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Co-selection in R&D Project Portfolio Management: Theory and Evidence

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"If you can look into the seeds of time,

And say which grain will grow and which will not,

Speak then to me…"

Macbeth, Act I Scene III

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Abstract

In the study I analyze the conflicting aspects of project portfolio evolution in a firm. The evolutionary principles of variation, selection and retention are applied to the management of new product development projects. Managers select projects for prioritization. A selection rule is the prioritization rule. In biology, living creatures develop specific features for adaptation as a result of selection rules. However, the selection of specific adaptive features carries along the retention of other, even unforeseen non-adaptive features. Drawing on the evolutionary principles forwarded by Darwin I examine how they manifest in the project portfolio. I define this non-adaptive mechanism as co-selection. By analogy, in portfolio management, if the selection rule for project priority is high revenue and feasibility to global access, other features also survive when the selection rule relating to the prioritization of projects is applied. The evolution of the new product development project portfolio in the case firm displays conflicting trends in the emerging project portfolio over time. Managers pursue prioritization to decrease product development times. But, alas, in the project portfolio the prioritized projects age to a greater degree than non-prioritized projects. Managers prioritize the projects held by the focal business unit more often than those of other business units. However, ultimately the focal business unit has less than a due share of prioritized projects in the portfolio. The results of this study question the applicability of optimizing models in R&D portfolio management in the presence of co-selection. The project portfolio management literature does not provide a mechanism to account for this type of portfolio development. Co-selection provides a mechanism that explains the observed evolution. The study contributes to the conceptualization of the notion of co-selection. The study also provides empirical evidence on co-selection, a non-adaptive evolutionary mechanism to modify R&D project portfolio outcome. The findings give a better understanding of portfolio management of R&D driven new product development projects.

Keywords: Co-selection, evolutionary theory, selection mechanism, project portfolio management, R&D projects

Abstract in Finnish

Tutkimuksessa analysoin kohdeyrityksen projektisalkun evoluutiota. Evoluutio kuvataan käsitteillä variaatio, valintasääntö ja kertautuminen. Sovellan tätä periaatetta tuotekehitysprojektien johtamiseen. Valinnan mekanismina toimii priorisointisääntö. Biologian piirissä elävät olennot mukautuvat valintasääntöjen seurauksena. Mukautumista auttavien piirteiden ohella valikoituu toisia, jopa ennakoimattomia, mukautumisesta riippumattomia piirteitä. Sovellan Darwinin esiintuomia evoluution periaatteita selittämään vastaavanlaisia havaintojani projektisalkun kehityksessä. Kutsun tätä ilmiötä rinnakkaisvalikoitumiseksi. Näin voi käydä myös tuotekehityssalkun hallinnassa. Jos valintasääntö projektia priorisoitaessa on korkea myyntiodotus ja globaali markkinoitavuus, muitakin projektin piirteitä säilyy rinnakkaisvalikoitumisen vuoksi. Tutkittavassa yrityksessä sattui, että tuotekehityksen projektisalkun sisältö muuttui ristiriitaisella tavalla. Johto priorisoi projekteja, koska haluttiin lyhentää tuotekehitysaikoja. Silti tuotekehityssalkun priorisoidut projektit ikääntyivät enemmän kuin muut projektit. Johto panosti yrityksen keskeiseen liiketoimintayksikköön ja priorisoi siinä useampia projekteja kuin muissa yksiköissä. Mutta keskeiselle liiketoimintayksikölle ei kuitenkaan karttunut eniten priorisoituja projekteja tuotekehityssalkkuun. Tutkimustulokseni kyseenalaistaa optimointimallien soveltuvuutta tuotekehitysprojektisalkun hallintaan, kun rinnakkaisvalintaa esiintyy. Projektisalkunhallinnan kirjallisuus ei tunne tapaa selittää näitä muutoksia. Rinnakkaisvalikoitumisen mekanismi selittää havaitun tuotekehityssalkun evoluution. Tutkimukseni määrittelee rinnakkaisvalikoitumisen käsitteen. Esitän kokeellista havaintoja tukemaan rinnakkaisvalinnan käsitettä. Rinnakkaisvalinta muokkaa tuotekehityssalkun sisältöä. Tutkimustulokseni lisäävät ymmärrystä siitä, miten tuotekehityssalkkua tulee johtaa ottaen huomioon rinnakkaisvalikoituminen.

Avainsanat: Rinnakkaisvalikoituminen, evoluutio, valintamekanismi, tuotekehityksen johtaminen, tutkimusprojektit

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Youth brings new variation to life. I dedicate this work to my children and grandchildren.

Espoo, January 29th 2010

Pertti Aaltonen

1. Synopsis

In biology, living creatures develop specific features as a result of selection rules. However, the selection of specific adaptive features brings with it the inheritance of other, even unforeseen non-adaptive features. Darwin's example, from the intentional breeding of domestic animals, is that white blue-eyed cats are deaf. Employing Darwin's example I define this non-adaptive mechanism as co-selection. The retention of white fur and deafness together with the selection rule to obtain blue-eyed cats is an instance of co-selection. Co-selection is caused by internal unalterable dependencies on dominant design in a cat's build-up. People do not pursue the breeding of deaf cats. Blue eyes are selected purposefully but deafness is co-selected. These co-selected traits survive even without intentional human breeding. They are functionally either neutral or harmful to the cat. In short, they are non-adaptive with regard to the selection rule. The fundamental premise of this thesis is that co-selection is as equally valid a concept in business as it is in biology.

From the perspective outlined above, I investigate the impact of top managers on the dynamics of their R&D project portfolio in a global pharmaceutical firm. In particular, I analyze conflicting portfolio dynamics through a theoretical framework that draws on evolution. The evolutionary principles of variation, selection and retention are applied to the portfolio management of intensive new R&D product development projects. During the period of observation, the case firm strongly expanded product development in one focal business unit. The evolution of a portfolio of new product development projects in the case firm displayed trends that would serve as a collision course for the outcomes of the emerging project portfolio over time. Managers increased R&D investment in a focal business unit at the cost of other business units. Managers pursue prioritization to decrease product development times. But, alas, in the project portfolio the prioritized projects become older than other projects. Managers prioritize projects of the focal business unit more often than those of other business units. However, in the end the focal business unit has less than a due share of prioritized projects in the portfolio.

By analogy, in portfolio management, if the selection rule for project priority is high revenue and the potential for global access, these features survive due to the application of the prioritizing projects selection rule. In addition, other project features such as business unit membership are co-selected. The selection rule does not specify business unit as such; once projects fulfill the prioritizing selection rule, projects from other business units, not only from focal business unit are also selected. Prioritizing is a form of vicarious selection, which means that it reflects managerial beliefs, and is internally driven. Although the selection rule for priority is, in the best intentions of the management, adaptive for the firm, the co-selection of other project features is non-adaptive. Co-selection accounts for the accumulation of projects from various business units of different ages into the portfolio if the projects fulfill the prioritization selection rule.

The dominant design in cats causes blue eyes and deafness to go together. By analogy, the dominant design of new product development projects determines the internal within-project dependencies of various project features. For example, the dominant design of new product development projects in pharmaceutical R&D consist of many strictly sequential development phases and a particular business unit membership. The prevalent dominant design accounts for the appearance of co-selection of project features when selection of the priority of projects that follow the selection rule is carried out.

Conducting new product development is uncertain, in the sense defined by Knight (1921). Probability estimates for the technological or commercial success of a single project are not known. Thus, technological failures of some projects that lead to project termination are unforeseen until they materialize as surprises; like the proverbial black swans. Managerial decisions to terminate projects result from external, usually technological causes. In the case firm, prioritized projects in the focal business unit were terminated much more often than in the other business units, although there were cumulatively more prioritized events in the focal business unit. Hence, the prioritized projects of the focal unit did not enrich the portfolio. The combined effect of undetected co-selection and unforeseen termination modified the portfolio dynamics in a path-dependent way so that prioritized projects aged and the focal business unit did not acquire the majority of prioritized projects. The interactions between prioritization decisions and the independent project stage development decisions reinforced the effect of co-selection on project aging.

The study contributes by conceptualizing co-selection in the business context. It provides empirical evidence on co-selection; an important non-adaptive evolutionary mechanism to modify the outcome of a R&D project portfolio. The study extends the research concerning different selection mechanisms in intra-firm environments, which have been little investigated in the previous literature. The results of this research question the applicability of optimizing models in R&D portfolio management and the assumptions behind them because of co-selection and under conditions of true uncertainty. The project portfolio management literature does not provide a mechanism to account for conflicting portfolio development. Co-selection provides a mechanism to explain the peculiar form of evolution that was observed.

The study contributes to a better understanding of portfolio management of new product development projects that is driven by R&D. To compensate the effects of undetected co-selection, when unforeseen terminations are likely to occur, managers should increase variation in the form of new project initiatives. Slack resources should be available to achieve more variation. Further studies of the co-selection mechanism in intra-firm evolutionary studies are encouraged.

2. The problem statement and research question

2.1 R&D project portfolio and top management

Innovations are of major importance for firms to be successful in competing to serve their customers and generate tomorrow's profit. For many firms, intensive investment in R&D effort is a necessary determinant of innovative new product development. Innovation activities are usually organized into projects. According to the results of recent bibliometric studies, the mainstream academic discourse concerning strategy and portfolio management has paid increasing attention to projects (Kwak & Anbari, 2009). Managing new product development projects in a portfolio has received ongoing attention from scholars (Adams, Bessant, & Phelps, 2006; Archer & Ghasemzadeh, 2004; Artto & Dietrich, 2004; Christensen & Bower, 1996; Cooper, Edgett, & Kleinschmidt, 2004; Krishnan & Ulrich, 2001; Milosevic, 2004; Martinsuo & Lehtonen, 2007a; Loch & Kavadias, 2008a).

Top management is important not only for supporting the success of single innovations (Brown & Eisenhardt, 1997; Milosevic, 2004), but also maintaining an innovative multi-project portfolio in the long run (Nobeoka & Cusumano, 1995; Artto & Dietrich, 2004). Building future success through new product development is a significant part of corporate investment strategy and a major managerial challenge (Bower, 1970; van de Ven, 1986; Noda & Bower, 1996; Burgelman, 2002b; Burgelman & Grove, 2007).

In practical business contexts, managers allocate resources for new product development that is driven by R&D by selecting and rejecting projects. Resourcing new product development projects is similar to capital business investment projects, albeit riskier (Bower, 1970). Portfolios of new product development projects consist of different categories of projects or programs depending on the firm or industry, and accordingly these portfolios are managed in different ways (Milosevic, 2004). In project portfolio management all projects are compared against each other in order to select a collection of preferred projects with which to work. Prioritizing projects is the core of project portfolio management. Top managers have to agree which projects are selected for prioritization. The selection of project portfolio by top management occurs during periodic reviews in portfolio committees. In portfolio committee reviews, managers settle a balance between different types of projects, choose to prioritize projects, and initiate and terminate projects (Archer & Ghasemzadeh, 1999, 2004; Cooper, Edgett & Kleinschmidt, 1998; Cooper, Edgett, Kleinschmidt, 2000).

Scholars observe that firms tend to have difficulties in sustaining innovative development (Brown & Eisenhardt, 1997; Burgelman 1994, 2002a; Christensen & Bower, 1996). For example, such difficulties may relate to choosing between an explorative or exploitative strategic orientation (Burgelman & Grove, 2007; Greve, 2007), locking in to aging technologies or markets (Arthur, 1989; Tripsas & Gavetti, 2000), or maintaining speed (Eisenhardt & Tabrizi, 1995), innovative impetus (Dougherty & Hardy, 1996) and firm growth (Baker & Nelson, 2005). Both the objectives and the success factors of new product portfolio management have been described in the portfolio management literature (Cooper et al, 1998). However, empirical evidence from the portfolio management literature suggests that, quite often, firms also have problems succeeding with R&D project portfolio management (Cooper, Edgett & Kleinschmidt, 2001a, 2004; Griffin, 1997; Griffin & Page, 1996).

The academic literature dealing with the strategic selection of investment projects and product development projects has largely focused on models that address optimizing decision outcomes (Schmidt & Freeland, 1992; Cooper, Edgett & Kleinschmidt, 2001b; Archer & Ghasemzadeh, 1999, 2004; Krishnan & Ulrich, 2001; Dean & Sharfman, 1996), with less focus on decision processes (Bower, 1970, Burgelman, 1983ab, 1994; Greve, 2007). Both content and process issues are important when studying innovative development projects (van de Ven, 1986). Studies in decision making have shown that strategic choices are often taken when there are mixed goals and preferences and under conditions of ambiguity (Cohen, March & Olsen, 1972; March, 1994b; Mintzberg, Raisinghani & Théorêt, 1976; Nutt, 2002). Observing decision making reveals that people follow rules rather than optimize (Page, 2008). However, decisions to prioritize projects by optimizing are the focus of studies that examine R&D project portfolio selection (Archer & Ghasemzadeh, 1999; Cooper, Edgett & Kleinschmidt, 2001b). The recommendations of scholars to practitioners are therefore partly based on an incomplete understanding of project portfolio management. In fact, no more than 50 % of firms use any form of portfolio management in implementing corporate strategy to projects (Jamieson & Morris, 2004). This indicates that top managers are uncomfortable with the tools they have at hand. In contrast, firms report that almost every firm uses project management processes.

Senior managers are important actors for determining the outcomes of new product project portfolios. Their actions and the consequences to a R&D project portfolio in the long run should be studied in more detail and from various perspectives. Because top managers give more time and value for current over new business, many portfolio decisions are made with an eye on short term considerations, (Dougherty & Hardy, 1996; Greve, 2008). In this respect exploitation is preferred over exploration. Managers may alter their prior choices and also re-direct the project outside of the strategy and product development processes (Steffens, Martinsuo & Artto, 2007). The portfolio selection literature gives examples of “mandatory” or “sacred cow” projects that are selected in any event (Archer & Ghasemzadeh, 2004). These “under the table” and “pet” projects do not fit any pre-defined portfolio evaluation framework (Loch, 2000; Blichfeldt & Eskerod, 2005; Martinsuo & Lehtonen, 2007a). Decisions to terminate projects depend on advocacy and performance thresholds (Green, Welch & Dehler, 2003). Project champion behavior is a key predictor of project performance (Howell & Shea, 2001).

Top managers’ support is an essential factor affecting the success of new product development projects (Burgelman, 1983b; Brown & Eisenhardt, 1997; Milosevic, 2004); however the influence of these managers on a portfolio has received less attention. Shenhar, Dvir, Levy & Maltz (2001) consider the replicability of project success to be an important criterion for a firm’s future success; however these authors do not address the idea of portfolio success at all. Very few organizations and scholars (Cooke-Davies, 2004) seem to pay attention to continuous portfolio success as opposed to project success. The management of new product development projects at a top executive level is largely an open research problem (Kavadias & Chao, 2008). There is a gap in the academic literature. The way top managers actually influence new product project portfolio in the long run is not thoroughly understood. Ultimately, R&D project portfolio decisions are strategic choices about the investment in innovations. If the goals of portfolio management are recognized but not achieved, it is likely that the day-to-day practical resolutions concerning a portfolio emerge from, and are consequences of, underlying mechanisms yet to be discovered in R&D project portfolio research.

My goal in this work is to study intra-firm selection mechanisms. In this study I consider the way that top managers in a pharmaceutical case firm assign priority to new product development projects driven by R&D as an example of evolutionary selection. In the pharmaceutical industry, new product development is essentially dependent on R&D activity. The outcomes of research efforts become new products from development projects over the course of many years, or even a decade. It is therefore appropriate to regard new product development projects as R&D development projects. The real consequences of prioritization in the case firm in this study turn out to be not quite in line with the expectations based on portfolio optimizing models, which is puzzling. This conflict led me to study the selection process that senior executives apply in portfolio management, and how this process influences the total portfolio of new product development projects. I seek better theoretical understanding of the observed evolution of the total R&D project portfolio in the case firm. I argue that optimizing project portfolio management is not sufficient to explain the real portfolio evolution that was observed. This idea seems plausible in the light of the following ten arguments.

1. Decision models for project portfolio management do not include all the factors which business leaders consider essential or pay attention to in strategic decision making (Bower, 1970; Jamieson & Morris, 2004; March & Shapira, 1987; March, 1994b). Since not all factors are modeled or can be modeled, this introduces ambiguity to decisions.
2. Managers make portfolio decisions to shape strategy jointly in teams where coalitions and power play an important, and sometimes even a dominant, role. In the context of top management teams, uniform rational decision making is constrained by conflicting opinions of goals, means, and preferences (March, 1994b).
3. Projects within a portfolio interact with each other, for instance, through competing for the same resources simultaneously. Thus, not every project obtains resources in a fully optimized way. Some projects are prioritized. For this to happen, executive judgment, including bargaining, is needed.
4. Managerial decisions at different levels may interact. Whereas portfolio prioritization can be changed at will, product development proceeds in a

sequence which cannot usually be rearranged. Hence, prioritizing cannot generally overrule the development sequence.

5. Decision models regard projects as fully decomposable into features, which can be optimized separately and then aggregated to yield a unique project ranking list of project candidates. However, the project development process has both interdependencies and an internal sequential structure with embedded milestone stage decisions. They restrict the optimizing of single features by inducing negative externalities for other features. This makes ordinal optimizing difficult.
6. Any instantaneously "optimal" portfolio needs to be reviewed from time to time by senior management. The impact of decisions about a portfolio made yesterday carries over to today's decisions. The past decision sequence, at least to some extent, creates path dependence affecting subsequent actions. The process of administering a project portfolio generates inertia. When new external or internal signals emerge, the existing administrative momentum influences future action, for example in the form of holding up resource redeployment.
7. Although Chandler (1962) claims that managerial choice of strategy shapes organizational structure, other scholars support the view that organizational structure shapes strategic decision making (Bower, 1970; Burgelman, 1983ab; Fredrickson, 1986). In the light of the empirical literature it is likely that "structure shapes strategy" much of the time (Bower, 2005). Behavior and learning in organizations is based on routines (Levitt & March, 1988). Hence, the way project portfolio management is organized and conducted would matter.
8. The outcomes of decisions may not be those that were intended. The realm of decision making beyond bounded rationality to cope with uncertainty is poorly understood and seldom used to explain managerial action in project portfolio management (Pich, Loch & De Meyer, 2002). Even assuming rational decision making, all combinations of managerial choices to select preferred project attributes are not possible due to the constraints and connections within projects. The unanticipated consequences of decisions can be very subtle and may become visible only after a while.
9. Despite all the planning, the unexpected does occur (Knight, 1921; Keynes, 1937). Environmental changes are sometimes sudden or drastic. Managerial

foresight cannot fully anticipate an uncertain future outcome when initiating or prioritizing projects (Klein & Meckling, 1958). Unforeseen decisions may be inevitable.

10. Top executives do have other ongoing processes and issues to care of, such as securing quarterly and annual financial performance targets. Hence, their attention is often diverted from R&D project portfolio management (Ocasio, 1997).

2.2 Research question

In managing R&D project portfolio, top management does not appear to rely only on decision models (Bower, 1970; Jamieson & Morris, 2004). Moreover, as observed by March & Shapira (1987), in studies of managerial behavior, managers do not associate risk with a fixed numerical probability. And yet, top executives pursue costly and uncertain R&D strategy through managing a project portfolio. This leads one to wonder, what is really going on in the management of portfolio of new product development projects that are driven by R&D. New theoretical approaches are therefore encouraged (Kavadias & Chao, 2008), and to this end I study the evolution of portfolio in one large pharmaceutical firm with intensive research activity. In the evolutionary framework I introduce the construct of co-selection to describe a specific evolutionary mechanism that constrains managerial decision making. The research question is formulated as follows:

How does the co-selection mechanism explain R&D portfolio evolution in the case firm over time?

In particular, four specific questions arise:

1. How are the activities of top managers described as selection mechanisms?
2. Which managerial activities are conducted on R&D projects in the case firm?
3. What is the evolutionary path of the R&D project portfolio in the case firm over time?
4. How do top management activities relating to R&D projects influence project portfolio evolution?

The structure of my thesis is as follows. In the next chapter, chapter 3, by reference to the literature, I formulate the concept of co-selection in the framework of intra-firm R&D portfolio evolution and introduce the theoretical constructs. In chapter 4 I then describe the methodology to make these constructs operational, give detailed information of the case firm and characterize measurable entities. The findings of the study are presented in chapter 5. The discussion of results and the justification for my conjecture on co-selection follow in chapter 6. Finally the implications of the study are presented in chapter 7.

3. Literature review

3.1 Previous studies on intra-organizational evolutionary theory

3.1.1. Evolution: variation and selection

Historically, the term evolution has referred to two very different concepts of change. On the one hand, it refers to a process of teleological development based on a pre-existing and unfolding, known or unknown plan. This notion, dating back to Aristotle, is exemplified, for instance, in the works of Herbert Spencer. Development is a series of necessary improvements to a "better" state in comparison compared to the previous historical state. On the other hand, evolution also refers to a process in a population of entities where the set of current specimens are the descendants of a variety of predecessors, some of which were selected to survive whereas others did not. It includes the idea of development, but not necessarily the idea of improvement to anything "better", beyond sustained persistence. This study uses the term evolution in this latter sense, and is that advocated by Charles Darwin in his theory on variation driven and selection based evolution of a descendant population (Hodgson, 1993).

Examining the literature of the past fifty years about firm evolution, Silva & Teixeira (2009) conclude in their bibliometric analysis that the field of evolutionary research lacks an overarching analytic framework from an intra-firm level to the level of firm populations. It also appears that a population ecology and intra-firm level of analysis do not approach each other. Based on keyword relatedness analysis, Järvinen & Sillanpää (2007) conclude that the connections between evolution and population ecology have declined and the connections between evolution and strategy and evolution and capabilities have increased. The connection between evolution and innovation has persisted over time. According to Nerur, Rasheed & Natarajan (2008), the contributions of evolutionary scholars to the strategic literature since 1980 also divide across different streams rather than constitute a coherent hub. Reviewing the literature of intra-organizational evolution, Warglien (2002) and Galunic & Weeks (2002) observe that much more theoretical than empirical research has been conducted. Although lacking overall consistency, many scholars think that the evolutionary approach will gradually offer a plausible dynamic mainstream theory to compete with classical equilibrium economic theory (Gavetti & Levinthal, 2004; Hodgson, 2007c).

There is confusion between teleological and Darwinian approaches in evolutionary scholarship. The bibliometric analyses of published evolutionary research also call for clear and precise definitions of constructs and measurable entities. This is necessary to better differentiate various meanings embedded in them, and to clarify their usage.

