledge of NPD gate decision-making.

However, the overall results of this project increase the current knowledge on NPD decision-making and especially gate decisions. The significance of this is high when considering the crucial position of gates in NPD and their poor execution in many companies (Cooper, 2008).

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Appendix: Regression coefficients for applied performance criteria

*In each column the significant regression coefficients for a decision criteria are presented across the five NPD stages

		Performance criteria dimensions														
		Technical			Financial			Strategic			Customer			Market		
Information source		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Exploi-tation	1			28,457**(4)	3,158[a](1)		-13,821*(1) -18,717*(4) -13,423[a](5)			12,990**(3) -10,308*(5)	-6,480**(3)		-9,892[a](3)			13,656**(5)
	4	5,668**(1) -6,860**(2) -6,981**(5)			14,832**(2)		30,684**(2)	-3,436*(1)						-5,265**(2) 4,341*(3)		-13,098*(5)
Balance	2	-5,166**(1) -4,646**(2) 6,090*(4) -7,273**(5)			5,376*(5)					9,364[a](1)	6,215**(1) 10,884**(2) 3,494[a](3)		8,167[a](5)			-10,968*(4)
	5	5,983**(2) -10,201**(4)			-7,856**(2) 7,780**(4) 3,685[a](5)		-7,582[a](1)	3,173[a](1)		10,970*(1)	-4,645[a](4)			2,996[a](2) 4,149*(4)		-10,844*(5)
Explo-ration	3			17,030*(5)			17,927*(4)			-19,298**(5)	-4,844*(4)		-21,317*(4)			-14,629*(2)
	6	-5,412**(1) 5,273*(2) 8,833**(5)		14,010*(2) 26,498**(5)	-3,246[a](1)			-3,471[a](4)		9,640*(1)	5,463**(1) 4,224[a](4)		-16,837*(2)	-4,707*(5)		-9,019*(5)
Pairs of information sources																
Exploi-tation	1_2					9,600*(3)	7,832[a](1) 10,203**(3) 9,400[a](4)		6,641**(2)	-7,837*(3)		-7,982[a](3) -8,616[a](4)			-6,392*(2)	-11,207*(5)
	1_4			8,346[a](2) -12,020*(4)			9,351[a](4)								5,125[a](3) 4,198[a](4)	5,697[a](3)
	1_5		4,643*(3) 7,710[a](4)				11,384*(1)		-8,215**(2) -6,005*(4) -5,677*(5)	-10,909**(2) -8,399[a](4)		-6,265[a](2)			7,438**(2)	6,749[a](2)
	2_4		-5,711[a](2)				-8,368[a](4)		-3,747[a](1)						-6,873[a](3)	-7,204[a](3) 9,041[a](5)
	4_5			8,836[a](2) 15,466*(4)			-11,318[a](2) -9,144[a](5)			7,713[a](4)		-6,912[a](4) -4,809[a](5)			-6,152*(2)	-10,186*(4) 8,332[a](5)

Balance	1_3			-12,663*(4)								-6,893^a(3)				7,053^a(2) -6,536^a(5)
	1_6		7,968*(2)	-15,930*(4)						-13,900** (3)		-10,670*(5)	-10,368*(5)			
	2_5		-6,251^a(1) -13,333*(4)	-15,547^a(4)		-11,609** (2) 8,651*(5)			8,715*(4)	9,352*(3)		7,406*(2)	-10,549^a(5)		4,358^a(2)	
	3_4		9,007**(1) 9,980*(4)	14,216**(4)		7,746^a(5)				-23,043* (3)		-7,659**(1) -6,764^a(4)	-9,240*(1)			-7,373*(4)
	4_6		-9,959*(2) -9,816^a(4)	-8,134^a(2)		8,952^a(2) - 10,566^a(3) - 10,556^a(5)	-10,637^a(3) -11,511^a(5)			7,278^a(4)			10,728*(5)		12,391** (3)	12,342**(3)
Exploration	2_3			-8,424^a(2) -10,943^a(5)		-8,835*(3)	-8,087*(3)		6,689*(1)	7,493^a(2) -6,301^a(4) 9,858*(5)		10,556** (3)	8,952*(3)		5,014^a(3)	5,745^a(3)
	2_6		9,211^a(4)						-9,411**(2)	-6,525^a(1) -10,148** (2) 8,683^a(3)						
	3_5					8,143**(1) -9,154*(5)	8,799**(1) -11,601*(4) -11,615*(5)		4,236^a(5)	5,996^a(4) 9,610*(5)						
	3_6		4,387^a(3)	-9,279^a(5)			-11,547*(4)		-4,311^a(1)	-7,151*(1)			9,875^a(4)			-5,606^a(4)
	5_6					-5,242*(1) -9,472*(2) 7,002*(4)			6,906**(1) 8,006**(2) -6,505*(4)	9,316** (2) 7,659*(3)					6,458**(4)	4,992^a(4)
R^2 (1)		,243	,261	,296	,075	,146	,203	,079	,135	,218	,151	,215	,238	-	-	-
R^2 (2)		,236	,252	,345	,250	,269	,332	-	,150	,164	,231	,259	,313	,121	,191	,252
R^2 (3)		-	,074	-	-	,171	,191	-	-	,196	,137	,202	,215	,033	,142	,148
R^2 (4)		,159	,299	,368	,097	,204	,286	,051	,203	,218	,104	,213	,267	,061	,145	,188
R^2 (5)		,199	,219	,323	,053	,185	,228	-	,062	,182	-	,106	,130	,033	-	,136

Sig. (2-tailed) $^{**}p < 0,01$ $^{*}p < 0,05$ $^{a}p < 0,10$
NPD stages: (1) = idea, (2) = concept, (3) = design, (4) = test, (5) = launch

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