3.1.2. Sources of evolutionary thinking

The central idea in Darwin's (1859) view of evolution is to causally explain change and development in the flora and fauna dwelling in nature, including humankind. For this purpose, the logic of evolution is introduced. The components of evolutionary logic are variation, selection and retention. Evolutionary theory is about the fate of a collection of individuals, not about a single individual. The driving force of biological evolution is a Malthusian abundance of variation in the form of excessive offspring. Specimens of offspring express individual variation. When resource supply is locally limited and the opportunities of finding a better settlement are restricted, not all of the offspring survive to reproduce. Some cope with the circumstances better than others. The circumstances in the environment provide a selection mechanism for survival. The next generation of the surviving offspring tends to do better in the same environment if the surroundings do not change. Scarcity of resources drives the selection process (Aldrich & Pfeffer, 1976; McKelvey & Aldrich, 1983). Differential rates of birth and death explain selection (Hannan & Freeman, 1977, 1984, 1989; Carroll, 1984). Sometimes the rapid rate of replication may be more successful than the superior fitness and slow death rate in adaptation. Evolution always occurs relative to the local current environment and is historically specific. The evolutionary process provides a causal explanation for the outlook of future generations of offspring that are retained.

Darwin had many predecessors of evolutionary thinking in the social sciences, for example: Mandeville, Hume, Smith, and Bagehot (Hodgson, 1993; Nelson, 2006). Hodgson (2004) provides an excellent introduction to the subtle history of ideas on evolution first posited by Darwin (1859) and others from the 19th century on. The great tradition of American pragmatists – Charles Peirce, William James, Thorsten Veblen and John Dewey – made efforts to cultivate Darwinian evolutionary thinking into social science, with some, but not an enduring, success. For various twists of circumstance in the history of ideas, the concept of evolution in the field of social theory, that had already been introduced a century ago, were largely lost (Foss, 1993; Hodgson, 2004). This started to first reappear after many decades of dormant interest.

The first formal account on human ecology was given by Hawley (1944). Building on his ideas and evolutionary heritage found in biology, Campbell (1969) introduced the few fundamental assumptions which are needed for an evolutionary theory in the socio-cultural realm. From this perspective, a process is evolutionary if the following three criteria are met. First, there must be a source of variation. Selection mechanisms do not have a chance to operate if all members in a population are identical. It makes no difference whether the causes of variations are natural, blind and haphazard, or cultural, purposeful and agent-induced. Second, a mechanism of selection must exist in order to account for differential survival rates of members in the population. The selection criteria must remain relatively constant to achieve propagation or elimination. Third, one needs a retention mechanism to preserve or duplicate the in-selected variants for selective accumulation for the future. The principle of evolutionary selection is not enough to explain sources of variance alone (Hodgson & Knudsen, 2008). A historically specific description of the precise circumstance needs to be added for a fuller evolutionary explanation.

Organizational structures offer resistance to adaptation (Burns & Stalker, 1961). Most organizations seem to have considerable inertia; they tend to resist change. Organizations often do not adapt readily when external conditions – business opportunity, competitive situation, legislative frame, or customer demand – change (Hannan & Freeman, 1977). There are restrictions to making and implementing strategic choices to effectively alter the destiny of the firm. On the other hand, organizational inertia is itself an outcome of responses to selective pressures. The sequence of previous successful survivals has created inertia. Over time, organizational responses tend to get simpler and more rigid (Miller, 1993, 1999). Changing environmental landscapes open new opportunities to some firms and remove such opportunities beyond the reach of others. These environmental changes can be too rapid or too discontinuous for an organization to adapt and survive.

There are many possible levels of analysis in selection and evolution (Lewontin, 1970; Aldrich & Ruef, 2006). Scholars who focus on the dynamics of whole industries, where firms are units of observation, do not make a forecast about which particular organization will survive or which mechanisms provide new entries (Hannan & Freeman, 1989; McKinley & Mone 2003). An intra-firm approach offers the possibility for more detailed study on the causes of firm level survival.

3.1.3. Firm level focus

Intra-organizational evolutionary research focuses on ecologies inside an organization, and on questions concerning the origin of variation and selection mechanisms. The notion of environment as a contingency to organizational function and success was introduced by Lawrence & Lorsch (1967). Piecemeal policy adjustment relying on past experience of what works is more typical than executing a grand plan of policy (Lindblom, 1959). Policy is made and re-made continuously. Decision making behavior in organizations can be “irrational” in order to make action possible (Brunsson, 1982). According to the behavioral theory of the firm, much of organizational “life” is about processes and procedures (Cyert & March, 1963). Organizations are also described as action generators (Starbuck, 1983). Action generators are automatic behavior programs that require no information bearing stimuli because they are activated through job descriptions, clocks and calendars. Organizations thus amplify the human propensity to generate behavior programs, or habits. In a firm, they include formalized procedures, training and rituals. For example, such procedures are periodic meetings, the planning and setting of evaluation criteria, or the circulation of documents for data retrieval or signature. In short, habits and routines are everywhere (Hodgson, 1997).

Early protagonists of the evolutionary perspective, McKelvey & Aldrich (1983) polemically state that the influence of a single individual manager in organizational action is often rather small. Intra-firm evolutionary theory postulates that internal selection rather than adaptive strategic decision making is the major driver of success or failure of an individual organization (Aldrich & Pfeffer, 1976). Rational adaptation is restricted because of obstacles in knowledge accumulation, and the existence of habits and routines (Hodgson, 2009). The causes of organizational selection structures are habits (Hodgson, 2007a, 2009). In evolutionary theory, organizations are often viewed as bundles of routines (Nelson & Winter, 1982, 2002). In this regard R&D is also regarded as a search routine (Nelson, 1995). Behavior in organizations is mostly programmed; this is even the case for non-routine decisions (Mintzberg, Raisinghani &

Théorêt, 1976). Organizations remember and act through routines that individuals perform. Behavioral evidence claims that organizational action stems from appropriateness, or logic of identity, not from intention or logic of consequence (Levitt & March, 1988).

Strategy is about how to be successful (Nag, Hambrick & Chen, 2007). In the strategic literature, firms or managers are often optimistically assumed to be capable of rapid and large adaptation or optimal redeployment of resources to meet the demands of the outside environment (for example, see Burgelman, 1983a, 1991, 1996). Rational adaptors are assumed to learn from experience as a way of adapting their actions. Organizational learning is either exploratory or exploitative (March, 1991), however, the exploitative learning mode drives piecemeal and process improvements, creating a "competency trap" with the curse of success breeding failure. Explorative learning may be too wasteful and myopic (Levinthal & March, 1993). Learning occurs not only through an extensive search but also through imitation (Bikhchandani, Hirshleifer & Welch, 1998).

Evolutionary theory contrasts sharply with the "rational adaptor" approach proposed by Chandler (1962, 1977), and Child (1972, 1997), and by many other scholars of strategic theory. Evolutionary theory is independent of any specific assumptions about human behavior or rationality (McKelvey, 1994). Hence, it is parsimonious compared to the notion of strategic intent. An evolutionary approach allows shrewd action and best effort. Individuals may have foresight and intention. Maintaining that structural selection mechanisms inside the firm are important, Lovas and Ghoshal (2000) allow more executive intention than many other evolutionary theorists. They argue that strategy, in the context of intra-organizational ecology, could be described as guided evolution. Top management gives direction by communicating their strategic intent throughout the organization. This pursuit of sense making by top management in shaping the direction adds human and social capital as further critical units of selection into the model; taking the model beyond only structure. In other words, it is not just structures, but also people that are involved and the relations between people do matter. Following Penrose's (1952) criticism of the lack of intentionality in biological evolutionary models, Augier & Teece (2008) also insist on a more prominent role for managers in firms. They perceive strategy as evolution with design. One way to incorporate intention and evolution is to introduce co-evolution; defined as the joint outcome of managerial intentionality, environment and institutional effects (Lewin & Volberda, 1999).

Scholars do not necessarily have to choose sides in the adaptation – selection debate (Astley & van de Ven, 1983; Burgelman, 1983a, 1991; Lewin & Volberda, 2003a). Intentionality or adaptation and selection can be treated as complementary (Hrebiniak & Joyce, 1985) or interrelated (Levinthal, 1991). For example, investment and new product development decisions are intentional. Darwin constantly gives examples of selection, by reference to when farmers breed domestic animals, where intention is present. But Darwin insisted that one must explain the causes of calculation, foresight and intention as well (Hodgson, 2004). The science of choice must go as far as explaining the reasons of "choice" beyond just assigning intentions and preferences to be the grounds (Hodgson, 2009). This justifies the use of an evolutionary framing when studying strategic intentions.

Applying the adaptation hypotheses uncritically leads to the danger of inventing *ex post* Panglossian irrefutable adaptive explanations to everything (Maynard Smith, 1978; Gould & Lewontin, 1979). No assumptions about progress, foresight, sense-making or success should be made in advance (Hodgson, 2004; Astley & van de Ven, 1983). Explaining success with the intention to succeed is retrospective reasoning (Aldrich, McKelvey & Ulrich, 1984; van de Ven & Engleman, 2004). In the pursuit of explaining success with intention, one should also take bad intention, folly, mistakes and luck into account. One should question an outlook according to which managers' intentional design produces success, whereas bad results stem from insurmountable obstacles of circumstance, not from managerial failure. Recently, Levinthal & Posen (2007) report that adaptation may limit selection if myopic selection selects "in" short term adaptive performance, and selects "out" long term performance. However, selection is always local and historically specific. Truly long term performance is, generally, inherently unknown at the time of selection. Hence, no long term fitness exists separately from short term survival, whether the actions are intentional or not.

An early critic of profit maximization as a meaningful guide to managerial action, Alchian (1950), raised concerns about uncertain foresight and proposed luck and chance as alternatives to the intention of rational profit maximization as a way of determining the course of a firm. Maximizing or optimizing behavior is not the only possible explanation for managerial action (Klein & Meckling, 1958). Behavior ruled by inertia also leads to profit maximization (Hodgson, 1997, 2007a). The concept of maximizing as such is also unable to differentiate between different scopes of time. Quarterly maximizing differs from annual and longer term maximizing. Short time maximization does not imply long term profitability or survival. The concept of level of aspiration offers an alternative to maximization. Aspirations trigger search and are performance drivers for investment. Business leaders maximize up to "good enough" performance, as specified by aspiration levels or stakeholders' interests that they have learned about (Cyert & March, 1963; Nelson & Winter, 1982; Greve, 2007, 2008). Selection is not an optimizing force. In biology, it makes no sense to try to specify what type of optimizing process would work; whether it is Pareto or another maximizing approach (Maynard Smith, 1978). Strategies successful at one time may be unsuccessful at another (Lamberg & Tikkanen, 2006). According to Barnett & Burgelman (1996), the space of possible business strategies is not given in advance. Analyzing only today's successfully surviving strategies or firms results in a sample selection bias. One must ask how one particular distribution in a population came about and not another (Nelson, 1995).

I have addressed managerial intention and optimization in order to point out that there are many approaches where intentions or optimizing need not be included in order to explain all managerial actions. Chance and coincidence play a role and events follow their own logic (De Rond & Thietart, 2007). Evolutionary selection in itself is not purposeful, "progressive" or "efficient". It does not necessarily produce better or more advanced individuals, species or firms (Hodgson, 2004). Evolution is not necessarily moving from the simple towards the more complex or towards a pre-established goal. Evolution in the sense used in this study does not follow "prescribed" (van de Ven & Poole, 1995), "necessary" or "emergent" trajectories of events.

In strategy research, Mintzberg & Waters (1985) have made a distinction between intended and realized strategies. They define strategies as patterns of actions. Decisions arise from intentions, but some of the intentions might not actualize. The evolutionary perspective encourages the study of the realized consequences of managerial action rather than managerial intentions. Just being lucky can be justified later as managerial intention. Intentions cover the hunches of a gambler as well as the inspirations of a perseverant visionary (Knight, 1921; Keynes, 1937; Thompson, 1967; March 1994a; Burgelman, 2002a). However, even intentions should be explained, lest they remain "the prime mover" without causes (Hodgson, 2004). In harmony with the distinction put forward by Mintzberg & Waters (1985), I observe both managerial actions (intended or not) and realized portfolio strategies arising from these actions or from other causes. I compare them in order to see whether they are coherent and aligned, or contradictory and conflicting. I do not examine sense-making (Weick, 1995), attention (Ocasio 1997) or the aspiration level (Greve, 2003ab, 2007), each of which precede action. I acknowledge the primacy of action over analysis in accordance with the ideas of Weick (1995), Weick, Sutcliffe & Obstfeld (2005), and Brunsson (1982).

Evolutionary theory defines retention as correspondence between the retained population with the original one (Price, 1995). To achieve this, no genetic mechanism is necessary (Knudsen, 2004). In social science, entities that resemble genes in biology that sustain the specimen selected by evolutionary mechanism in the population have been proposed by a number of authors (McKelvey, 1982; Nelson & Winter, 1982; Nelson, 1995; Weeks & Galunic, 2003). But evolution does not presuppose genes. Neither Darwin (1859) nor Campbell (1969) incorporated genes to their thinking. Since selection in biology operates at a phenotype level, not at gene level, entities such as genes are not needed to explain selection mechanism (Warglien 2002). According to Hammerstein (1996) and Maynard Smith (1978), the relationship between a genetic message and phenotype in biology are inherently complex and do not display anything like a one-to-one correspondence. The information in genes is not enough to determine the development of an entity. The distinction between phenotype and genotype is blurred in social evolutionary theory (Warglien, 2002). A retention mechanism involves genes in biological evolution but not necessarily in socio-cultural evolution. Hence, it is not helpful to try to find an analogy here that may not exist (Singh & Lumsden, 1990). A mechanism of replication can be something entirely different (Price, 1995). For example, routines have been identified as entities that can be retained, but this does not assume that they are like genes (Vromen, 2004; Hodgson & Knudsen, 2004; Hodgson, 2007a).

3.1.4 Selection in intra-firm R&D project population

In empirical studies on intra-organizational populations, scholars have paid attention to organizational processes as objects of selection. These include, for example, imitative rules of behavior (Alchian, 1950), routines (Nelson & Winter, 1982, 2002), competencies – "comps" – (McKelvey, 1982), changing routines (Feldman & Pentland, 2003), capabilities (Vromen, 2004), rules and procedures (Levitt & March, 1988), habits and routines (Hodgson & Knudsen, 2004), jobs (Miner, 1991), rules (Schulz, 1998), manufacturing competences (Kogut & Zander, 1992; Zander & Kogut, 1995), cultural factors and values (Miller, 1993; Burgelman, 1991), "memes" (Weeks & Galunic, 2003), sense making frames (Weick, Sutcliffe & Obstfeld, 2005), technology diffusion (Cool, Dietrickx & Szulanski, 1997), co-operative strategies (Axelrod, 1984), and economic policies (Witt, 2003).

Very few scholars have studied populations of material artifacts, such as strategic business initiatives (Burgelman, 1983ab, 1991, 1994, 2002a), product families (Lovas & Ghoshal, 2000) or technologies (Mokyr, 2000). In building the framework for intra-firm evolution I make two choices. First, I focus on populations with material artifacts. As Burgelman (1983b), Lovas & Ghoshal (2000) and Mokyr (2000) point out, objects, such as new product development projects, rather than routines or capabilities directly relate to the external world and are easy to detect and measure. Organizational structures and processes to manage projects are also well defined. R&D driven new product development projects are objects for vicarious selection in the internal environment, and their outcomes compete as new products in the external environment. Following Bower (1970) and Burgelman (1983ab), I treat R&D projects as risky strategic investment initiatives or new business ventures. As a second choice I focus on the mechanism of selection. My use of the term evolution denotes an open-ended selection process. A selection mechanism is essential to deliver evolutionary explanations. As Ruse (2009) points out, Darwin very clearly indicated the necessity to causally explain evolution with a selection mechanism. His followers were rather vague about mechanisms and emphasized other aspects of evolution. Considering the importance of selection events in shaping evolutionary outcomes (Aldrich, Hodgson, Hull, Knudsen, Mokyr, & Vanberg, 2008; Aldrich & Ruef, 2006; Hodgson, 2004; McKelvey & Aldrich, 1983; McKinley & Mone, 2003; Nelson, 1995; Singh & Lumsden, 1990), the lack of more detailed documentation on selection mechanisms is remarkable. Indeed, selection mechanisms warrant an empirical study. Variation may interfere with selection (Maynard Smith, 1978). For that reason the variation in population is also studied.

Managerial activities on R&D projects drive an internal vicarious selection process inside the firm. Internal selection serves as a proxy for the external selection system whereby new products survive or fail in the outside world (Campbell, 1994). One does not know for sure, if the projects preferred today are successful or survive in a future competitive environment. Vicarious selection may be intentional or not and vicarious mechanisms may or may not follow external selection (Meyer, 1994). Internal selection processes may be driven by diffusion, imitation, and promotion or incentive systems. Imitation of “good” practices and avoiding the “bad” is vicarious learning (Delacroix & Rao, 1994). Vicarious learning can also be superstitious. Imitation and fad are simple least action types of learning.

Prioritizing R&D projects is vicarious selection. Project terminations due to outside circumstances such as technological or competitive failure are instances of external selection. The two ecologies inside a firm and outside it have two distinct sets of selection mechanisms. Internal selection is not wholly adapted to an external environment. Internal selection may be good, neutral or harmful (Aldrich & Ruef, 2006). Internal selection and external survival tend to be loosely coupled (Aldrich & Ruef, 2006). Three mechanisms of internal selection promote this. First, there are pressures toward internal stability and homogeneity. Second, past selection criteria tend to persist. Third, organizational stakeholders approve lower performance thresholds than are present in the environment. Strategic choice scholars claim that establishing a strategic direction followed by organizational design select a successful strategy (Lovas & Ghoshal, 2000). Scholars should not implicitly assume that internal selection mechanisms are effective at anticipating outside selection mechanisms (Warglien, 2002: Galunic & Weeks, 2002). All managerial guidance is not likely to be successful. For example, vicarious selection of development projects may conflict with termination in the outside world due to unforeseen technological hazards.

3.1.5. Selection mechanisms

Investment in new product development for future success is complex and risky and involves many levels and processes in a firm. New business venturing occurs through experimentation and selection of some initiatives from a variety of strategic investment projects rather than through planning and optimizing (Bower 1970, 2005). Mechanisms for resource allocation of strategic new business initiatives also apply to investment decisions about R&D projects (Bower, 1970). Both are iterative selection process (Noda & Bower, 1996). Different firms starting from the same platform arrive at different results as a consequence of their actions and decisions (Bower, 2005).

Utilizing Bower's (1970) investment model, Burgelman (1983ab) constructed a two-way process model of the evolution of project and business development strategy. According to Burgelman (1983b), strategy formation occurs, at least partially, through experimentation, and selection of strategic initiatives rather than through explicit strategic planning. He identifies two kinds of strategic activities. One type of strategic behavior is "induced" by the firm's current concept of corporate strategy. Another type of strategic behavior, internal corporate venturing, emerges from "autonomous" activities that fall outside the current concepts of strategy. Building on Bower (1970), Burgelman observes that strategy formation, such as a major capital investment decision, contains both top down and bottom up processes, manifested as induced and autonomous behavior. Corporate structure, however, is built to reinforce the current strategy and behavior that supports this strategy, namely induced behavior. Corporate structure, set up by top management, is a collection of various administrative mechanisms. It includes the overall levels of hierarchy in organizational configuration, formalization of positions and relationships, project screening criteria, measures of performance, appointment of middle level managers, and risk minimization over time. Current structure does not favor autonomous activities, such as internal new business venturing. Rather, structures try to select "out" any such initiative that falls outside current corporate strategy.

For Burgelman (1983ab), "structural context" is a selection mechanism in the stream of induced strategic behavior which backs an "orthodox" initiative. Few projects have a significant impact on changing the concept of strategy under standardized quantitative project screening procedures and uniform categories of strategic planning systems. The selection of higher managers to their jobs favors those candidates who show strong corporate orientation in their decision making. Hence, this structure has selective effects on the stream of strategic behavior at the middle manager level. Another mechanism, "strategic context" is a selector for autonomous behavior. It favors unorthodox approaches with high reward. The mechanisms of structural content and strategic content work differently. Structural context serves the purpose of aligning projects to corporate strategy. The selection process leads to retention of conservative rather than novel initiatives. "Normal" product development has an advantage over new business ideas in the administrative structure. However, somehow some "autonomous" initiatives survive in lower structures with the help of project championship. Successful "autonomous" behavior is later justified to be rational. This retroactive rationalization legitimizes autonomous initiatives to be treated as normal strategy and they are perceived as induced initiatives. Managing strategic initiatives is essentially a two-way process.

To escape the sieve of existing selection structures, autonomous initiatives need to gain political support but they may also happen by chance. Burgelman (1983ab) is somewhat vague about the details of how autonomous initiatives circumvent the sieves of selection structure. Burgelman does not always clearly distinguish between selection structure as an entity or routine in the organizational hierarchy and the selection rule as a criterion for retention. He sometimes refers to selection mechanisms as an "internal selection environment", comprising both structural (organizational) and strategic (content) issues (Burgelman, 1991). Burgelman gives examples of vicarious selection in terms of an "internal selection environment", "selection structure" or "organizational culture". However, he precisely identifies both a selection rule and selection structure when middle level operations managers succeed in circumventing the induced strategy when they reshape product lines (Burgelman, 1994).

Other scholars also have noted Burgelman's vagueness in the way that selection mechanisms are described. According to McKinley & Mone (2003) and Warglien (2002), Burgelman does not focus on describing selection mechanisms by level of hierarchy in any detail. According to Galunic & Weeks (2002), Burgelman does not define routines clearly. Selection in internal routines may have causes other than adaptation to the external environment, which may be neutral or harmful in adaptation to external conditions (Galunic & Weeks, 2002; Meyer, 1994). Long term survival for the organization as a whole depends on the fit between internal ecological processes and external ones (Galunic & Weeks, 2002). If a routine is maladaptive, it should be possible to replace it with some other routine; otherwise no selection mechanism will build up selection pressures within organizations. There is no guarantee that internal routine selection produces external adaptation. Intra and inter-organizational selection and evolution must be defined independently. Lewin & Volberda (2003a) claim that Burgelman (1994) assumes correspondence between external evolutionary selection criteria (demand of microprocessors increases) and internal selection environment (wafers are more profitable). Moreover, they claim that Burgelman (1983ab) is not specific about the interplay between levels of hierarchies where selection happens.

Levinthal (1997) suggests that loose coupling between different parts of the organization enables autonomous activities. The problem of internally supporting autonomous initiatives is that top managers may not always correctly perceive the opportunities in the external environment (Burgelman, 1996). Maintaining a pragmatic balance between "induced" exploitative and "autonomous" explorative processes is a major challenge (Burgelman, 2002a). Variation increases in the exploratory mode and decreases in the exploitative mode. There is evidence that this might often happen in cycles (Burgelman, 1983b; Burgelman & Grove, 2007). When the new CEO repositioned Intel to an exploitative mood, he, according to Burgelman (2002a), was "lucky" in anticipating the change in environment "early enough". According to de Rond & Thietart (2007), strikes of luck do occur, but this does not explain managerial foresight. It ignores the question of how to explain bad luck and managerial failures. It creates a selection bias (Barnett & Burgelman, 1996). As Burgelman & Grove (2007) describe, Intel switched from exploration to exploitation and back. The question of how to manage internal vicarious selection in order to cope with external selection still remains open.

I suggest that in order to improve the conceptual analysis of an internal vicarious selection mechanism one should distinguish three parts within it. First, a selection structure provides the organizational conditions under which selection takes place. A selection structure includes organizational hierarchies, procedures and routines. The importance of organizational connections to selection has been emphasized (Vromen, 2006). Second, a selection rule specifies the criteria for preference that is applied in the selecting mechanism. Third, a selection object refers to the entity upon which a selection rule is applied within the selection structure. A selection mechanism is defined when all the three aspects are well characterized. A selection event is the exact temporal manifestation of a selection mechanism at work. A vague characterization of a selection mechanism may lead to problems in distinguishing between vicarious and environmental selection and defective causal explanations. It is not easy to explain the causes of the continuous shifts between explorative and exploitative strategic behavior Burgelman & Grove (2007) report a lack of a specifying a mechanism that explains these shifts and the changes in variation. On the contrary, the argument for causal connection is especially strong when a selection mechanism has been specified in detail; as is the case with Burgelman (1994). Observing the various selection mechanisms characterized in Burgelman's research, Table 1, I rearrange some of the results of his main studies with the help of my own framework.

Table 1 Internal selection mechanisms found in Burgelman's research

Nr*	Selection mechanism	Selection structure	Selection rule	Selected entity
1	Choose induced initiatives Choose autonomous initiatives	top management, internal selection environment top management, internal selection environment	aligned to strategy good champions, political success, belief in external fit	strategic business initiatives, projects strategic business initiatives, projects, middle managers
2	Internal administrative and cultural mechanisms, strategic planning, managers' assessment	top management	resource allocation rules, managers' promotion	strategic business initiative, project, middle managers
3	Choose type of products for manufacturing	middle management	highest production site profit margin	raw production wafer
4	Choose induced initiatives	CEO led top management	choose specific product family	strategic business initiatives, projects
5	Choose induced and autonomous initiatives in a cyclic manner	many CEO led top management teams	choose, maintain and change product families	strategic business initiatives, projects

* References: 1: Burgelman, 1983ab; 2: Burgelman, 1991; 3: Burgelman, 1994; 4: Burgelman, 2002a; 5: Burgelman & Grove, 2007.

3.2 Co-selection and research framework

3.2.1 Introducing co-selection

In his influential treatise "On the Origin of Species by Means of Natural Selection", Charles Darwin (1859) observed a phenomenon he called "correlation of growth". Pondering on why certain features appear together in organisms growing to maturity and considering malformations as an extreme example of this phenomenon, he wrote:

"Some instances of correlation are quite whimsical: thus cats with blue eyes are invariably deaf; color and constitutional peculiarities go together, of which many remarkable cases could be given amongst animals and plant."

A few lines later, noting correlations recurring from generation to generation, he wrote:

"Hence, if man goes on selecting, and thus augmenting, any peculiarity [of animals or plants], he will almost certainly unconsciously modify other parts of the structure [of animals and plants], owing to the mysterious laws of the correlation of growth" (Darwin 1859, Chapter I, in Watson 2005, page 351)

Later on, he explicitly notes that correlation is independent of utility:

"Hence we see that modifications of structure […] may be wholly due to unknown laws of correlated growth, and without being, as far as we can see, of the slightest service to the species." (Darwin 1859, Chapter V, in Watson 2005 page 423)

Darwin described instances, where human endeavors in breeding for specific features of plants or animals result in the inheritance of other features, although these are not selected. If you want white-fur blue-eyed cats, you will also have a deaf cat. This is caused by the inner connectedness of traits in cats. The selection rule for choosing blue eyes results in co-selecting other features that will be presented in a bundle; for example those that cause deafness. A selection rule, whether occurring naturally or chosen intentionally, picks one feature for retention whilst other features attached to the selected one are retained by co-selection. By analogy, I suggest that when selecting

R&D development projects for priority in a population then co-selection of project attributes occurs.

I define co-selection in projects as follows:

When a selection rule referring to a specific attribute of a project is applied to a project, co-selection causes some other attribute of the project being selected which the selection rule does not address.

The co-selected attribute does not by itself fulfill the criteria of a selection rule regarding a project. In R&D project portfolio management, the selection of survival is a project prioritization. Co-selection attaches additional attributes to the prioritized project. In biology, Darwin's correlation effects that caused co-selection are often hard to detect (Endler & McLellan, 1988; Stern, 2000). Co-selection is an example of a non-adaptive evolutionary mechanism. A non-adaptive mechanism does not select for current fitness, but affects evolutionary outcome in an indirect way. The co-selected features of the internal selection process are externally neutral or maladaptive.

In biology, the timing of an adaptive feature is crucial. A non-adaptive trait may also become adaptive in two ways. First, a trait selected for some specific function starts to serve another function. Second, a trait, the origin of which is not a result of a selection rule, starts serving a new current function. In other words, unselected traits start to be useful in a novel way. The reverse is also true. Former adaptive traits may become non-adaptive or harmful. The notion of ex-aptation in biology has been introduced to account for fitness resulting from traits which were non-adaptive at the time of selection, but were later opted for use (Gould & Vrba, 1982). In the organizational context the concept of ex-aptation has been used to describe innovation development (Dew, Sarasvathy & Venkataraman, 2004; Villani, Bonacini, Ferrari, Serra & Lane, 2007), and resource generation (Grandori, 2007). Ex-aptation is often seen in evolution (Murmann, Aldrich, Levinthal, & Winter, 2003). The concept of ex-aptation makes it easy to understand the temporal nature of fitness and adaptation in biology (Gould & Vrba, 1982). Developing the taxonomy proposed by Gould & Vrba (1982) adding co-selection leads to a classification, where time, adaptive value as fitness, and a selection mechanism are all included. Co-selection is a non-adaptive evolutionary mechanism.

The retention of a co-selected attribute does not depend on the selection rule that drives the primary selection mechanism. In the terminology of Gould & Vrba (1982), direct action of natural selection refers to a selection mechanism which selects the fit for survival. My use of the term co-selection refers to the broader class of non-aptation referred to by Gould & Vrba (1982); this includes neutral or detrimental effects. Table 2 is useful for comparing adaptive and non-adaptive selection mechanism.

Table 2 Co-selection, adaptation and fitness

Timing of selection event	**Process description**	**Adaptive value as current fitness**	**Selection mechanism**	**Gould & Vrba (1982)**
Current	Natural or artificial selection shapes the character for a current use	Current adaptation	Selection	Adaptation
Past	A characteristic previously shaped by natural or artificial selection for a particular function, is co-opted for a new use	Past adaption, current new adaptation	Selection	Ex-aptation
Current	A characteristic whose origin cannot be ascribed to the direct action of natural or artificial selection	Current non-adaptation	Co-selection	Non-adaptation
Past	A characteristic whose origin cannot be ascribed to the direct action of natural or artificial selection is co-opted for a current use	Past non-adaptation, current adaptation	Selection	Ex-aptation

One might object to the use of the term co-selection since it detaches the idea of selection from adaptation and fitness. I think there are four reasons to define the construct of co-selection as suggested. First, co-selection specifically refers to the micro level mechanism of non-adaptive selection as a means to distinguish a detailed mechanism from a larger set of adaptive transformation with imprecise references to a "selection environment" that causes the selection for fitness. Second, a historical differentiation between the instant of a selection event and its subsequent consequences is more easily kept in mind if co-selection as a mechanism is identified. Third, using the term co-selection makes it clearer that the selection event itself may give rise to unforeseen consequences that not only increase but also decrease fitness. This is even more important in artificial selection, where, due to rapid changes, the limits of adaptation are hard to conceptualize and easy to reach. Fourth, co-selection arises from the connections of features in bundles due to the overall design and hierarchy of an entity. This helps to further analyze the roots of the phenomenon.

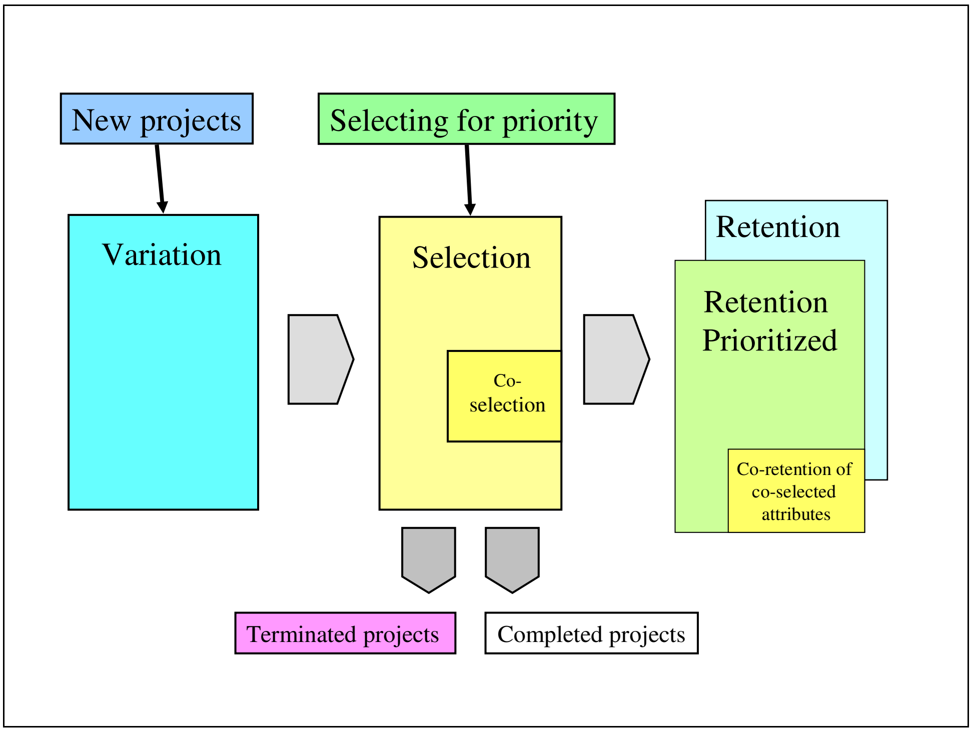
The main reason for Gould & Vrba (1982) to advocate ex-aptation as a concept, in the Darwinian spirit, was to displace the term pre-adaptation and thereby to avoid the misleading ‘pre’ suffix connoting the teleological concepts of pre-planning and purpose, which do not belong to Darwinian evolutionary theory. In the innovation literature, their approach has been both challenged (Cattani, 2005, 2006, 2008) and defended (Dew, 2007). As a term, pre-adaptation is used casually (Murmann et al, 2003). I suggest one should follow Gould & Vrba (1982) for clarity on timing the appearance of the new aptation. This differentiates between an adaptive and non-adaptive selection mechanism more precisely at a given instant in time. The timing of the act of selection is important. Using the term pre-adaptation is blurring the fact that, in general, there is no possible way to distinguish in advance, a beneficial pre-adaptation or “fit” from a non-adaptation.

I offer an example of co-selection in the business context. The celebrated case history of Intel’s strategic exit from memory devices documented by Burgelman (1994) resulted from a co-selection process. Production wafers at Intel constitute a population. The population of wafer starts is selected based only on a production capacity prioritization rule in order to maximize profit when bottlenecks of production capacity arise. This rule for production co-selects specific types of devices (processors) designed for new end-users, that is, new products and markets, in an unanticipated way and against strategic intent. Co-selection provides a micro-level causal explanation of what initially led to the switch of Intel’s strategic focus over time. The mechanistic explanation of co-selection digs deeper towards understanding the root causes of the selection phenomena. Therefore, I suggest that it is important to be more specific about a selection mechanism than Lewin & Volberda (2003a), who label the Intel development as “micro co-evolution”. The use of this term is also at odds with their definition of co-evolution. According to their definition (Lewin & Volberda, 1999) managerial intentionality is assumed, however this is not present in the case of Intel at the top management level.

3.2.2. Research framework and construct definitions

Developing the ideas of evolutionary scholars, I have derived the following model for studying intra-firm evolution of R&D project portfolios. Project prioritization is an internal vicarious selection event and project termination is an external natural selection event. I have adopted the evolutionary logic of variation, selection and retention proposed by Campbell (1969), as previously described. As suggested by Lewin & Volberda (2003b), I allow for intentionality. My framework has analogies with the variation, selection and retention framework used by Burgelman (1983a, 1991, 1996). For example, as shown in Table 1, a variety of induced and especially autonomous strategic initiatives are put forth (Burgelman, 1983a). Internal mechanisms select from these business initiatives the ones fulfilling selection criteria based on resource allocation (Burgelman, 1991) or strategic alignment and project championship (Burgelman, 1983a). The initiatives selected are then pursued in the organization. However, managers making selection may not always recognize external opportunities (Burgelman, 1996). In building my framework, the work of Aldrich & Ruef (2006), Aldrich, Hodgson, Hull, Knudsen, Mokyr, & Vanberg (2008), Bower (2005) and the conceptual analyses of Hodgson (1993, 2002, 2004) have been valuable. I have conceptualized the co-selection phenomenon based on the examples on "correlation of growth" given by Darwin (1859). The role of internal constraints has been presented in the writings of Gould & Lewontin (1979) and Gould & Vrba (1982). For a general background on evolutionary theory, I refer to Stern (2000), and to Endler & McLellan (1988). The conceptual framework is presented in Figure 1.

Figure 1 Conceptual framework



The selection of projects to a portfolio and their being given a priority is essential for portfolio management. Definitions of project portfolio selection emphasize that selection has a repeating process nature, some projects are prioritized over others, and selection has a long time horizon and influential strategic consequences (Archer and Ghasemzadeh, 1999, 2004; Cooper et al, 1998; Standard for Portfolio Management, 2008; Jamieson & Morris, 2004; Thiry, 2004; Artto & Dietrich, 2004; Dye & Pennypacker, 1999; Milosevic, 2004). In the following, I always refer to portfolio of new product development projects when discussing portfolios. In the literature, project selection may mean a process in which projects which are not selected are killed (Archer & Ghasemzadeh, 1999), or a process where projects are prioritized or not prioritized, but not killed (Cooper et al, 1998). A comparison of concepts used in evolutionary theory and in project portfolio management is presented in Table 3.

Table 3 Comparison of concepts in evolutionary and portfolio literature

Evolutionary theory	**R&D project portfolio management**
Population	Project portfolio
New project	Decide to initiate a new project
Variation	The total scope of projects and their attributes in the portfolio
Selection	Choosing projects in the portfolio
Select for priority	Decision to prioritize a project
Co-selection	Set of project attributes accompanying a project which is prioritized
Retention	Set of projects remaining in the portfolio
Prioritized retention	Set of prioritized projects remaining in the portfolio
Co-retention	Set of co-selected project attributes in prioritized projects remaining in the portfolio
Attribute	Property of a project
Completed projects	A set of projects which end successfully
Terminated projects	A set of projects which are terminated

The following definitions explain the concepts used in more detail. I define the concepts: population, project, project portfolio, project attribute, variation, selection, selection mechanism, selection event, selection rule, selection structure, decision, prioritization, retention, co-selection, co-retention, new project, project termination and project completion.

Population is the collection of entities inside an organization under study. Entities in this study are R&D new product development projects.

Project refers to an R&D driven product development project. If successfully completed, it will enter the market as a new product or lifecycle improvement.

Project portfolio is the population or the totality of R&D development projects. It is synonymous with population in this study.

Project attribute is a property of a project. Examples of project attributes are membership of a business unit, project age or development stage.

Variation in the project population arises from either new project entries or an ongoing project development process to push new projects to the successive development stage.

Selection is the set of actions concerning objects that lead to their retention or exit. Selection denotes a selection mechanism at work.

Selection mechanism consists of selection structure, selection event and the object of selection. *Objects of selection* are projects.

Selection events are decisions about projects in instances of time when applying the selection rule leads to their retention or rejection. Decisions occur repeatedly in selection structures.

Selection rules specify the criteria for selecting objects at selection events.

Selection structures are organizational committees at different levels of hierarchy in the organization whose members are managers and where selection mechanisms are localized. An example is the portfolio committee.

Decisions are selection events of managerial action regarding projects. Examples are project initiations and terminations or project prioritizations and de-prioritizations.

Prioritization is a decision by which management gives the project prime access to resources in bottlenecks and in this way reduces time to market in comparison with other projects. Prioritization and selecting for priority are synonymous. *De-prioritization* is the negation of prioritization.

Retention is the outlook of the remaining project population when the selection mechanism is choosing "in" some projects of the population. This population is reselected over time. Examples include the population of prioritized projects.

Co-selection is the mechanism that causes some other attributes of the project to be selected when a selection rule referring to specific attributes of a project is applied on that project. Examples include the retention of business unit membership during prioritization.

Co-retention is the retention of a co-selected attribute.

New project refers to the initiation of a new project to increase variation in the portfolio. New project entry is decided by top managers.

Project termination refers to the exit of any project. Exit is decided by top managers. Termination is one type of selection mechanism

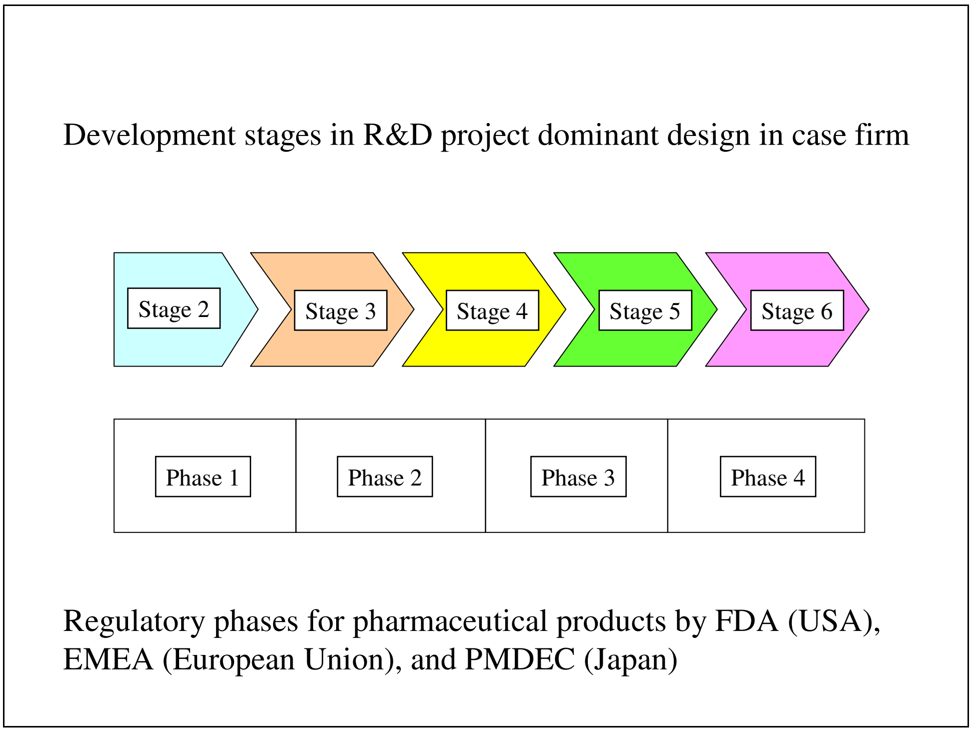
Project completion refers to a successful ending of a project. Project delivers an innovative product as an outcome.

3.2.3 Co-selection and project dominant design

The conceptualization of co-selection utilizes a fruitful analogy from biology. The concept of dominant design also has its roots in biology. Biological organisms are not decomposable to unrestricted combinations of traits for malleable adaptation (Gould & Lewontin, 1979). White blue-eyed cats are deaf (Darwin, 1859). Forcing effects of internal constraints bind different traits together. These constraints like Darwin's correlation of growth can be used to understand the origin of co-selection. Ex-aptation (Gould & Vrba, 1982) and pleiotropy (Gould & Lewontin, 1979; Hodgkin, 1998) are well-known constraints to adaptation. Pleiotropy means that one biological entity, such as a gene, an enzyme or an organ, executes a number of different functions. High pleiotropy describes a system where many things change when one trait or component is changed due to a physical connection or dynamic interrelatedness. The notion of pleiotropy has been used to conceptualize dominant designs in innovations (Murmann & Frenken, 2006) or more generally in technologies (Mokyr, 2000).

Pharmaceutical R&D product development projects display a typical stepwise dominant organizational and technological design (Ethiraj & Levinthal, 2004; Murmann & Frenken, 2006; Foulkes & Morris, 2004; Langlois, 2002; Sanchez & Mahoney, 1996). The contents of different stages of the dominant design are described in more detail in chapter 4. Figure 2 presents an overview of the dominant design of R&D projects in the pharmaceutical field.

Figure 2 Dominant design of pharmaceutical R&D product development project



The dominant design of a pharmaceutical R&D development project consists of different development stages. They are unique and must be conducted in sequence rather than in parallel. This design has evolved due to extensive medical regulatory requirements for product safety and attempts to reduce technology and market risk in product development. Development stages are regarded as project attributes. The sequential development in stages of a pharmaceutical product is a dominant design in the sense that it is an industry standard enforced by regulatory authorities (Suárez & Utterback, 1995). Regulatory authorities categorize these steps as phases. The correspondence of development stages and regulatory phases is illustrated in Appendix 6. Development stages or phases are also cognitive categorizing models for defining project milestones in the industry (Porac, Thomas, Wilson, Paton, & Kanfer, 1995). Modularity in innovation project design and design of organizational structure reflect some similarity (Langlois, 2002, Sanchez & Mahoney, 1996). McGrath, MacMillan & Tushman (1992) suggest that managers can or should pursue activities that shape the dominant designs of new products.

Project dominant design accounts for co-selection. Managers prioritize projects whose attributes are connected; connections that are retained after prioritization. A new product development process is hard to change once goals have been set (Milosevic, 2004.) Revisions can arise either from "external" factors, such as the lack of scientific evidence to support project goal, or "internal" factors, which depend on the firm's ability to innovate. In quite a number of cases in pharmaceutical R&D, new product development projects just fail to meet specification criteria. The candidate product either is not effective enough to treat the condition for which it is being developed, or some serious adverse event may become evident that makes the product unsuitable for use by humans. If the project does not quite achieve its goals, the product may occasionally be approved for a restricted therapeutic application only. For the project, this is a change in goal and specification and radically affects the commercial outlook for the product. Sometimes, in early development, an improvement in pharmacological properties or a synthetic production route may be needed, which cause delay and additional investment, but do not necessarily damage the project. However, if revisions arise, most of these projects are terminated.

Some of the development stages can be accelerated, others cannot. For example, firms must know and provide data to authorities on the stability of intermediate chemical compounds used in the manufacturing process and in the end product for many years. These processes can be accelerated. Increasing temperature to decrease observation time is a scientifically valid method to check stability. However, it is not medically valid to run a clinical study where patients receiving long term treatment require an observation time for two years in less than two years by just increasing the number of patients in order to obtain the same number of days of exposure with shorter duration of treatment. Sometimes parallel development is possible but there are also limits here. To conduct clinical trials on patients, one must use the final form of the drug product intended for commercial use. This means that it is necessary to complete all stability trials relating to manufacturing before one can proceed to treat humans. Toxicology studies must also be completed before human clinical trials commence.

Every managerial decision concerning a project changes at least one of its attributes. Project attributes add up to portfolio level attributes. However, the literature is not clear about what are the most relevant categories and attributes and how they are derived (Crawford, Hobbs & Turner, 2005). Based on a large survey, the results of Crawford et al (2005) indicate that the categorizing of products varies a lot across firms and between industries. The average number of attributes used to categorize projects in general is between five (mode) and eight (median). This is not a large number, but categories vary a lot from firm to firm. For strategic alignment, the themes that are important include commitment to capability, prioritizing, managing risks, allocating budget, balancing the portfolio, and identifying an approval process.

Categorizing products by size and development stage is extremely common. Geographic scope and market potential are explicit or implicit in prioritization. Project attributes and organizational purposes are interconnected and inseparable. They also serve multiple purposes and are not exclusive. The dominant attributes of innovation projects for normative portfolio management include size and risk, and project stage (Cooper et al, 2001b). All portfolio selection activities rely on this kind of listing of industry-specific categories (Suárez & Utterback, 1995; Porac et al, 1995). However, due to industry and firm level idiosyncrasies, it is by no means certain that these categories relating to project selection accurately reflect the dominant modular design of project. Since modularity, dominant design, and pleiotropy are connected, any "optimizing" level of modularity in dominant designs is based on a process of trial and error (Ethiraj & Levinthal, 2004).

3.2.4 Uncertainty and evolution

In his analysis of risk and uncertainty, Knight (1921) made a fundamental distinction between forthcoming events to which managers can assign "a priori or statistical" probability estimates, and events where "there is no valid basis to classify instances". According to Knight, it makes sense to talk about risk only when probability estimates apply and the risk can be insured against. However, some events or outcomes are inherently unknowable beforehand until they materialize. The definition of uncertainty further distinguishes between known unknowns and unknown unknowns. Known unknowns refer to states of affairs that are perceived as possible future eventualities, but there is no meaningful way to talk about their probabilities. Unknown unknowns refer to events that are not anticipated at all (Thompson, 1967; Nutt, 2002). When no exact probability or probability distribution measure for an event to occur can be made, then the event is inherently uncertain. Not all future events can be anticipated even at a concept or category level.

The precise wording that Knight himself used yields two interpretations. Some scholars maintain that Knight (1921) included both known and unknown unknowns to his definition of uncertainty (Langlois & Cosgel, 1993; Dequech, 2006; Loasby, 2001; Nightingale, 2000). Others consider he only referred to known unknowns (Davidson, 1991; Golosnoy & Okhrin, 2008; Sommer, Loch & Dong, 2009). I concur with the argument of Langlois & Cosgel (1993) who base their claim on careful text analysis of Knight's (1921) work and the general background of his philosophical thinking. Following Langlois & Cosgel (1993) and Loasby (2001), in this study I shall refer to Knightian uncertainty as covering both known and unknown unknowns. Post-Keynesian economists, especially Davidson (1991, 1996, 2004), point out that Keynes (1937), in his general theory, assumes an unknown future. The study by Lawson (1988) on the nature and relations between Keynesian and Knightian views on probability and uncertainty also suggest this.

Scholars provide many ways to estimate risks in product portfolios, and techniques to manage such risks; for example, mathematical models (Chapman & Ward, 2002, 2003), the experimental project risk funnel (Wheelwright & Clark, 1992), trial-and-error experimenting and selection for unforeseeable events (Loch, De Meyer & Pich, 2006; Sommer, Loch & Pich, 2008) or preparing for a broad variety in organizational response (Weick & Sutcliffe, 2007). Risk estimates from extrapolating past experience (Wheelwright & Clark, 1992) give rough guidance, but they do not include surprises due to Knightian uncertainty in fat tail distributions (Mandelbrot & Hudson, 2004), metaphorically called "Black Swans" (Taleb, 2008). Some scholars of risk estimation deny Knightian uncertainty and maintain that managers always estimate subjective probabilities (for example, see Chapman & Ward, 2003). Their rejection of true uncertainty is not in line with what we know about managerial behavior connected with risk (March & Shapira, 1987). It also conflicts with the ideas of Knight (1921), Thompson (1967) and Weick (1995), that humans in an uncertain world are unable to categorize even future occurrences, not merely their probabilities of occurrence.

The notion of uncertainty must not be confused with the notions of complexity and difficulty (Page, 2008). The research tradition advocated by Simon (1947, 1955) and many others tends to assume that complexity is the cause of uncertainty. If one could understand the computationally difficult behavior of complex entities then uncertainty would vanish. Bounded rationality and "satisficing" solutions would be put aside as unnecessary approximations. This view presupposes a universe where rational calculation about future states is possible. Evolution would be the teleological unfolding of events from potential to actual in a life cycle manner, with an imminent goal.

If future events are essentially predictable based on past information this type of world is called ergodic (Davidson, 1996). In a sense, the future is like the past. The notion of ergodic systems is borrowed from the mathematical physics of particles moving on trajectories in phase spaces. In an ergodic world the future is predictable. Any future event will be arbitrarily close to being similar to some previous event. Assuming eternal absolute time, once all event categories and their combinations have made their presence on the world stage they start to reappear. History repeats itself.

In a non-ergodic world, some realized events are unforeseen and genuinely unpredictable. In a non-ergodic world the future is not a repeat of the past (Arthur, 1989; Davidson, 1982; Dunn, 2000). Davidson (2003) gives a devastating critique of using a mathematical axiomatic model in economic theory based on the assumption of an ergodic future. Davidson's argument of for true uncertainty follows from the idea that the world of economics is non-ergodic, path dependent historical and irreversible.

Path dependence implies some form of historical irreversibility. Although intuitive, path dependence is difficult to define precisely. Many definitions have been presented in the strategic and evolutionary literatures (Lamberg & Parvinen, 2003). In path dependence, different sequences of past events cause different future outcomes. In strong path dependence, this is always the case. In weak path dependence, this is not always the case (Page, 2006). Nevertheless, the sequence of events matters. There are many types of phenomena related to, but not necessarily manifesting, path dependencies. Expressions to describe different kinds of concepts related to path dependencies in social theory include "increasing returns", "self-reinforcement", "positive feedback", "founder process", and "lock-in". Not all of these constructs need to be path dependent. Path dependence may be forgetful so that only more recent events count. According to Mahoney (2000b), there are two types of path-dependent event sequences. Self-reinforcing sequences refer to a pattern of events ("increasing returns" or “lock in”). Reactive sequences refer to inherently causally dependent events leading to outcome as time unfolds.

In a project portfolio negative externalities exist. This is because selecting for priority to distribute limited resources occurs repeatedly, unless all projects are prioritized (Page, 2006). The later set of projects is not likely to be the same as earlier ones. Since prioritizing implies queuing for resources, R&D project portfolio management is path dependent, and the prioritizing of decisions makes negative externalities inevitable. According to Page (2006), selection rules derived through optimization cannot be path-dependent. Sequential decision making may lead to path dependence even under the unrealistic assumption of full rationality (List, 2005). According to List (2005), in collective sequential decision making a “discursive dilemma” or Concordet’s paradox may arise, where “agenda setting” influences the outcome of the decision process. Portfolio selection is a recurring process. In this context, self-reinforcement is likely to occur. Because new projects are introduced that were not there in the past and projects pass to new development phases there is ongoing variation. Hence, project portfolio selection is neither an ergodic nor a Markov process (Page, 2006). Furthermore, the sequence in which selections are made over time does matters. It is quite likely that permuting the ordering – in time – of project proposals results in a different set of approvals.

In the strategic intention stream of research, path dependence is often regarded as harmful; whereas in evolutionary theory, it is considered necessary (Lamberg & Tikkanen, 2006). The escalation of commitment in concerted decisions refers to behavior where the initial course of action is maintained in spite of negative feedback from the outcomes. In resource allocation, this is paraphrased as the effect of sunk costs (Staw & Ross, 1978). An escalation of commitment does not necessarily reverse although increasing information is available (Schmidt & Calantone, 2000). Bikhchandani et al (1998) observe that the cause of this is information cascading. In sequential decision making people start to ignore their private information and conform to previous decisions. This gets amplified by others who act alike. This mechanism is behind also fads and fashions. Different factors are likely to influence escalation in different contexts and points of time (Brockner, 1992).

Past research has found no explanation for the escalation of commitment to older products other than sunk costs (Brockner, 1992). However, sticking to one's choices is beneficial in trial and error learning and experimenting with many probes (Garud & van de Ven, 1992; Turner & Keegan, 2004). Long term commitment to competitive strategy is beneficial for firm survival (Lamberg, Tikkanen, Nokelainen & Suur-Inkeroinen, 2009). To conclude, path dependent phenomena arise in evolutionary models, but not in ergodic optimizing models. Co-selection is a manifestation of path dependence in evolution. Structures from the past are the building blocks of new structures.

Selecting a novel frame of study, a new ontology, is a way to tackle conceptual impasses (Weick, 2006). Portfolio management decisions are not optimal (Klein & Meckling, 1958). Scholars suggest trying alternative theoretical perspectives beyond rational equilibrium economic theory and "optimizing" (Alchian, 1950; Cyert & March, 1963; Greve, 2008; Hodgson & Knudsen, 2008; Nelson, 1995; Nightingale, 2008; Nelson & Winter, 1982). Framing the problem of managing a project portfolio in a novel way could help to explain the empirical bias found between portfolio management dynamics in practice and the expectations provided by normative decision theory based on optimizing. Interestingly, the rational optimizing approach in resource allocation for R&D development projects was conceptually challenged many years ago (Klein & Meckling, 1958). Some scholars suggest that variation and selection is an alternative way to analyze portfolio management without using traditional normative decision theory or portfolio models (Pich, Loch & De Meer, 2002; Loch, De Meer & Pich, 2006; Loch & Kavadias, 2008b). Indeed, evolutionary theory provides a framework to study time dependent processes longitudinally. Importantly, evolutionary theory can conceptually cope with Knightian uncertainty (Brandon & Carson, 1996).

The framework of intra-firm evolution allows a fresh look into portfolio dynamics. There are three main reasons to use an evolutionary perspective to study innovative R&D project portfolio dynamics rather than the traditional, rational optimizing, form portfolio management. First, the evolutionary approach can cope with the notion of Knightian uncertainty. Second, the evolutionary outlook does not employ rational normative decision theoretical tools as a means of optimizing and does not share the associated assumptions. Third, in evolutionary theory no specific assumptions about managerial intentions and human behavior are made. This allows me to choose a framework where neither normative optimizing nor strategic intentions are used as theoretical constructs, but with which the phenomenon of portfolio dynamics can be tackled.

4. Methodology

4.1 Research methodology

4.1.1 Realism in ontology and epistemology

According to Nightingale (2008), we are witnessing a major change of deeply seated research paradigms in social science. There is a shift from an optimizing, reductionist, axiomatic, static and deterministic mindset towards a one that is dynamic, evolutionary, and history-dependent. Rational choice theory is losing its privileged status (Hodgson, 1993; Simon, 1979; Whitford, 2002; Vanberg, 2004). The mode of inquiry is moving away from explaining events and things with the help of "essences", such as factors, towards recognizing the primacy of variation in the world. This change of atmosphere in social science increasingly encourages the inclusion of both time and variety in academic research (Beinhocker, 2006; Nightingale, 2008), also in project portfolio management (Kavadias & Chao, 2008).

The philosophical outlook in this study is scientific realism (Popper, 1963, 1972; Niiniluoto, 1999a). According to the realistic position, social phenomena, such as organizational hierarchies and managerial decisions, exist objectively in the world irrespective of the researcher who studies these phenomena. Although the world is not assumed to be deterministic, it is appropriate to look for internal and external causes of events. The fallible realism of evolutionary epistemology pursues an explanation of why some entities survive through analyzing the variation of these entities, together with the changes in external conditions (Popper, 1974; Campbell, 1960, 1974; McKelvey, 1999).

The Darwinian evolutionary framework maintains that causal explanations are to be pursued with the help of selection mechanisms (Darwin, 1859; Gould, 2002; Hodgson, 2004). Causality in the ontological context of determinacy means that all events have causes, though these may not be unique (Hodgson, 2004). Causality is assumed to be determinacy and selection can be carried out by human agents (Hodgson, 2002; Hodgson & Knudsen, 2006). The criticism of evolutionary ideas as deterministic is not tenable (Singh & Lumsden, 1990; Hodgson, 2004). According to Hodgson (2004) the various ideas lumped together as "social Darwinism" arose from an autonomous life of many concepts; biological reductionism perhaps being the most prominent one. Co-operation, not just self-interest, is also a prevalent adaptive option in nature (Hodgson & Knudsen, 2008). Evolution does not imply the reductionist notion that sociological or psychological phenomena can be explained with the concepts of biology (Vromen, 2004). Still, human intentions and preferences ought to yield to causal explanation, too (Hodgson, 2007c). Evolutionary theory provides a causal explanation of the retention observed in the population (Nelson, 1995).

4.1.2 Process research

Processes describe how things evolve over time and why. The observer looks at the time axis of unfolding events rather than dissects a slice of the chain of events at a certain instant of time. A process is a sequence of events that tells how things change in the historical perspective. After decades of elegant variance-based scholarship there is an ever stronger trend to pay more attention to process based approaches (van de Ven & Poole, 1995; Abell 2004; Mayntz, 2004). Scholars have proposed process perspective as a means to understand innovations, uncertainty, evolution, selection, and causal pathways (van de Ven & Poole, 2005; Beinhocker, 2006; Dooley & van de Ven, 1999; Nightingale, 2008; Pich, Loch & De Meyer, 2002). Although many scholars have advocated a process approach, few researchers (for example Bower, 1970; Garud & van de Ven, 1992; Noda & Bower, 1996; Burgelman, 1983ab, 1991, 1994, 1996, 2002a; Tripsas & Gavetti, 2000; Pajunen, 2008) have conducted process studies inside firms. Older reviews on process research (van de Ven, 1992; Pettigrew, 1990, 1992a; Miller & Friesen, 1982), and those that are more recent (Pettigrew, Woodman & Cameron 2001, van de Ven & Poole, 2005, van de Ven, 2007), reveal a remarkably sluggish pace of advancement. The challenges for studying organizational change with process research have persisted. The methodology is developing slowly, and accordingly, the shift of emphasis is gradual.

As a means to study managers, Pettigrew (1992b) promotes a process approach, which has the following characteristics. Process study is embedded in the day to day unfolding of events. A process extends across a number of levels of analysis. The temporal interconnectedness of holistic actions is retained, and problem sensing is acute. Explaining events such as actions, decision makings, and outcomes through actors and the involvement of participants is possible. Through a process approach one can analyze temporal interconnectedness in order to detect antecedents and causes of events.

In the terminology of van de Ven & Engleman (2004), I pursue an event driven explanation. In the forward looking event driven explanation, observed events defined in the study are causes to later outcomes which are also observed. An event may act as a necessary cause meaning that this event is necessarily needed to occur to observe the outcome, but other events are needed too. A sufficient cause is one where the consequent outcome needs no other causes to occur. Standard regression frameworks incorrectly estimate causal effects when there is a need to postulate necessary or sufficient causes (Mahoney, 2004). Following Mayntz (2004), I choose process theory research as a methodology in order to explain causal effects and mechanisms rather than variance theory research that delivers outcome-driven explanations. Mayntz (2004) defines mechanisms as recurrent processes generating a specific kind of outcome. Mechanisms are causal links to explain events. Portfolio selection fits this criterion of a mechanism.

To conduct process research on the portfolio of projects I conduct historical comparisons between projects to unveil patterns of change. Event histories from many projects are cross-compared to uncover their similarities and differences. In historical social science, there are no repeated experiments that one can carry out at will. Yet, it is possible to observe many event sequences and their outcomes in different times and places, where some but not all conditions are equal. Event sequences cannot be reproduced, but one may argue by analogy. This “replication logic” captures something from a series of independent experiments (Brown & Eisenhardt, 1997). One compares many event sequences and their outcomes to learn about larger scale similarities and rejects smaller scale dissimilarities. The concept of evolution entails a process outlook. Analyzing process data requires a means to conceptualize events and detect patterns among them. Both Miller & Friesen (1982) and Pettigrew (1990) propose historical data sources as a convenient and relatively fast way of carrying out a process study. Defining a process is far from unique (van de Ven, 1992, 2007; van de Ven & Poole, 1995). The process research design in this study integrates practices from various authors (Miles & Huberman, 1994; Poole, van de Ven, Dooley & Holmes, 2000). The seven steps of study design are described in the flowchart presented in Table 4.

Table 4 Flowchart of methodological steps in collecting and analyzing data

	Step in analysis	Outcome
1	**Data coding from primary source** I identify managerial reviews and decisions on projects as events of study from primary archival sources on project and portfolio meeting histories. I code all managerial events. To categorize project attributes I follow R&D project dominant design and industry conventions. I code changes in project attributes due to managerial events.	**Primary data matrix** - Unit of analysis is a project - Primary data matrix on Excel sheet - Managerial actions coded as events - Project attributes and their changes coded - Ordinal time sequence conserved - Project attributes persist in time unless managerial events change them.
2	**Data development to portfolio level and aggregation to annual level** I add together data on project attributes of all projects to express the properties of total portfolio at any instant of time. I aggregate coded data from primary data matrix to characterize event sequences and changes in portfolio at annual level. This temporal bracketing helps the comparison of annual financial data with event data.	**Tables of annual time series on portfolio attributes and managerial events** - Unit of explanation is the portfolio - Project data are added up to portfolio attributes - Project attributes aggregated as annual median averages - Managerial events aggregated as annual total sum of events
3	**Analyzing annual data tables and listing portfolio level events and changes** I observe trends and changes in managerial events and portfolio attributes to specify interdependencies. I catalogue the findings. I include the analysis of financial data from annual reports.	**Summary tables of managerial actions and portfolio changes** - Summary tables on trends and amounts of changes - Managerial events on different levels of hierarchy - Portfolio dynamics - Project development stage dynamics - Figures to illustrate main findings
4	**Cross comparison of events and portfolio attributes and their patterns** I compare longitudinally the observed trends and deviations between trends across portfolio. I make a list of conflicting findings in portfolio dynamics and managerial events. I apply case firm definition on prioritizing criteria and other internal conventions. The observed trends in portfolio are realized strategies.	**List of conflicting findings to be explained** - Conflicting trends between managerial events and portfolio outcome - Conflicting trends in portfolio outcome - Conflicting trends in managerial events - Triangulation from financial data and industry evolution - Pairs of conflicting strategies
5	**Conducting QCA analysis** I construct a QCA data input table. The focal event is prioritization. I calculate the project attributes which are logically necessary conditions of prioritizing events.	**Data input table and table of co-selected attributes** - Primary QCA data input table - Project attributes that are necessary conditions to prioritization as the co-selected attributes
6	**Arranging managerial events to selection mechanisms** I apply definitions of selection mechanism to construct a set of selection rules and selection hierarchies to describe managerial events. I characterize how portfolio dynamics is determined by managerial intended events and other unpredictable events.	**Table of selection mechanisms** - Two levels of selection structures - Portfolio and project meeting level selection rules - Non-adaptive co-selection - Unforeseen terminations
7	**Preparing causal explanation** I describe how the co-selection mechanism provides explanation for observed conflicting realized strategies in portfolio dynamics. I compare the causal narrative with other different explanations and previous literature. I compose the narrative to illustrate the coherent pattern that integrates managerial action and portfolio outcome.	**Narrative** - Causal explanation of portfolio dynamics with selection mechanism - Interdependence of variation and selection

Different temporal patterns of various frequencies can be distinguished in a long term longitudinal observation. Pattern matching is a powerful tool for the falsification of conjectures. I use pattern matching to study the effect of managerial events regarding portfolio changes, selection mechanisms, interactions of selection levels, and how project age and project development stage are related.

I use triangulation by collecting data from different sources. Archival documents disclose the dynamics of the internal project portfolio and managerial behavior. Annual reports provide to the public financial and other history details of the firm. They reveal the firm's cost structure and success in collecting revenues and earning profit. Publications concerning the historical development of the industry, and the rise of R&D cost in particular, put project portfolio evolution into an external context.

4.1.3 Qualitative Comparative Analysis

I use Qualitative Comparative Analysis (QCA) to infer the causally necessary conditions for a co-selection mechanism during prioritization events. I interpret the necessary conditions as evidence for co-selection of these attributes. Initially developed for macro-social research, Qualitative Comparative Analysis (QCA) was first proposed by Ragin (1987) as a way to use Boolean algebra in comparative case analysis in order to find joint causes of outcomes in different event histories. According to Mahoney (2000a), extensive combinations of antecedents can be most conveniently handled with Boolean algebra. I shall use QCA to show that when an event in which a selection rule for project prioritization occurs, co-selection of some project attributes takes place. QCA is highly suitable for analyzing the presence and absence of necessary and sufficient conditions. The work of Fiss (2007) provides a review of the potential of using QCA in organization research. QCA is also increasingly applied in strategic management research (Pajunen, 2004; Greckhamer, Misangyi, Elms & Lacey, 2008).

The comparative method of QCA imitates John Stuart Mill's method of agreement for causality (Ragin, 1987). If investigators want to know the cause of a certain outcome, they should first identify instances of the outcome and then determine which circumstances invariably precede its appearance. These are the antecedents to the outcome. Mill's indirect method of difference can also be incorporated. If a second set of instances shows the absence of both the outcome and its invariantly preceding event, the conclusion is that the outcome did not occur for lack of its antecedents. Many possible causal explanations are permitted at the start of analysis. The approach aims to achieve maximum variability and therefore it is appropriate for using in an evolutionary framework. The main epistemological problem of QCA is that Mill's ideal method is not fully replicated; this is because the list of possible coded attributes has to be truncated for practical reasons. In order to select relevant events for coding, comparison and for the drawing of conclusions, researchers need good judgment, both theoretical and empirical, about the phenomenon they are analyzing. As, Amenta and Poulsen (1994) suggest, reasoning through the assistance of QCA is conjectural; QCA helps to conduct a dialogue between conjectures in order to suggest justification for a conjecture put forward by the researcher through a process of abduction.

QCA has the power to preserve the richness and complexity of event histories; however, to compare effectively such histories, data reduction may be necessary. Data that is analyzed by this method must be coded in a discrete binary yes/no form; the event or outcome is either present or not and it is usually necessary to use both partitioning and clustering of data from event histories. In this respect further data reduction through selective coding and meta-level aggregation may be needed. This therefore makes coding a creative procedure. Many visual display techniques can be used to make cross-history and cross category clustering plausible. For example, levels of data from event histories are easily presented in the form of a meta-matrix ordered in time.

After explaining event histories and outcomes, all earlier events about an outcome of interest in different cases are examined. One discovers whether one or more antecedent events always precede the outcome event. The aim is to also examine whether there are instances, in which no outcomes occur, and the antecedents were absent. If both of these conditions are fulfilled, then the antecedents are the cause of the outcome. The presence or absence of antecedents for an outcome in all different event histories is then compared in a logical procedure following the rules of Boolean algebra. Propositional calculus or elementary set theory is an equivalent formulation of the technique using Boolean algebra.

After the comparative analysis according to the logic of Boolean algebra, one arrives at expressions for antecedents that are logically reduced to a minimum. However, sometimes it may be more sensible to abstain from complete minimization; a richer structure of antecedents may better reflect a theory that explains the observed process. Observing which arrangements of antecedents and outcomes are not present may further help to provide justifications for researcher's conjecture and in this regard there are additional techniques and concepts in Boolean algebra to elaborate the analysis whereby sufficient conditions - prime implicants - for an outcome can be derived. Such minimization and prime implicant analyses simplify complex and lengthy logical sentences. Factoring is used for determining equivalences of logical sentences, and here De Morgan's rule for substituting logical connectives may be helpful for analyzing which antecedents go together with negative outcomes.

Antecedents in Boolean logical expressions that need to be present for consequent outcome to appear are called necessary causes. I apply QCA to detect the necessary conditions for prioritizing events and I interpret these necessary antecedent conditions for prioritizing as evidence of the co-selection of these attributes. All of the attributes that are attached to the project, and only these, are co-selected because they were parts of the project at the time of prioritization. Hence, I do not analyze whether collective attributes such portfolio size are antecedents to prioritization. It is possible that there is more than one necessary cause to prioritizing, and therefore more than one attribute may be co-selected. The application is summarized and presented in table 5.

Table 5 Application of QCA to warrant co-selection

QCA	**Application for detecting co-selection**
Focal event	Managerial action to prioritize a project
Antecedent	Project attribute
Necessary antecedent	Co-selected project attribute

There are a number of limitations to using QCA as a research method. The number of antecedents should be small compared with the number of event histories, since otherwise all event sequences for an outcome would be unique. QCA in its elementary form does not differentiate between antecedents that occur in the proximal or the distal past. However, these concerns do not matter when applying QCA for necessary causes in this study as there are ways to overcome this issue. One may introduce temporality by allowing antecedents from the more distant past to fade or totally vanish. One can also aggregate data to macro-level time epochs. These content-determined epochs provide a temporal demarcation between different sets of antecedents. A third method is to treat the different sequential permutations of antecedents in time as separate event histories for an outcome (Caren & Panofsky, 2005). In explaining causes, QCA is able to utilize only those antecedents which have been categorized to enter the comparison. QCA is sensitive to coding errors (Ragin, Schulman, Weinberg & Gran, 2003). Moreover, there is no mechanism to exclude "non-significant" attributes. The researcher must judge this from the context of the study or from theoretical considerations. It is worth bearing in mind that QCA does not resemble the aims of variance analysis which are to "explain" more or less of the observed variance; neither does it assess net effects. Rather QCA considers combinations of causes, and it is this property of QCA that is used when treating the co-selected attributes as necessary causes for prioritization.

4.1.4 Inference by abduction

Reasoning by abduction means the formulation of conjectures (denoted by A in the quotation that follows) that are evaluated in order to make sense of puzzling events (denoted by C in the quotation that follows). Charles Peirce (1903, CP 5.189) introduced the concept of reasoning by abduction "for studying facts and devising a theory to explain them":

"The surprising fact C is observed.
But if A were true, C would be a matter of course.
Hence, there is reason to suspect that A is true."

Substituting "conflicting strategies" for C and "co-selection" for A, the inference reads:

Conflicting strategies are observed. But if co-selection were true, observing conflicting strategies would be a matter of course. Hence, there is reason to believe that co-selection is true.

Today, abduction as a method of explanation by establishing novel ideas has secured a seat in the canon of reasoning. A conjectural explanation is fallible and tentatively valid until proven false (Niiniluoto 1999ab; Peirce, 1878, 1903; Popper, 1972). One infers causes as antecedents from their observed effects. The cause → effect relationship constitutes a mechanism. Compared with a formally consistent syllogism, abduction presents a strategy for gaining new knowledge rather than merely consolidating old knowledge at hand (Hintikka, 1998). Syllogistic reasoning is placing formal consistency of knowledge and avoiding mistakes above the growth of knowledge (Paavola, 2004). Syllogism is also a way of making the knowledge derived from axiomatic systems irrefutable knowledge, i.e. dogmatism (Hodgson, 1993; Vanberg, 2004). In this regard, syllogistic inference is the foundation of an axiomatic methodology.

Pursuing the growth of knowledge is in accord with Nightingale's (2008) demand for a shift in the foundations of new social science and also a hallmark of Popper's (1972) theory of conjectural knowledge required to solve Hume's problem of empirical inductive inference. Cultivating abduction logic invites scholars to engage in a continuous interplay between observational and conceptual work. Increasing numbers of scholars in business research turn to abduction as the model of reasoning in order to provide explanations (Weick, 2006; van de Ven, 2007; van Maanen, Sorensen & Mitchell, 2007). Scholars increasingly realize that all statements relating to evidence about measurement and history, even statistical tests of significance, involve abduction (Niiniluoto, 1999b). Using abduction invites scholars to offer justifications to support their conjectures and encourages others to refute them. I offer a conjecture relating to a co-selection mechanism and seek justifications from case data regarding conflicting developments in portfolio dynamics to justify this conjecture.

4.2 Research strategy and case context

The choice of research strategy is interplay between research question, the nature of data and the choice of method. In this study the data source is a unique archival history of events. The nature of data invites a process approach and event-driven mode of explanation. The history of projects describes a process where events occur at specific instances time, and changes over time are explicitly documented. The objective of my research is to discover, how co-selection explains the evolution of project portfolios.

Evolutionary theory is selected as a research framework. This perspective is able to incorporate the notion of Knightian uncertainty.

4.2.1 Case firm and its R&D project portfolio

I employ a longitudinal, explanatory case study in one international pharmaceutical firm that is R&D intensive and has a strong portfolio relating to innovative new product development. For reasons of confidentiality, the case firm has been given the pseudonym "Cinnamon". It is a listed pharmaceutical company present in all major markets. The company was organized into global business units that developed new products and delivered these to local subsidiaries for marketing and selling. At the time of study, the company had four business units, here each given color code names "Lime", "Lavender", "Blue" and "Tan". Lime and Lavender were the two larger business units. They both had a very large number of ongoing innovative R&D projects. Based on the number of new project initiations, Lavender was the focal business unit for Cinnamon. More R&D initiatives were launched in Lavender than in the other business units. The customer base of Lavender was different from, and more diversified than, that of Lime. Blue was smaller than Lavender and Lime and Tan the smallest of these units. Divergent from the three other business units, Tan was not really a global unit. R&D and product development were separately organized in each business unit, but controlled jointly by all business unit executives and other top managers. A pre-project research phase relating to innovation development was conducted separately from new product development projects and this was excluded from this study.

Some time before the nine year observation period that is the focus of this research the case firm divested their other smaller businesses to become a single industry pharmaceutical firm. The firm made acquisitions shortly before the observation period and consolidated the new pharmaceutical firms which were purchased. The years that were the focus of observation for Cinnamon were characterized by few and small changes in corporate structure. The business unit structure remained stable. No major acquisitions or divestments were made during the observation period. Some time after the observation period, following a merger with a global multi-industry firm, the case firm ceased to exist as a separate legal entity. During the observation period, the firm achieved steady organic growth of sales and maintained a high level of investment

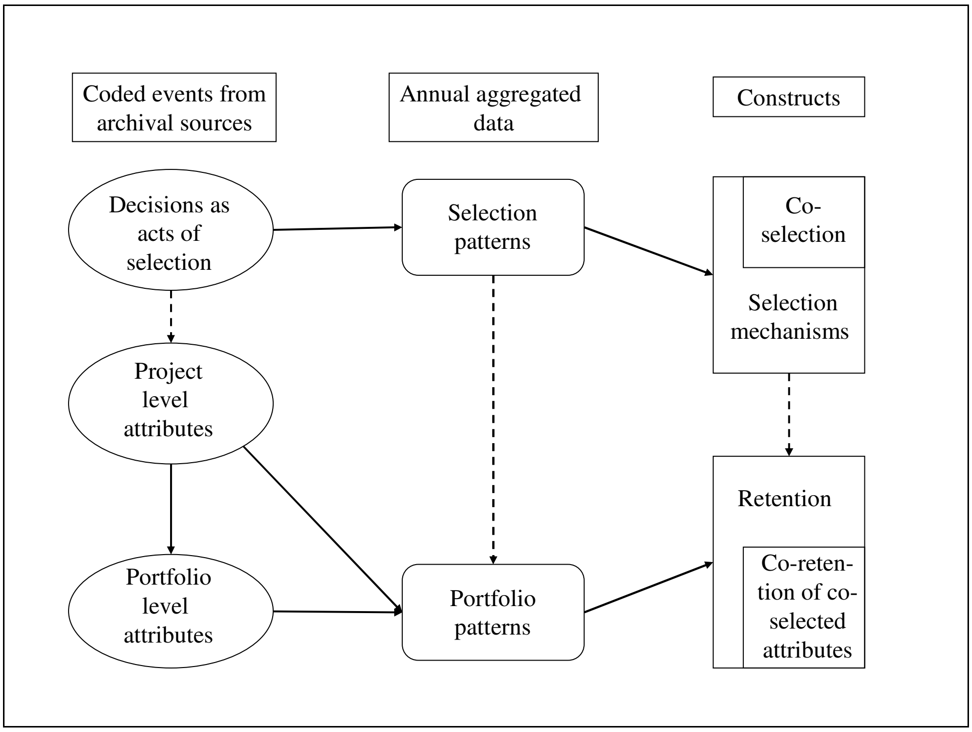
R&D, and a constant R&D investment to sales ratio. No sudden cataclysmic events in the industry took place during the period and market and competitive trends were somewhat different for each of the different business unit during these years. In general, the growth of generic manufacturing firms and the increase of R&D cost were typical for the pharmaceutical field.

Each product development program started as a new project from a pre-project discovery stage. Projects that were completed were released to market. Innovative R&D projects in the firm constituted a population. Variation was provided through new projects that entered the development process and through the progress of projects towards new development stages. Top management set up rules of procedure and organizational structures for the selection of R&D projects. In this regard an organizational selection structure – a review committee - channeled all projects to periodic portfolio reviews. Some projects were prioritized to shorten time to market and they were given a privileged position in terms of the allocation of resource. This prioritization was the mechanism for selecting projects to form a preferred population of projects in the portfolio. At any moment, a project was either labeled as "prioritized" or "normal". Termination and completion were the mechanisms that were employed to end the project. Some projects were terminated prematurely, due to either technological or to commercial hazards. Completed projects were either launched as new products or these projects were out-licensed. The activities of top management team constituted selection events, and therefore selection can be perceived as a consequence of top management decisions. The selection process led to the retention of preferred projects. Because a project portfolio review took place many times a year, every project was exposed to repeated selection during different development stages.

4.2.2 Defining measurements

Cinnamon had a long history of reviewing and selecting new product development projects. According to company documents, the structures and procedures for project and portfolio reviews were revised a year before the observation period commenced. The selection rule for prioritization was also formulated at this time. Organizational selection structures, processes and routines were then quite stable during the observation period. Project and portfolio evaluations were carried out in two committees at two levels of top managerial action. Details of managerial committees are given in appendix 5. The routines for new product development followed a consistent milestone decision procedure for passing projects to the next development stage. They had been established in Cinnamon a long time previously. Cinnamon followed a typical normative portfolio management process. The dominant design of product development in the firm corresponded to a sequential life cycle model with milestone decisions. Details of the product development process are given in Appendix 6. Following Bagozzi and Phillips (1982), a holistic model of constructs and measurable entities was crafted. Figure 3 shows the relations between constructs and measurable entities.

Figure 3 Constructs and measurable entities



In the following I define the following constructs and measurable entities: business unit, instant of time, project age, project lifetime, project average age, project development process, project development stage, milestone decision, portfolio decision, project committee, portfolio committee, criteria for project prioritizing and termination, criteria for milestone decision, portfolio attribute, and pattern. Other constructs seen in Figure 3 have been defined earlier.

Business units to which any project is assigned are designated as: *Lavender, Lime, Blue and Tan.*

Instant of time refers to the actual moment of recording an event. These are the dates of committee meetings.

Project age is the chronological age of a project at any specific instant of time. The age of the project indicates how long that project has been running since initiation.

Project lifetime is the total time that has passed from project initiation to completion or termination.

The average age (median age) of projects represents the duration in time when half of the projects are younger and the other half are older.

Project development process means to run a project from initiation to completion by executing all development stages of the project in the sequential order defined by industry dominant design of a project.

Project development stage is a part of the project development process. It is a sub goal. A project consists of a number of consecutive stages through which the development process runs. Examples of stages in new product development in the pharmaceutical industry are animal toxicology studies, pharmaceutical development and clinical trials. A project is within one development stage at time. The process consists of five stages designated as S2, S3, S4, S5 and S6. Some projects in stages S5 or S6 were already marketed and the project goal was, for example, either to follow up or a new therapeutic application. A pre-project discovery stage indicating that it was awaiting project initiation was not recorded in this study.

Milestone decisions steer the development process of a project. Access to the next project development stage is granted as a milestone decision. The more stages a project passes, the further product development has advanced. The five milestone decisions are designated as D2, D3, D4, D5 and D6. For example, a project approved for milestone decision D3 moves to stage S3 and remains in this stage until milestone decision D4.

Portfolio decisions refer to actions taken when the whole portfolio is examined. The decisions are project *initiations, prioritizations*, *de-prioritizations*, *successful project completions*, and *terminations*.

There were two permanent committees that undertook a project and portfolio review. Committee membership was authorized by top executives. Both committees had a meticulous approval procedure and a tradition of producing meeting minutes to document their decisions. These committees were the two selection structures for the whole population of R&D projects.

Project committee granted or recommended milestone decisions for entering the next development stage. It was responsible for project resource release according to milestone. A milestone decision presupposed that the previous stages in the project had been accomplished. Thereafter resources for the next stage were granted. Members of the project review committee were function and business unit leaders. For milestone decisions, the accomplishment of technological goals and risk was evaluated, but business and market risk or financial attractiveness beyond positive net present value threshold was not. Formal milestone criteria for achieving sub goals were applied. The process utilized all medical and regulatory understanding in the firm. Company business units were not entitled to approve milestones wholly on their own. Milestone decision for an individual project affected the overall portfolio resource status.

Portfolio committee decided on project prioritizations, de-prioritizations, initiations, completions and terminations. It was also able to veto a positive milestone decision but not overrule a negative milestone decision for not achieving a sub goal. The milestone decision D5 from pre-clinical stage to resource intensive clinical development stage S5 was formally approved in portfolio review after approval in project review. Members of the portfolio review committee were top executives, including the CEO. Formal criteria for terminations were established. Projects could be terminated for technological or commercial reasons. Terminations resulted from technology risk more often than from commercial risk. Prioritizations were clearly the most significant decisions in guaranteeing access to resources for running projects that were competing for limited resources. Prioritizations were proposed by the business unit. A portfolio board assigned formal prioritizations for projects. Although formal project technological and financial evaluation criteria were defined for the project review, no formal portfolio evaluation criteria existed for prioritization in the portfolio review.

Criteria for prioritizing projects, according to the managerial intention documented in the archival minutes, were to shorten time to market for products with high market potential and the opportunity for global exploitation. The two criteria were interdependent but not reducible to a single ordinal measure. For example, global access was important in itself for maintaining market presence and local sales organizations. This selection rule classified projects either to the category “prioritized” or to the category “normal”. Portfolio reviews utilized different techniques for evaluating and comparing projects, but according to the archival documents there was no specific procedure for establishing a unique ranking. Managers were entitled to take into account various sudden and unexpected twists of circumstance when making decisions about the portfolio. Decisions to prioritize represented real selective actions under uncertainty, with no guarantee for success.

Criteria for terminating projects were technological failure or re-evaluation of commercial potential and exploitation opportunity.

Criteria for milestone decisions were to fulfill the technological success criteria of a development stage.

Portfolio attribute is a property of the collection of projects that is not reducible to a project attribute. For example, the total number of projects, and the rate of change in portfolio size are portfolio attributes.

Pattern refers to the overall evolution of portfolio or selection properties based on annual aggregated data.

4.3 Data gathering and analysis

4.3.1 Coding of events

The primary data in this study were archival records of past portfolio committee and project committee meetings. The meeting minutes were reviewed and approved by the participants and thereby they constituted an authoritative internal record on what actually happened, which decisions were made, and what actions were taken. They were not intended to be publicly available. These reports formed an uninterrupted source of documented managerial action. Internal research and development handbooks covering the years of study were used as sources for clarifying standard operational procedures in the project and portfolio management. Additional data sources included the case firm's annual reports, and their website for detail of the general financial performance and firm structure. This study did not try to discover the internal process of arriving at the documented decisions. Furthermore, archival data from committee meetings did not provide details of any discussions during the meetings that revealed the rational, political or bargaining decision processes in the interactions of top managers.

In the process of coding information from archives, the critical question for each meeting document was: what happened? What were the actions taken or decisions made by this body of managers? The coding of events was mostly straightforward, since archival documents were written in a brief manner, only for internal use. The language of archival records was English. The following quotations from archives indicate the minimalistic, even laconic style and easy readability of the text that required coding.

The milestone decisions of the project committee were typically recorded as follows:

"Stage 3 was granted [to the project x]"
"The decision for stage 4 was granted [to the project x]."

The decisions to prioritize were also short, as the following examples from the portfolio board committee meeting minutes show:

“The project [x] was redefined to global and prioritized.”
“Project [x] status was switched to priority.”
“Top prioritized development projects are listed in the [table in the] appendix.”
“Milestone for stage 5 was granted. The project [x] was prioritized”

Decisions made by the portfolio and project committee (who recommend the decisions to the portfolio board committee) to initiate and terminate or complete a project were reported like this:

“The development [of project x] was terminated due to insufficient bioavailability.”
“The stage 2 [for project x] was approved.”
“The decision to terminate [project x] was approved.”
“The project [x] was terminated due to successful completion of development.”

During the period, in total the top managers discussed 274 projects. For some projects, part of the data was missing. Some projects were so short lived that it was not possible to document initiation and end in a reliable way. In addition, for some projects, development stages were not fully recorded. A few projects were renumbered or united. I coded the project attributes of all projects (stage of development, age, business unit membership, priority status) at the point of the project and portfolio meeting during the project’s lifetime. If a project was not discussed at a meeting, for coding purposes I assumed that its attributes were unchanged from the previous meeting. I also chronologically coded all decisions and other actions made in the project and portfolio committee meetings that changed project attributes as events (project initiation, project completion, project termination, project prioritization, project de-prioritization, project milestone decision, and project review). This resulted in 508 portfolio committee decisions and 347 project review committee decisions. A total of 746 review events where no specific decision on change of attributes was made were also recorded. Altogether, 10 different types of project attributes and 11 types of managerial actions and decisions were recorded. Decisions and portfolio status were recorded between 6 to 9 times annually for 9 years. In total, 83 meetings were held during the time period. The sequence and timing of actions and events were preserved. Data on all project attributes and events was coded by a nominal yes/no classification according to the presence or absence of an attribute of any project, or an event at an instant of time. A full data coding dictionary is presented in Appendix 2.

The sequence of time found in the primary archival data was chronological. Data included the date for the meeting and the approval of the minutes. In this study, time was represented as an ordinal scale, which preserved the temporal order. Events were also aggregated to obtain annual average or cumulative figures. This temporal bracketing permitted comparison between event data with the corporate financial data collected from annual reports.

The unit for measuring time was the chronological number of a committee meeting. Meetings had ordinal numbers from 1 to 83. The number of and type of meetings by year is set out in Appendix 4. The project age was chronologically given as the number of meetings of the project and portfolio committees from project initiation to present. For example, a project initiated in meeting 23 was 14 units of time old at the time of meeting 37. The meetings took place at almost, but not quite, regular intervals. Their number per year varied a little. It might have been possible to measure time with an interval calendar scale; however this approach would not improve the explanatory power because the intervals between meetings differed by only a few weeks. The time interval between actual meeting date and the approval date of the recorded minutes was typically 2 weeks. These differences were small against the study period of nine years. Moreover, data was aggregated to an annual level. The date when a meeting was held was recorded as the time of an event. Appendix 4 presents the chronology of committee meetings and units of time.

Project age provided a crude proxy for measuring the resources used for the project from initiation until present. Resources for development stages S2 to S6 were not generally interchangeable. This was particularly the case when clinical trials were conducted in stages S5 and S6; they needed resources radically different from resources required for stages S2 and S3.

Budget planning and investment decisions for research facilities were not addressed in primary data. Total R&D resources were allocated to business units through annual budgeting.

4.3.2. Constructing data matrix and aggregating data

Following Miles & Huberman (1994), event histories were developed for each project; they were recorded in an Excel file. Time sequences and types of action were conserved in the data reduction. All other variables were discrete and nominal; however the timescale was an ordinal, indeed almost interval. The data matrix contained 22742 rows and 21 columns in binary coding. Portfolio evolution was examined based on the data matrix. The observational unit of analysis was a project, whereas the explanatory unit of analysis was a project portfolio.

Event histories at a micro level may be too rich in detail for analysis. After coding was completed, project data was aggregated to annual median values. The aggregates of project attributes are portfolio attributes (number of projects, number of prioritized projects, number of projects by business unit, number of projects by development stage, and number of projects by age). Changes in project attributes in meetings created annual level changes in the portfolio. Event data concerning managerial actions was aggregated to an annual total number of events. The actions are portfolio level changes (number of prioritizations, de-prioritizations, initiations, terminations and completions, reviews, and milestones decisions).

The aggregated managerial events formed patterns which were examined as a means to understand managerial action. The aggregated portfolio attributes formed patterns which were examined to understand portfolio evolution. The analysis was carried out at an annual level to gain an understanding of the action pattern, portfolio development pattern and their matching. The time series of managerial action was compared with the time series of portfolio outcome. Managerial actions and portfolio changes were compared internally in order to detect patterns of change, and their consonance or dissonance.

Due to incomplete information, the age of projects initiated before year 1 could not be determined accurately. This left margin bias affects the data on project age and previous prioritization. To avoid left margin bias, portfolio meeting minutes from three previous years were examined to reveal the priority status decisions before year 1. This information was incorporated into the coded data. There are two systematic errors in recording project age. For projects that were initiated before the observation period, data on project age is incomplete in the archives of the three previous years that were available. For lack of complete data, project age was not calculated for years 1 and 2. From year 3 on, projects surviving over 2 years would actually be older than project median age which is 2 years, as calculated in chapter 5. The error would result in some projects being older than was coded. The exact date of some project initiations was not visible in archival meeting minutes. This is because no meeting records existed until the project was evaluated for the first time after being given project status. The overall development time for projects varied a lot because medication for acute use (days to weeks) require a shorter time for clinical trials than products for chronic use (years).

Because some decision was documented in two separate meeting minutes a few decisions were recorded twice. It was hard to identify, after which of the two committee meetings a decision was really put to action. For example, the portfolio committee confirmed the fact that project committee had effectively, but not formally, terminated a project for safety reasons. Here, the consequences of the two coded decisions had an effect on one project only.

Some projects in Cinnamon continued although the product had already been launched. This was either due to regulatory requirements for collecting phase 4 clinical data, or to the documenting of new applications or other ancillary properties in stages S5 or S6. All these cases had a project team assigned to perform R&D project development, so it was appropriate to list the ongoing activity as product development project; hence, it was not an artifact of the project notation conventions. Some projects were combined or the number switched, but this occurred only a limited number times.

4.3.3 Detecting co-selection

The attributes of and managerial actions relating to 274 projects were recorded to create QCA data input table. The software used was that developed by Ragin, Kriss & Davey (2006). The focal event was the prioritization decision. The attributes which could be co-selected were coded; these were business units (4), development stages (5), and previous prioritization. The QCA data input table had 274 rows and 11 columns. The simplified example in Table 6 with three attributes depicts the process of analysis. The label attribute C in the Table represents that the project had already been an object of managerial prioritization.

Table 6 Extract from QCA data input table

Attribute A "Member to Lavender"	Attribute B "Member to Lime"	Attribute C "previously prioritized"	Attribute D "project stage S5"	Focal event P "project prioritized"	Number of instances
0	1	0	0	0	43
1	0	0	0	0	17
0	1	0	0	0	8
0	1	0	1	1	3
1	0	1	0	1	3

The analysis proceeded in three steps. First, the QCA data input table was constructed. Three possible co-selected attributes were listed. The number of projects for each event history was also displayed. When analyzing a single event history, one checks which attributes are present and which not. The Boolean values for a given attribute are either 1 (true) or 0 (false). In Table 6, rows 4 and 5 denote different event histories with the outcome "project prioritized". In 43 projects, the sequence of antecedents was the same as displayed on row 1. In the second step, once all projects have been included, Table 6 shows the combination(s) of attributes present when the outcome event occurs. Third, necessary conditions are identified. The analysis compares attributes across projects using Boolean truth tables to discover which logical alternatives for co-selected attributes are realized.

Consider rows in Table 6 where the truth function in the column P takes the value 1 (true). The Boolean comparison shows that when prioritizations of projects occurred, then, as necessary conditions, either the attributes business unit Lime in development stage S5 were co-selected or the attributes of business unit Lavender and previously prioritized status were co-selected.

4.3.4. Testing reliability and validity

There is an ongoing debate on how to estimate reliability and validity in qualitative research (see for example Shenton, 2004). In the present study, which considers a single firm's R&D portfolio in which projects are embedded as cases within the case firm, validity and reliability are evaluated following the quality criteria presented by Yin (2003) with regard to case studies, and by the work of Singleton & Straits (1998) and van de Ven (2007). Reliability and validity are interdependent. Highly unreliable measures are not valid but highly reliable measures can still be quite invalid (Singleton & Straits, 1988).

Reliability measures how well another investigator can reproduce the findings of the study by following the same procedure (Yin, 2003). Reliable findings are consistent and repeatable (Singleton & Straits, 1998).

The principal data sources employed in this study were internal archival documents. There are problems associated with extracting events from historical records (Bryant, 2000). All meeting minutes for the period under study were preserved; however, there were some inconsistencies in the archival record, and some events may have remained unreported. Their style varied a little according to the person who had written them but, overall, they were short notes regarding the decisions that were made. Generally, the archival documents did not contain background information regarding discussions or arguments about how decisions were arrived at. I used the electronically archived original source documents in a pdf-format so that the need for any later editing would be unlikely.

Analyzing the wealth of narrative historical data leads to simplifications (Abbott, 1992). However, the style of archival documents was short, even laconic. The interest of the writers was only to report what specific types of decisions were made at the meetings on projects. I have provided quotations from archival material to illustrate the precise style of the documents. From the researcher's perspective a benefit of examining such concise texts is that their coding is easier than that of a very lavish text. Hence, interpreting which scripts refer to the events for coding was much less problematic than for most archival records. Two key informants gave advice with regard to details on the coding of events, operational procedures and organizational structure. However, these key informants did not review the results for reasons of retrospective bias. For selected samples of documents the reliability of coding of the events from archives was tested with the help of a third person, and was found to be consistent with the author's own coding scheme.

The database containing primary data table was produced on Microsoft Excel spreadsheets, and the collating of such data were conducted by standard tools available in Excel. The coding for QCA analyses was copied from an Excel data sheet to a QCA data sheet. To ensure completeness and of transfer the copying between the different software products was checked by paper and pencil.

Validity, with regard to measurement, means the congruence between an operational definition and the concept it is supposed to measure (Singleton & Straits, 1998). High validity means a good convergence of various findings. The problem remains that we do not usually know the "correct" value or answer, and therefore the assessment of validity is either subjective or indirect. The assessment of validity is inherently more problematic than the assessment of reliability. In qualitative empirical research, tests of validity are most often used to examine construct validity, internal validity and external validity (Yin, 2003).

Construct validity refers to how well operational measures capture the meaning (but not necessarily the accuracy) of the concepts being studied. Data collection affects construct validity. To assure good construct validity I used multiple sources of evidence in order to carry out data triangulation. The study relied on two types of archival data: internal meeting minutes, not meant to be publicly available, and publicly available annual reports. I compared the evidence from internal sources with public financial data sources. I also used research papers published about the evolution of the industry as a means to reflect on the institutional and competitive environment in which the case firm was embedded during the period of analysis. For internal consistency the standard categories of pharmaceutical industry and project portfolio management were employed. Operationalization was conducted according to the outline proposed by Bagozzi & Phillips (1982) which was adapted for qualitative research.

Although triangulating with the help of data from interviews is often useful, a retrospective bias might easily confuse the explanatory narrative; particularly in this study so because the time span is a decade and therefore, differentiating between intended and realized outcomes in portfolio management could be affected. Although retrospective data sometimes provides information that is not available from other sources, distortions may arise when interviewers require actors or subjects to looking back and explain the past. The problem of bias relating to memory of the past (retrospective bias) has been recognized, and techniques to minimize such bias have been presented (Huber & Power, 1985). However, according to Huber & Power (1985), individual and universal biases in combination "can be expected to have important impacts on retrospective report from strategic-level managers."

Retrospective bias has been documented, for example, in the context of research leaders reporting their research projects (Huber, 1985). Sometimes there may be an intentional motivation to do so. There is also empirical evidence of the limitations to reliability and validity when top managers retrospectively account for a firm's strategy. Scholars such as Golden (1992) seriously question using retrospective accounts in management research, and Miller, Cardinal, & Glick (1997) warn against indiscriminate use of retrospective reports. For this reason it was decided that interviews did not offer a satisfactory source of data, although key informants were used to check the reliability of coding.

Internal validity in explanatory studies is an estimate on how strongly the causal explanations are derived from data analysis. As suggested by Miles & Huberman (1994), I employed a data matrix to analyze coded events. Following Langley (1999) and van de Ven (2007), as a means to identify event patterns from coded data I used the synthetic processes of the temporal bracketing of data – aggregating events at an annual level – and visual mappings to seek patterns in the data. I aggregated information from individual projects to numerical tables and pictures in order to reflect the whole portfolio.

Sequences of events and outcomes, visual mappings, temporal bracketing, and narratives are considered helpful ways to make sense of patterns and mechanisms (Langley, 1999). In building an explanation I used pattern matching. I aggregated data into annual time series in order to detect such patterns and tabulated observed events and portfolio outcomes and compared these against each other and pair-wise. I used Qualitative Comparative Analysis (Ragin, 1987) to logically validate co-selection as a new type of evolutionary mechanism. I also addressed and analyzed a number of alternative rival explanations.

Following Abell (2004) and Pentland (1999), I condensed my descriptive findings into a concise narrative synthesis as a means to causally explain evolutionary events with co-selection mechanism; thus the composition is chronological. Actors are managerial teams. The narrator is the author of this study; a story that describes managers in pursuit of success for the business units of the case firm. Over time, constraints for making choices emerged.

External validity addresses the generalizability of the results of the study. I used the evolutionary theory framework of variation, selection and retention. In addition to the theory framework, I formulated the conjecture that co-selection should be regarded as a novel evolutionary mechanism. In this respect, I applied an analogy from biology (Darwin, 1859) and I inferred by the logic of abduction that there are justifications for this conjecture. To an extent, QCA applied replication logic to units of measurement at project level. However, it is important to underline that the conjecture was theory driven.

Of importance is that the conjecture of co-selection can also be falsified; a distinct sign of critical theorizing (Bacharach, 1989). The utility of the conjecture derives from the fact that no such entity is previously described in management theory. Therefore, by analogy, the concept is used to bridge two theoretical discourses and thereby serves as a valid explanation mechanism.

5. Results

5.1 Managerial action on R&D portfolio

The results of the analysis of R&D portfolio and managerial action in Cinnamon are reported in three parts; these follow the steps that were presented in Table 4. First, the action patterns of managers are portrayed and summaries of these patterns are presented. Second, the dynamical pattern of change in R&D projects and portfolio is described and the key findings are crystallized. Third, key findings are grouped together to form a set of contradictory statements. Tables of aggregated numerical data are presented in Appendices 7 to 12. The annual aggregated data is also displayed as Figures 4 to 10 in text and in Appendices 13 to 27. The figures display the numerical data of tables in the appendix in a concise and easily perceivable form. Key figures are presented in the text and others in the Appendices.

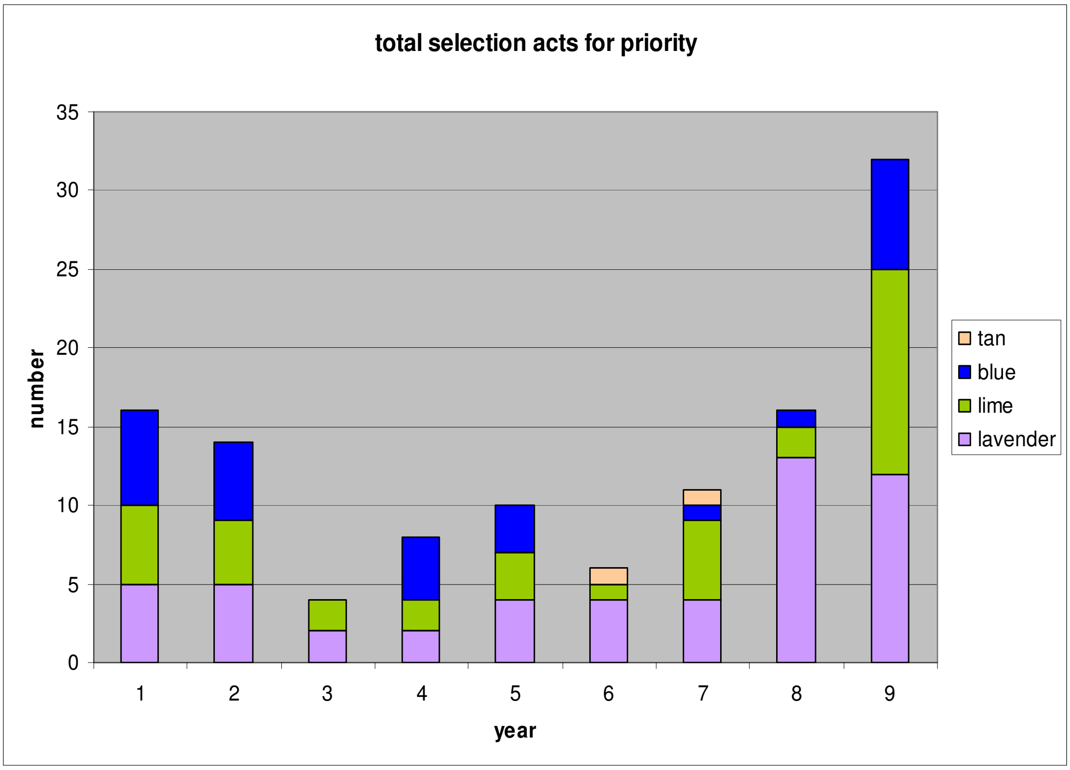
The results relating to managerial influence on projects are summarized in the following statements as conclusions. The annual event sequences are tabulated in Appendix 7. The figures that illustrate annual event sequences are given in Figures 4 and 5 and in Appendices 24 to 26. The details of QCA crisp-set Boolean analyses are presented in Table 7 and Appendix 12.

Altogether 26 portfolio committee meetings and 57 project committee meetings were held fairly regularly during nine years. The total number of all events was 1601. Of these events, 855 were decisions and 746 were reviews. The portfolio committee made 508 decisions and the project committee made 347 decisions. The portfolio committee undertook 72 reviews and project committee undertook 674 reviews. The number of review events decreased over time. *Conclusion*: the project and portfolio committees differed substantially with respect to numbers of events, the proportion of decisions to reviews, and the frequency of assembly.

There were 192 project initiations (Appendices 7, 25). Initiations were at a maximum in year 4. There were 83 initiations in the Lavender business unit, more than in any other business unit. There were 50 initiations in the Lime business unit, and their number was decreasing. *Conclusion*: The number of initiations was largest in the focal Lavender business unit. The number of initiations in Lime business unit decreased.

There were 118 project prioritizations (Appendix 7). Attaching priority was at the lowest level between years 3 to 6, and a maximum at year 9 (Appendix 7). In the Lavender business unit, 51 events of prioritization occurred. In Lime, 37 occurred. Some prioritizations were applied to a project already prioritized. *Conclusion*: The number of prioritization events in the focal Lavender business unit was larger than that in Lime or the other business units, as shown in Figure 4.

Figure 4 Acts of prioritization by business unit

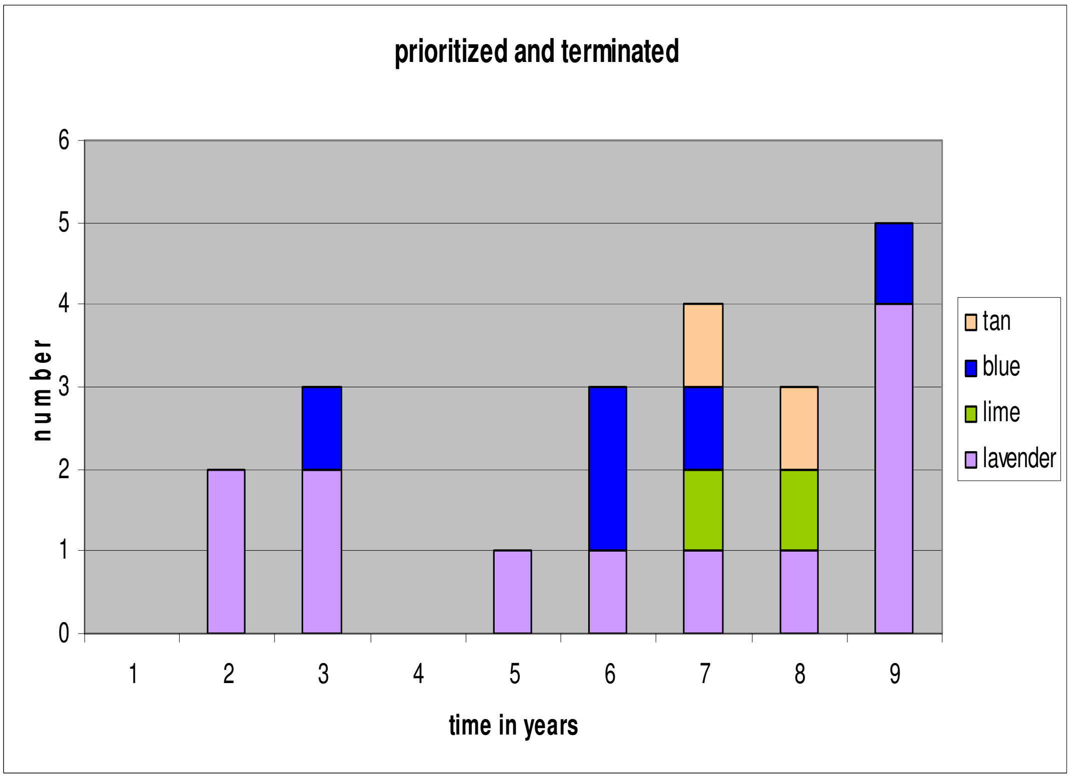


During the nine years covered by the observation period, 22 de-prioritization decisions were made (Appendix 7). For 17 events to de-prioritize, termination events soon followed. Two projects were de-prioritized twice. The lowest levels of de-prioritizations were between years 5 to 8, and a highest in year 9. *Conclusion*: The number of de-prioritizations was small.

Project terminations, totaling 103, were at there highest in years 4 and 5, and a lowest in years 6 to 8 (Appendices 7, 26). There were 40 terminations in the Lavender business unit and 26 terminations in Lime. The rate of initiations to terminations was 48 % in Lavender and 52 % in Lime. *Conclusion*: The rates of terminations to initiations in Lavender and Lime business units were comparable.

Altogether 27 % of prioritized projects were terminated against 40 % of all projects. Of the projects prioritized by Lime, 2 were terminated. In Lavender 12 prioritized products were terminated. *Conclusion*: The number of terminations of prioritized projects in the Lavender business unit was much higher than in the Lime business unit, as shown in Figure 5.

Figure 5 Terminations of prioritized projects by business unit



The total number of completed projects was 18, of which 4 were prioritized. The number of completed prioritized projects was 2 for the Lime business unit and 1 in Lavender and Blue business units. A completion was either an out-licensing or a successful ending of a project. All but one completion of both the total projects and prioritized projects occurred in the final two years. The completed projects were not the only ones that were introduced to the market or out-licensed. Some projects delivered products that were launched in some markets and the project continued for filing in other countries (USA, Europe or Japan), or for more extensive documentation due to post-launch follow up commitments. *Conclusion*: There were few completed projects.

The total number of project committee milestone decisions peaked in year 4 (Appendix 7). Project milestone decisions by phase did not vary over time. Milestone decisions D2 for projects to enter stage S2 were the most numerous. Not all projects commenced at stage S2 because some benefited from earlier development work and may have started at later stages. *Conclusion*: Milestone decisions were almost evenly spread across years.

The QCA results displayed in Table 7 are evidence that the various attributes were co-selected when the selection rule for prioritizing was applied. Projects prioritized once in business unit Lavender were in stages S2 and S3. Projects prioritized twice or more were in stages S4 and S5. The priority status of projects in development stages S4 and S5 in Lavender was reinforced by reprioritization. It is noteworthy that only 12 configurations of attributes out of a possible 40 possible were co-selected. *Conclusion*: Necessary causes of prioritization include the selected development stages in business units.

Table 7 Project attributes that were co-selected in prioritizing projects

Business unit	Development stage	Development stage of previously prioritized projects
Lavender	S2, S3	S4, S5
Lime	S2, S3, S4, S5	
Blue	S3, S4	S6
Tan	S3	

5.2 Portfolio evolution

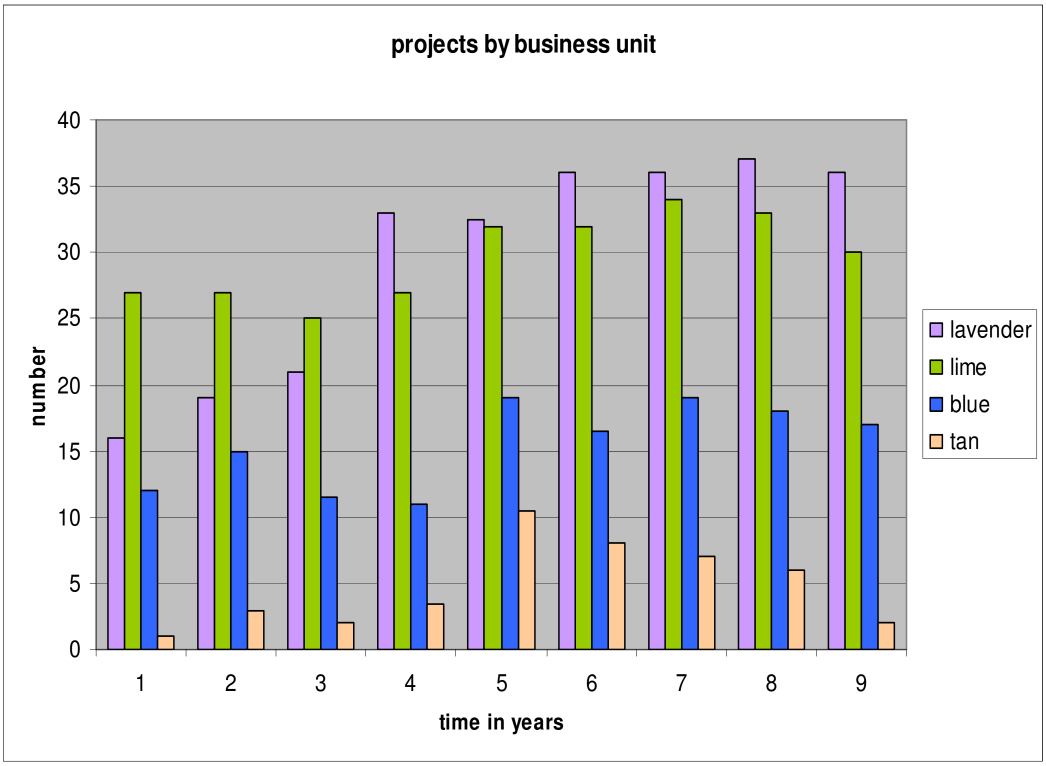
The major findings concerning portfolio dynamics over nine years are summarized in thirteen statements. The illustrations of annual event sequences are provided in Figures 6 to 7 and in Appendices 13 to 16 and Appendices 21 to 23. Numerical data on portfolio evolution is displayed in Appendix 8. Numerical data on the age distribution is provided in Appendices 9 to 10 and figures in Appendices 17 to 20. Performance and

R&D cost data gathered from annual reports are presented in Appendix 11 and in figure form in Appendix 27.

The total number of projects in the portfolio initially increased up to year 7 from 56 to 95 projects, and then declined to 85 projects (Appendix 8). From years 5 to 8 there was a plateau of the maximum portfolio size. *Conclusion*: Portfolio size first increased and then decreased.

Projects in the Lavender business unit increased from 16 to 36 corresponding to a growth of the portfolio from 29 % to 43% (Appendix 8). After year 3, Lavender was the largest business unit. *Conclusion*: The focal Lavender business unit grew to have the greatest number of projects, as seen in Figure 6.

Figure 6 Number of project by business unit



The Lime business unit increased slightly in size from 27 to 30 projects. This business unit declined in relative size from 48 % to 36 % of the portfolio and lost the majority to Lavender. The Blue and Tan business units were smaller. The relative size of the Blue business unit decreased during the nine year period and the Tan business unit almost died out (Appendix 8). *Conclusion*: The number of projects in the other business units decreased relative to those in Lavender.

The number of prioritized projects increased from 11 to 29, amounting to 35 % of portfolio projects in year 9 (Appendix 8). During years 6 to 9 there was a constant number of projects in the portfolio, but a relative increase of prioritized projects. During nine years, the portfolio size increased by 34 %, and the prioritized projects by 171%. Of the total of 20 de-prioritized projects, 17 were soon terminated. One de-prioritized project was quickly reprioritized and two projects remained de-prioritized until completion or to the end of the observation period. *Conclusion*: The number of prioritized projects increased both relatively and absolutely.

Prioritized projects in the Lime business unit grew from 5 to 10. The Lavender business unit grew from 3 to 15. In year 8, Lavender still had less prioritized projects (11) than Lime (12). During the observation period, the Lime business unit altogether held 84 prioritized projects, and Lavender held 73. *Conclusion*: The number of prioritized projects in the Lime business unit remained larger than in the focal business unit Lavender, as seen in Figure 7.

Figure 7 Number of prioritized projects by business unit

The cumulative age of the total portfolio increased (Appendix 9). The annual median average project age rose to 37 unit of time by year 8, after which it started to decline. The age of a project varied from less than 1 to over 9 years. The annual median age of projects increased during the observation period. Median age of a project was 2 years. The median age of projects in all business units increased until year 9, with a slight decrease on that year (Appendix 9). The frequency of very old projects was highest in the Lime business unit (Appendix 9). The mean age of projects particularly increased in the Lime business unit, to 46 units of time compared to 35 in Lavender. *Conclusion*: the age of the projects increased.

The age of prioritized projects increased. The annual median average age of prioritized project rose to 52 units of time by year 8, after which it started to decline. Prioritized projects were older than other projects. In the Lime, Lavender and Blue business units prioritized projects were markedly older than other projects. Prioritized projects were older than all projects in terms of development phase. Although the mean age of prioritized projects in these three units and those in Lavender declined in year 9, those in Blue and Lime increased to 70 and 59 units of time respectively (Appendices 9 and 10). *Conclusion*: Prioritized projects grew older than other projects.

The mean age of projects particularly increased in the Lime business unit to 46 units of time compared to 35 units in Lavender. Although the mean age of all prioritized projects and prioritized projects in Lavender declined in year 9, those in Blue and Lime increased to 70 and 59 units respectively. *Conclusion*: Prioritized and other projects were older in the Lime business unit than in Lavender.

There were 7 prioritized projects in Lime that were older than 60 reviews and correspondingly, 1 project in Lavender (Appendix 10). There were 16 prioritized projects in Lavender that were younger than 20 units of time and 2 projects in Lime. *Conclusion*: There were more old prioritized projects in the Lime business unit than in Lavender.

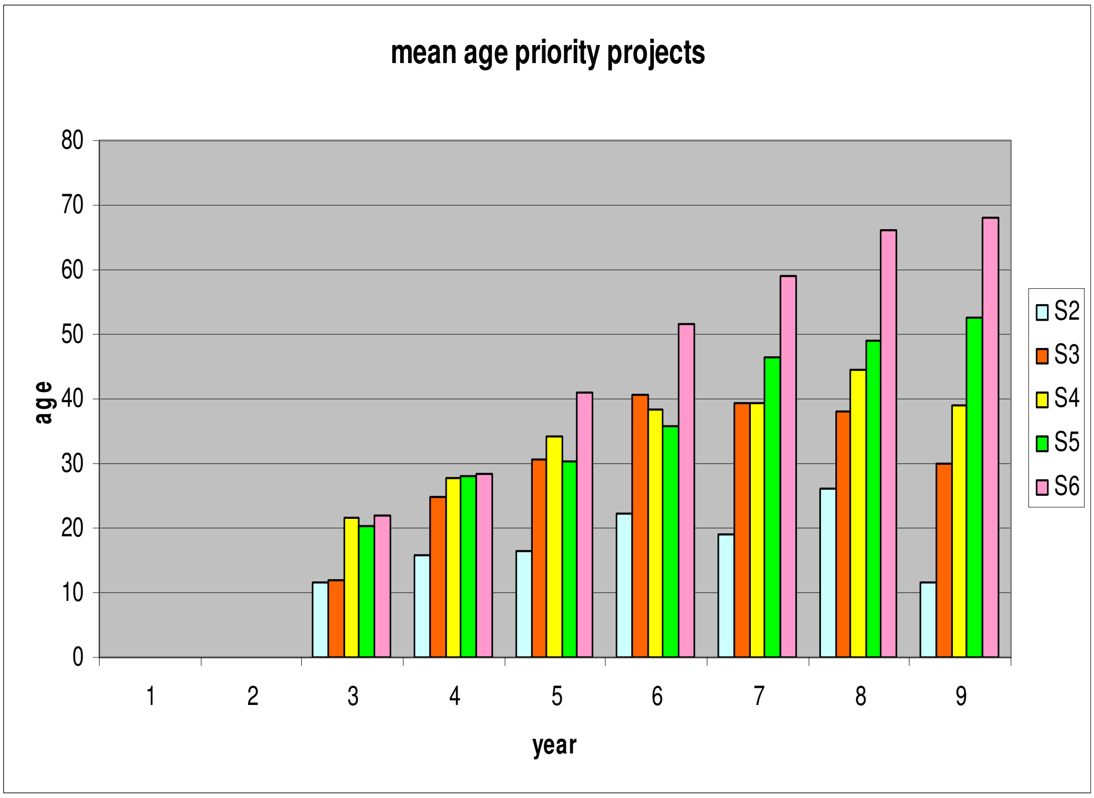
Due to left margin error, the age of all projects initiated before year 1 could not be determined accurately. The age of all projects was therefore set zero in the beginning of year 1 (Appendix 7), and project age for comparison purposes was reported first from year 3 on. Since there were 48 initiations and 17 terminations during the two first years (Appendix 7), the number of young projects at the beginning of year 3 was at least 31, compared with the total average of 65 projects during year 2. The left margin error would mean that no more than 34 projects were older than 2 years at the beginning of year 3. The lag of 2 years in reporting the ages was selected because it is the median age of all projects in the observation period. Technically, this means that the average ages are somewhat higher by a constant than those reported, and this only diminishes because 40 % of all projects were terminated during the nine years (Appendix 7). Hence, the annual increases in project age are not an artifact, although the real values of median ages are higher than reported.

The distribution of projects to different stages remained remarkably stable with respect to all stages over the years (Appendix 8). But for year 3, projects in stage S2 were the most numerous throughout the years. In year 8, projects in stage S5 become more numerous than those in stage S2. *Conclusion*: Distribution of projects by development stage remained approximately constant in the portfolio.

There were more old projects in stages S5 and S6 both overall and with regard to prioritized projects (Appendix 10). *Conclusion*: Projects in stages S5 and S6 were older than the others.

Prioritized projects in stage S5 dominated the portfolio between years 5 to 8. The number of projects in stage S6 increased steadily (Appendix 8). The average age by project stage increased (Appendix 9). *Conclusion*: Prioritized projects in stages S5 and S6 increased in the portfolio, as shown in Figure 8.

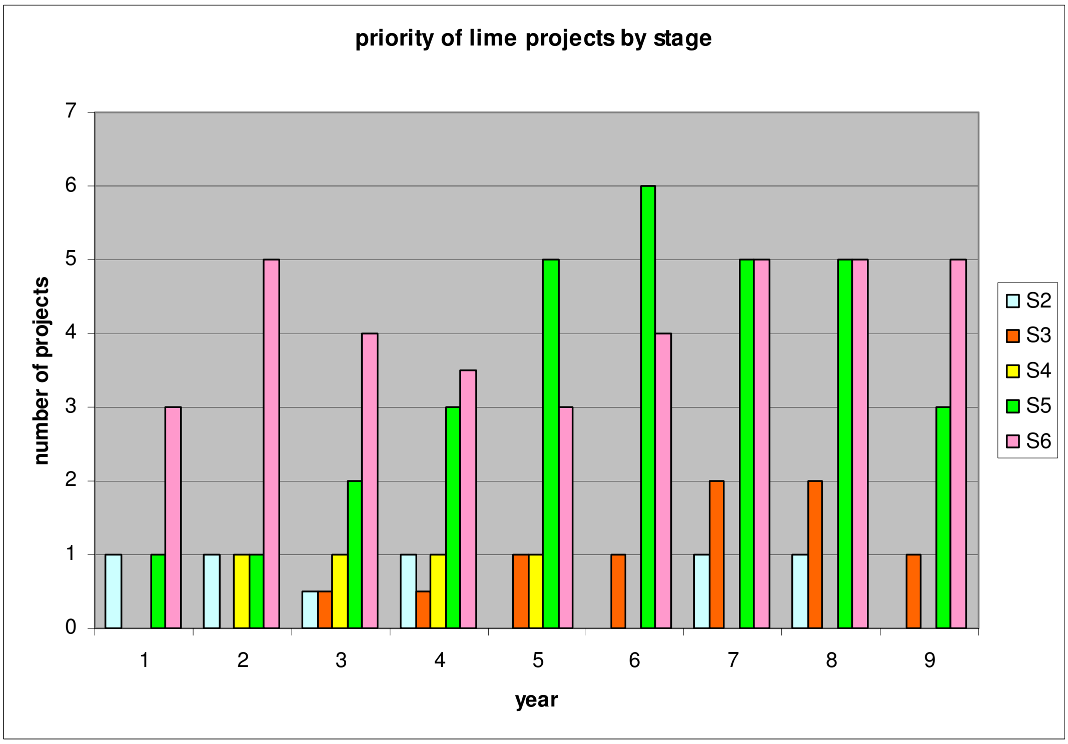
Figure 8 Mean age of prioritized projects by development stage



The total number of prioritized projects in stages S5 and S6 taken together is larger in the Lime business unit than in Lavender. In Lime, the majority of prioritized projects were in stages S5 and S6 taken together. In the Lavender business unit the prioritized projects were more evenly distributed by phases (Appendix 8). *Conclusion*: Lime had more prioritized projects than Lavender in stages S5 and S6, as seen in Figures 9 and 10.

Figure 9 Prioritized Lavender projects by development stage

Figure 10 Prioritized Lime projects by development stage



The total number of completed projects was 18, of which 4 were prioritized. No projects were completed between years 4 to 7 (Appendix 7). *Conclusion*: The number of completed projects was low, and there was a gap in the middle years.

Total investment in R&D increased 72 % over the nine year period. R&D costs increased more than the 34 % increase of the number of projects in portfolio over the years in question, but less than the 171 % increase of the number of prioritized projects in the portfolio (Appendix 11). *Conclusion*: The annual R&D costs increased more than portfolio size, but less than the amount of prioritized projects.

The overall development of R&D spending compared to sales and earnings was fairly constant. Earnings developed more slowly than sales in years 5 to 7. R&D funding was constant between years 7 to 8 (Appendix 11). The duration of a project provides a crude proxy for R&D investment used by the project and business units. *Conclusion*: The rate of R&D investment to sales remained constant.

5.3 Comparison of empirical findings

Data from the case firm at an annual level is condensed into five tables displaying core empirical findings. The analysis of managerial action in Table 8 reveals a historical development that also displays managerial intentions. The majority of the project initiations were in focal business unit Lavender. Managers prioritized more projects in the Lavender business unit more often than elsewhere. Terminations occurred evenly in the two largest business units. However, in the focal unit many more prioritized projects were terminated than, for example, in Lime.

Table 8 Patterns of managerial selection action

Action / Target	Initiations	Prioritizations	Terminations	Completions
Total projects	peak in middle	low in middle	low in middle	low
On Lavender projects	largest number	largest number	moderate	low
On Lime projects	decrease	moderate	moderate	moderate
On prioritized Lavender projects	n. a	n. a	high	low
On prioritized Lime projects	n. a	n. a	low	low

The empirical results relating to portfolio development in Table 9 show that in Cinnamon, the management invested continuously in R&D projects. Total spending and investment by projects increased. However, due to the remarkable increase in prioritized projects, R&D investment calculated per prioritized project nominally decreased. The specific historical situation at Cinnamon at the beginning was that the

Lime business unit held the majority of projects. Lime also held the majority of prioritized projects. The development history of the focal business unit Lavender presents a conflict, as seen in Table 9. Lavender soon became the biggest business unit in the R&D project portfolio. However, this unit did not achieve the largest business unit status in the subset of prioritized projects.

Table 9 Patterns of portfolio evolution

Entity	Pattern	Volume/Quantity
Number of projects, portfolio size	First increases and then diminishes	Portfolio size doubles at the peak to diminish somewhat
Number of prioritized projects	Grows	Absolute and relative increase
Number of Lavender projects	Grows	Absolute and relative increase to become the biggest business unit and overtake Lime
Number of prioritized Lavender projects	Grows	Absolute and relative increase does not lead to overtake Lime in the number of prioritized projects
Number of Lime projects	Almost flat	Absolute increase but relative decline
Number of prioritized Lime projects	Grows	Absolute increase but relative decline
R&D spending	Grows	Constant to sales and earnings
R&D spending per project	Grows	Constant to sales and earnings
R&D spending per prioritized project	Diminishes	Constant to sales and earnings

The distribution of managerial decisions in comparison with reviews in the two committees presented in Table 10 differs remarkably. In the portfolio committee, very few reviews were conducted. Most of the reviews were conducted in the project committee.

Table 10 Patterns of selection structures

Property	Portfolio committee	Project committee
Decision pattern	Fluctuates	Constant
Decision volume	Somewhat lower	Somewhat higher
Review volume	Very low	Very high

Looking at the progress of project development at a portfolio level (Table 11) reveals that there were no large changes in the distribution of projects at each stage. In particular, the proportions of projects in stages S5 and S6 remained constant. In contrast, the proportion of prioritized projects at stages S5 and S6 increased. Projects in stages S5 and S6 were accumulated in the subset of prioritized projects. The distribution of prioritized projects by stage differed from the distribution of all projects by stage.

Table 11 Patterns of project development stage evolution

Entity	Pattern	Volume/Quantity
Project in stages S2, S3, S4, S5, and S6	The distribution by stage fluctuates but no changes in relative ratios	Absolute increase in all development stages
Projects in stages S5 and S6	The distribution by stage fluctuates but no changes in relative ratios	Absolute but not relative increase
Prioritized projects in stages S5 and S6	Grows	Absolute and relative increase

The analysis of project according to chronological age history (Table 12) shows that the age of the total portfolio increased. Remarkably, prioritized products were older than all projects on an average. The older projects accumulated at stages S5 and S6 and were held by business unit Lime. Both the prioritized and all projects in the focal business unit Lavender were younger than those in Lime, and there were less at stages S5 and S6.

Table 12 Patterns of project age evolution

Project age	Age pattern	Volume/Quantity
Total projects	Increases	n. a
Lavender projects	Increases	younger than Lime projects
Lime projects	Increases	older than Lavender projects
Projects in stages S5 and S6	Increases	older than projects in other stages
Prioritized projects	Increases	prioritized projects are older than other projects
Prioritized Lavender projects	First increases then declines	younger than prioritized Lime projects
Prioritized Lime projects	Increases	the oldest prioritized projects
Prioritized projects in stages S5 and S6	Increases	Less projects in Lavender than in Lime, older than other projects

The findings in case firm Cinnamon indicate that the relationship between actions relating to the project portfolio and portfolio evolution were not straightforward. The evolution of the portfolio displayed conflicting pairs of actions and outcomes. For example, managers prioritized projects to shorten time to market, but the age of prioritized projects increased. The conflicting actions and outcomes are referred to as observations A and B. Six pairs of observations are presented in summary in Table 13.

Table 13 Observed pairs of evolutionary patterns

Number	Observation A	Observation B
Pair 1	The total number of projects first increased and then diminished.	The number of prioritized projects increased both absolutely and relatively.
Pair 2	Managers prioritized projects to reduce time to market.	The age of prioritized projects increased.
Pair 3	Managers initiated more projects in focal business unit Lavender than in the other business units. Lavender became the biggest business unit.	Management made more prioritizations of projects in focal business unit Lavender than in the other business units. Lavender did not become the biggest business unit by the number of prioritized projects.
Pair 4	Managers terminated projects in equal proportion to initiations in all business units.	Most of the terminations of prioritized projects occurred in Lavender business unit.
Pair 5	Managers made milestone decisions at a fairly constant rate.	The relative number of all projects by development stages S2 to S6 remained quite stable. The absolute and relative number of prioritized projects at development stages S5 and S6 increased.
Pair 6	Managers made portfolio decisions to initiate, prioritize, terminate and complete projects at fluctuating rates.	Portfolio productivity measured as the number of completed projects presented a gap.

The observed pairs of actions and outcomes arose and were sustained in the R&D project portfolio in Cinnamon. To justify whether co-selection is a major mechanism to causally explain this pattern, one must clarify to what extent the findings are plausible if the conjecture of co-selection is assumed.

6. Discussion

6.1 Co-selection in project portfolio evolution

6.1.1 Prioritization as a means to focus R&D investment

During nine years Cinnamon's total investment in R&D increased by 72 %. This increase did not match the increase in cost of executing a single pharmaceutical R&D project. The amount of corporate resources available for R&D was limited by the relatively moderate 66 % growth in overall sales volume and 95 % growth in profitability over nine years. Moreover, the drop in revenues in year 7 resulted in flat R&D funding increase in years 7 to 8 which worsened the situation. This made it increasingly difficult for Cinnamon to maintain higher than average levels of R&D spending. Over the period, the number of Cinnamon's R&D projects increased 34 % and the number of prioritized projects 171%. At the beginning, 20 % of projects in the portfolio were prioritized, by the end, the figure was 34 %.

In the environment in which Cinnamon operated, developing new products became more expensive. The overall average R&D costs of a new drug were escalating in the pharmaceutical industry. The average total R&D cost to sales ratio doubled between years 1980 to 1993; from 7 to 13 % (Grabowski & Vernon, 2000). The complexity of clinical trials increased significantly in the 1990s which partially explained the fourfold increase of clinical trial costs in one decade (DiMasi, Hansen & Grabowski, 2003). This trend continued in the 2000s amounting to a tenfold increase of the real R&D costs per new molecule in a thirty year period since the mid-seventies (DiMasi & Grabowski, 2007). The escalation was larger in product development costs than in product discovery costs (DiMasi et al, 2003; Gilbert, Henske, & Singh, 2003). Despite the increase of R&D spending in the industry, the number of new chemical entities introduced decreased (Cockburn, 2004).

Firm size has been shown to be a determinant of research productivity both in scale and scope (Henderson & Cockburn, 1996). Selecting and prioritizing the most promising new product development project is a standard technique in project portfolio management (Archer & Ghasemzadeh, 1999, 2004; Cooper et al, 1997ab, 1998;

Standard for Portfolio Management, 2008; Jamieson & Morris, 2004; Thiry, 2004; Dye & Pennypacker, 1999; Milosevic, 2004).

Cinnamon was a sizeable global player but not one of the very few industry giants. Firm size may have emerged as a limiting factor in the attempts to maintain a diversified R&D project portfolio and four business units in Cinnamon. The allocation of resources in the firm was fully in line with the standard prescriptions relating to resource allocation and prioritizing in the project portfolio management literature. The growth in number of prioritized projects in comparison with portfolio size suggests that prioritizing in Cinnamon was a way to improve resource allocation in order to cope with the escalating R&D costs. According to corporate documents, prioritizing was pursued to shorten the time to market of these projects. This makes the increase of prioritized projects a plausible solution to the problem of managing expenses at the time when the total project portfolio was not growing, but rather diminishing.

6.1.2 Prioritization and co-selection mechanism

The construct of co-selection mechanism turns out to be a very helpful way to understand the divergence of managerial action and portfolio outcome in the focal business unit Lavender. The prioritization rule in Cinnamon was to select projects with high commercial potential and the opportunity of global exploitation. The selection rule for prioritization was built on managers' best understanding of the anticipated adaptive success of a project in the future, not merely on the facts about external environment at the time. This type of internally driven selection was vicarious with regard to external environmental selection.

When managers selected for priority, the prioritized projects had additional attributes which were co-selected. Applying QCA confirmed instances of co-selection of a selected set of attributes in Cinnamon. For example, when the focal business unit Lavender projects were prioritized, these projects were in development stages S2 to S5. When Blue projects were prioritized, these projects were in stages S3, S4 and S6 (Table 7). In Lime, projects were prioritized throughout stages S2 to S5. Thus, in the act of prioritizing, different project development stages by business unit were co-selected. Business units were co-selected too. Co-selection was non-adaptive, since it did not follow as a consequence of the selection rule for prioritizing in itself, but rather from internal constraints. Managers could not influence the dominant design of the pharmaceutical project stages. Since internal constraints between project features appeared, co-selection was unavoidable. Table 14 summarizes the selection mechanisms for priority at work in the portfolio committee at Cinnamon.

Table 14 Selection and co-selection mechanisms in prioritizing

Selection mechanism	Selection structure	Selection rule	Selection object
Prioritization decision vicarious selection internally driven	Portfolio Committee	high commercial potential and global exploitation opportunity to shorten time to market, vicariously adaptive	Project
Co-selection	Portfolio Committee	non-adaptive selection when applying prioritization rule	Project attributes, like business unit and project stage

Studies on managing portfolio of new product development projects recognize the challenge of interactions between different projects (Ghasemzadeh & Archer, 2000; Girotra, Terwiesch & Ulrich, 2007; Chan, Nickerson & Owan, 2007; Loch & Kavadias, 2002; Kavadias & Loch, 2003; McCarthy, Tsinopoulos, Allen & Andersen, 2006). Types of project interdependencies have been classified (Blau, Pekny, Varma & Bunch, 2004). Projects should be prioritized according to both project and portfolio level criteria (Archer & Ghasemzadeh, 1999, 2004). A portfolio ought to be balanced with the help of dividing the total available resources due to the constrained allocation to resource quota, by the type of project, the resource type, geography or business unit (Standard of Portfolio Management, 2008; Cooper et al, 2001b).

Intra-firm competition of business units presents a challenge to achieving a balance by business unit. According to Birkinshaw & Lingblad (2005) and Galunic & Eisenhardt (2001) intra-firm competition may arise from a business unit charter overlap or by the fluid definition of a charter. The practical project portfolio management literature recommends the grouping of R&D projects into “buckets” according to various categorizations in order to balance risk and interdependencies (Cooper et al, 1998, 2001b). Taking account of project interdependency requires the organization-dependent weighting of goals (Dickinson, Thornton & Graves, 2001). Empirical scholars suggest there is no one single technique that satisfies the needs of a practical R&D project selection technique (Ringuest, Graves & Case, 2004). Balancing requires that the project attributes are categorized. Project attribute categories and metrics to measure them are firm and industry specific (Crawford et al, 2005). Dividing the R&D investment into a quota for explorative and exploitative (March, 1991) or "induced" and "autonomous" development projects (Burgelman, 1983ab) have been suggested (Wheelwright & Clark, 1992; Artto & Dietrich, 2004).

In Cinnamon, business units were buckets to which R&D funding was allocated independently from portfolio selection. This allocation did not limit project initiations. Business units in Cinnamon had high barriers as a result of rather permanent heterogeneous choices that defined fundamental customer orientation, therapy sector, research and marketing strategies, and therapy reimbursement policies. The business unit charters in Cinnamon did not change and their overlap was minimal due to different end-user customers. Business units naturally competed to attain increases of the annual R&D budget quota. The task of applying this allocation was given to the portfolio committee. The size of the R&D funding quota influenced initiations and the overall number of projects in a business unit. Prioritization was made across all R&D projects by the portfolio committee. Allocating R&D resources to buckets did not affect prioritizations as such.

R&D project categories other than business unit memberships coded in Cinnamon were the project development phase and age. The number of prioritized projects in stages S5 and S6 increased. Projects in stages S5, and especially in stage S6, when a new product had been already marketed, were exploitative rather than explorative by nature. According to the archival minutes, achieving a balance for these categories was not undertaken in the portfolio committee. There is no information available of whether any other attributes were balanced at the portfolio level. There is no mention in the archives to support the idea that prioritized projects were balanced against other projects. Clearly, their relative proportion increased. There is no straightforward explanation to the question of why managers reprioritized some but not all of the prioritized projects; especially in the Lavender business unit portfolio committee meetings. This may relate to the managerial focus of attention, agenda setting at business unit level, or it may have occurred by chance. During reprioritizations, the development stage could change, but the business unit would not.

I have found no mention in the previous project portfolio management literature that intra-project constraints due to the dominant design inside an R&D project affect selection. There is no overarching idea about the dominant design of projects that is explicitly stated in the literature. However, co-selection makes constraints by dominant design empirically visible. Co-selection caused the projects of business unit Lime and projects in development stages S5 and S6 to be retained in the prioritized project portfolio.

6.1.3. Initiations, terminations and co-selection

In Cinnamon, the size of R&D funding budget was fixed in relation to sales. To qualify as a new project, the initiative had to fulfill technical "proof of concept" requirements at the project committee approval stage D2 in order and to enter development stage S2. Business units were free to propose new projects under annual budget constraints. Initiations proposed by business units were approved by the portfolio board. There were 191 initiations. The highest amount of project initiations, 44 % of all, were made in the focal business unit Lavender compared to the remaining three units; indicating intent to invest heavily in this business unit over the nine years. The number of projects in portfolio at the same time was not restricted.

The dynamics of project initiations (191 times), terminations (101 times) and project completions (18 times) in Cinnamon determined the net increase in portfolio size. Table 15 presents the termination mechanism.

Table 15 Selection mechanism in termination

Selection mechanism	Selection structure	Selection rule	Selection object
Termination decision environmental selection externally driven	Portfolio Committee	Technological failure or re-evaluation of commercial potential and exploitation opportunity	Project

The highest amount of project terminations, 40 % of all, occurred in the focal business unit Lavender. However, 60 % of terminations in prioritized projects hit this same business unit, compared to 10 % in Lime. The unforeseen large number of terminations in the prioritized projects of Lavender business unit led to a relative dominance of the prioritized Lime projects. Looking backward, the prioritized projects in Lavender business unit were riskier than those in Lime business units. The overall termination rates for all projects in business units Lavender and Lime were comparable.

According to the funnel approach put forward by Wheelwright & Clark (1992) choosing the size of a R&D portfolio is related to risk and development success. The funnels are firm and industry specific and build on past experience. In the new product development literature there are no general criteria for choosing the optimal number of projects for total R&D resources (Adams et al, 2006). The number of R&D projects to be developed at a given resource level is dependent on the screening process (Lieb, 1998). Scoring models are typically used to screen new project candidates, and their criteria are set at the firm level (Calantone, Benedetto & Schmidt, 1999). Measuring development capacity by total budget or by total resources for different project stages is not a very accurate approach (Seider, 2006). A recent review notes that scholars do not yet understand the relationship between selection tools and project portfolio size (Killen, Hunt & Kleinschmidt, 2007). The previous literature concurs that there are often too many projects for the amount of resources (Cooper et al., 2001a, 2001b, Engwall & Jerbrant, 2003), and that this may increase portfolio aging (Lieb, 1998).

Managers' decisions about the number of new projects given to business units are acts of business strategy. The project portfolio management process both aligns a portfolio with old strategy and creates new strategy (Cooper et al., 1998; Englund & Graham, 1999; Smit & Trigeorgis, 2006). There are few tools to address the problem of alignment in portfolio management (Iamratanakul & Milosevic, 2007), although strategy table approaches are recommended for such alignment (Spradlin & Kutoloski, 1999). However, comparative metrics fail to account for "mandatory" or "sacred cow" projects that get selected in any case (Archer & Ghasemzadeh, 2004). The normative models of project portfolio management cannot explain the two-way interaction found in empirical studies relating to project portfolio dynamics. The two-way interaction becomes plausible in studies reporting the struggle of autonomous explorative strategic initiatives for legitimacy (Burgelman, 1983b), the importance of project champions for project success (Howell & Shea, 2006) and the existence of individual project strategies (Artto, Kujala, Dietrich & Martinsuo, 2008; Jamieson & Morris, 2004).

The specifications of a new product development project are very hard to change once the project is set into motion (Milosevic, 2004). This restricts the opportunities to increase the portfolio variation by redirecting the goals in early projects. According to Christensen & Bower (1996), in allocating resources for new R&D investment, technological risk is underestimated, whereas market risk is overestimated. Hence, terminations for technology reasons tend to be unpleasant surprises which can only be overcome by new project initiations.

In Cinnamon, the exact reasons for termination were not always available in the archival documents. In a few instances termination was reported to come about from changes in the market, and in other instances, milestone decisions were not granted for lack of fulfillment of technical criteria. If technological risk is generally underestimated, there is reason to suggest that project terminations in Cinnamon were quite often due to failures to meet technological specifications. Although managers formally decided to terminate projects, terminations were effectively caused by external selection that was based on either technological or commercial reasons.

The projects in Cinnamon which were prioritized and not terminated were retained with their non-adaptive co-selected attributes, but prioritized project that were terminated were not. In Cinnamon, co-selection during prioritizing and unexpected terminations due to Knightian uncertainty (Knight, 1921) shaped the realized strategy. Old prioritized projects in the Lime business unit accumulated at the expense of the focal business unit Lavender.

The unexpected terminations of projects created a sudden need in Cinnamon to refill the portfolio with new project candidates for the Lavender business unit; this was not fully met. In the light of data from the firm, it was perhaps not very easy to swiftly replace projects that were suddenly terminated with new ones. Finding a candidate for pre-development discovery already required screening, therefore suitable candidates were not always hand in the pool of prospects; nor could projects that had already commenced be easily redesigned. Hence, it was not possible to immediately repair the consequences of unforeseen terminations in the Lavender business unit. The number of completed projects remained low. The unforeseen terminations helped the unexpected co-selected attributes to dominate the prioritized proportion of the project portfolio.

This suggests an explanation for the productivity gap which was not compensated by increasing variation.

6.1.4. Project age, project stage and co-selection

In Cinnamon, project age increased in the course of the observation period (Appendix 9). Remarkably, the age of prioritized projects increased too. Moreover, as an average, the prioritized projects were older than other projects. The projects which had reached development stages S5 and S6 were older due to the sequential dominant design by stages in R&D projects in the pharmaceutical industry. The average age of projects in stages S2 to S4 showed fluctuation and a small increase, whereas the age of projects in stages S5 to S6 steadily increased year by year.

Analyzing the overall frequency of project age by business unit in the course of nine years reveals an important difference between the Lime unit and Lavender, the focal business unit. Giving consideration to the difference between all business unit projects (Appendix 10), altogether there were 14 of 67 Lime projects aged over 70 units of time (over 7 years) compared to 6 of 91 projects in Lavender. There were 41 projects younger than 40 units of time (under 4 years) in Lime and 69 projects in Lavender. This trend is also visible in the prioritized projects. Altogether there were 5 of 16 Lime prioritized projects aged over 70 units of time (over 7 years), compared to none of the 31 Lavender prioritized projects. Altogether 24 Lavender prioritized projects were younger than 40 units of time (under 4 years) compared with 8 Lime prioritized projects. This comparison shows that there were very many young prioritized Lavender projects in the portfolio and few old ones.

Further analysis shows how age depended on the project development phase in Cinnamon (Appendix 10). All of the 11 prioritized projects aged older than 50 units of time (about 5 years) were in development stages S5 and S6. Of these, 8 projects were held by Lime and 2 projects to Lavender. As a result, prioritizing projects in the portfolio increased the project age of projects that were in development stages S5 and S6. .When Lime projects were prioritized their projects in advanced stages S5 and S6 were retained. Since these projects were old to begin with, their retention contributed to the further aging of prioritized projects in the portfolio.

The projects' chronological age increased daily until the projects were terminated or completed successfully. Project age also depended on prioritization to shorten time to market. Portfolio age as an aggregate attribute depended on the age of its projects. The rate of initiations and terminations or completion of projects set the pace of portfolio aging. By reference to unforeseen terminations in prioritized projects (Figure 5), as noted in the previous section, altogether 12 (60%) of these terminations took place in the focal business unit Lavender, and 2 (10 %) in the Lime unit.

Due to Knightian uncertainty (Knight, 1921) in project development, Lavender prioritized projects were hit by terminations but not Lime; this created a gap of missing Lavender projects. Hence, the proportion of prioritized Lavender projects did not surpass that of Lime. The effect of co-selection combined with unforeseen terminations that 'knocked out' young projects explains the problem of missing prioritized projects in focal business unit Lavender. This also reinforced the productivity gap since old projects were not completed, whereas they were continued in the Lime business unit.

6.1.5. Milestone decisions for project development

Managing the product development process took place in the project committee making milestone decisions to allow projects to advance to the next development stage. Making milestone decisions was also a selection event. The selection rule was the compliance with technical – rather than commercial – specifications. Selection occurred at every specific stage in a project. The successful fulfillment of project criteria by stage entitled the project to pass on, however, if the stage specifications were not met, the project stage was not changed. Indeed, the reasons to terminate projects by technical criteria usually arose from the fact that project stages were not completed. Milestone decisions reveal the micro-management of R&D projects. Table 16 presents the selection mechanism of project milestone decisions in Cinnamon.

Table 16 Selection mechanism in milestone decisions in project development

Selection mechanism	**Selection structure**	**Selection rule**	**Selection object**
Milestone decision	Project Committee	Fulfill the technological success criteria of a development phase	Project development stage attribute

In Cinnamon, milestone decisions were made at a fairly constant rate throughout the observation period. In the project portfolio, the number of projects at different development stages fluctuated somewhat (Appendix 7). The proportion of projects in stages S5 and S6 was slightly larger, and the proportion of projects in stage S2 was slightly smaller in year 9 than in year 1. Remarkably, the overall relative distribution of projects by stage fluctuated but changed very little during nine years (Appendix 8). The constancy of both milestone decisions and total project distribution by development stage in the portfolio is in contrast to the increase in variation resulting from decisions to initiate projects. Five explanations to this constancy of distribution by development stage seem plausible.

First, the project committee deliberately controlled the distribution through milestone decisions. If this were the case the following problems would arise. The portfolio would expand and shrink over time, which would make the task of controlling it more difficult than if portfolio size were constant. The milestone selection rule did not contain this type of empowerment. The project committee did not restrict the number of initiations, in other words, the number of projects at stage S2 of R&D funding. There were no comments to suggest this kind of behavior in the meeting minutes; nor was there evidence of bookkeeping of this kind of quota in other documents.

Second, the effect arose from additional project specifications and ongoing changes in goal setting by external or internal stakeholders. Although regulatory requirements became more complex in some instances, this external effect was not evenly distributed across projects, business areas, and therapy fields. Hence, it could affect the overall portfolio age but not the balance of project distribution by development stage. The onset of this effect would be gradual. Although project goal setting was refined due to reconsiderations, and the results of new information from project development, this again could increase the total age of the project but not lock the distribution of projects in portfolio by project stage.

Third, the capacity to execute tasks by development phase was 100 % saturated, and therefore a constant distribution of projects by project stage could arise. But these events would probably affect different development stages in different ways and cause deviating trends in quota rather than dampening them. If development capacity in all stages was already saturated before prioritizing started, then there were probably more projects than the development funnel could absorb. If the funnel is saturated, then there is reason to prioritize, but if full capacity has already been reached then this leaves no room for prioritization. Since portfolio initiations grew in the early years, managers considered the funnel not fully saturated. Hence, this scenario is unlikely.

Fourth, the portfolio committee intentionally balanced the portfolio by development stages. This view is not supported by the evidence from the archival data, where no reference of balancing was made. Nevertheless, should this have happened, the explanation goes against the consequences of applying the selection rule for prioritizing. Prioritized projects in development stages S5 and S6 in the Lime business unit increased due to co-selection. This fact is at odds with the idea of the undocumented balancing activity of top management.

Fifth, the effect arose from restricted resource quota with regard to personnel, capacity and timing in the critical chain either at the business unit or corporate level. Some organizational friction may have arisen when corporate functions with different types of resources within R&D were negotiating the annual workflow. This could affect the critical path of ongoing projects. For lack of additional evidence, this proposal also remains conjectural.

6.1.6. Interaction of portfolio and project committee selection rules

In Cinnamon, the two organizational selection structures, the portfolio committee and the project committee, had different tasks and partly different people nominated to each. Both committees did have a say about the resourcing of projects, although in different ways. Both committees also observed whether projects should be terminated due to technological hurdles. The way the two selection committees worked differed radically with reference to review events. Projects were reviewed in both committees, and sometimes no changes to their status were made. These review events that did not result in further decisions can be regarded as events for information gathering. The review of any project could, for example, signal the importance of the project, lack of some critical information, or an unexpected turn of events. A project review event was an opportunity to gain more information about project status, although the decision was to make no decision on the project status.

The two committees differed radically with regard to the number of review events. No less than 90 % of review events without decisions took place in the project committee, and only 10 % in the portfolio committee. There were about two times more reviews than decisions in the project committee and eight times more decisions than reviews at the portfolio committee. Portfolio committee meetings were also held less frequently than project committee meetings. This suggests that there was a lot of detailed fact gathering in project committee in order to make milestone decisions. Project specific issues regarding detailed information gathering were more important to project committee, but less significant to portfolio committee.

In Cinnamon, there were inevitable interactions between the two selection committees. Prioritizations followed the selection rule to choose products of high commercial potential and global exposure. The portfolio committee initiated and prioritized projects so that priority status and portfolio size were advised to the project committee by the portfolio committee. But the dependencies between the two selection structures were in both directions. A project's dominant design did not change when it was prioritized. The business unit membership and development stage remained unchanged. The stages of project development were strictly sequential and according to the dominant design. Internal procedures in accordance with regulatory requirements specified the selection rule for a project milestone decision. The project committee did not pass a milestone decision to release resources for the next development stage unless a project fulfilled technical specifications relating to the ongoing stage. If milestone requirements were not met, additional testing would cause delays, and such testing would require more resources. The timing of milestone decisions could not always be anticipated, but failure to pass project committee selection delayed the project, and this would affect time to market. Worse still, the portfolio committee sometimes had to terminate the project if the project committee refused to give a milestone decision to pass the project forward to the next stage.

Although prioritized projects were allowed to let resources to sit in bottlenecks, they were unable to utilize these resources if milestone requirements were not met. Milestone decisions could delay prioritized projects but not accelerate them. Project committee could not accelerate product development beyond a minimal throughput time dictated by the dominant design even if resources were available for the prioritized projects. In this regard the time to complete a development stage was hard to compress. In Cinnamon, the cumulative age of both total portfolio and the prioritized portfolio increased to lengthen time to market.

The evolutionary literature suggests that different selection structures at different levels interact (Burgelman, 1983ab, 1994; Aldrich & Ruef, 2006; Murmann et al, 2003). To function at all, selection structures at different levels are suggested to be loosely coupled (Levinthal, 1997; Weick, 1995) or informal (Brown and & Eisenhardt, 1997). Studying Intel, Burgelman (1994) showed the conflict between two levels of a hierarchy. The hierarchies had two selection rules that conflicted. Top management wanted to sell memory chips. Middle management applied the selection rule for highest profit and initiated production wafers to manufacture processors, which were more profitable than memory chips. Applying the selection rule of middle management, processor as the product type was co-selected. This was against top management's intent. There is very little project management literature on multi-tasking congestion in a multi-project environment where priority coordination is important (Adler, Mandelbaum, Nguyen & Schwerer, 1995).

Optimizing resource interactions to maximize the efficiency of portfolio management by trading off capacity against speed, as recommended by Kolisch, Meyer and Mohr (2005), could not be realized in Cinnamon due to the project dominant design. Prioritizations could accelerate a project only up to the next milestone decision at any one time. Time to market has been measured for example by comparing on schedule delivery with an accelerated schedule (Filippini, Salmaso & Tessarolo, 2004). Some scholars pay attention to the difference between moment of entry and development cycle time (Artto & Dietrich, 2004; Langerak, Hultink & Griffin, 2008). Artto & Dietrich (2004) contrast efficient, goal setting clock time "chronos" required for planning with effective strategic opportunity timing "kairos" for choosing the right moment to act.

The prior literature claims that prioritizing would speed up time to market (see Archer & Ghasemzadeh, 2004). Best practice studies have not specified the actual effect of prioritizing (Cooper & Edgett, 2003; Cooper et al. 1997a, 1997b, 2001b, 2004; Griffin & Page, 1996). Brown and Eisenhardt (1997) note that prioritization seeds efficacy.

Prioritizing is beneficial to pacing (Thiry, 2004), securing resources and scheduling for initiations (Leach, 2004), and determining portfolio size and balance (Archer & Ghasemzadeh, 2004). One should pursue to shorten time to market even at the expense of elevated development costs (Cohen, Eliashberg & Ho, 1996).

The reasons to shorten time to market as much as possible in the pharmaceutical industry are twofold. First, a shorter time to market before expiry of the patent is directly related to brand saliency and growth of sales. It goes together with gaining access to a large territory as early as possible. Second, many new products try to establish a new therapy standard, which would be disruptive to old products at the marketplace, and can thus claim premium pricing. Product launches in the pharmaceutical industry usually follow the "Winner-take-all" model of market entry.

In Cinnamon, selection structures at different levels of the organization had different selection criteria, and these levels did not function in a concerted manner. The interaction between the selection structures created a negative externality which served to delay project development. Top management would be likely to note if prioritized projects were not given fast lane, but whether they were delayed is another thing. The only legitimate delay would arise from selection in the project committee. For milestone decisions, specifications had to be met even if it created a conflict with project priority. The interaction between selection structures is suggested to explain the relatively constant quota of project development stages in project portfolio.

According to the evolutionary literature, there is no necessary match between the hierarchies of populations and selection mechanisms (Baum & Singh, 1994; Warglien, 2002). Interactions between portfolio management and project management at different levels of hierarchy that results in conflicting outcomes have not been addressed in the portfolio management literature. In this study this interaction arose from the conflicting selection rules of the two hierarchies and the resultant co-selection to block the resources of the ongoing development stage if a timely milestone decision was not made. This also affected time to market.

Decreasing time to market was a highly relevant goal for Cinnamon. Prioritization was a deeply seated and well documented management practice in the firm and is typical portfolio management practice. Evidence from Cinnamon challenges the view that prioritizing as such is considered effective in shortening project lead time. Scholars have not paid enough attention to selection rules and structures, their interactions and the need for additional resourcing.

6.1.7. Portfolio management success

The ultimate success of projects as launched products was not examined in this study. Very few new projects were completed successfully. Some projects in Cinnamon continued although the product was launched. This was either due to regulatory requirements or the documenting of new applications or other ancillary properties. These projects were in either stage S5 or S6. All these projects had a project team assigned to perform R&D project development, so it was appropriate to list the ongoing activity as a product development project. It would take some years to discover how successful a product launch was. However, it is possible to recognize a performance gap in the portfolio. Very few product completions at a portfolio level (Appendix 7) indicates that new market entries were rather a result of product improvements (new applications and galenic forms) and increase in the scope for marketing (regional to global) than with totally new products. Slow annual sales growth also suggests this. However, data relating to the exact unfolding of portfolio projects to products generating new revenue year by year was not available. Some products were launched although the project still continued to gather regulatory phase 4 clinical data for regulatory authorities.

Measuring the success of Cinnamon with project output as revenues generated from completed development projects depends not only on portfolio success but also on, for example, the success of production and marketing functions. This approach equates portfolio success with firm strategic success. However, the two performance criteria differ. R&D portfolio success relates more indirectly to firm success and also reciprocally (Miller, 1999). It is not easy to determine the arrow of causality. Another problem in measuring success is the very long period of time – typically a decade or more - of R&D project deliverables before they have a large enough effect on firm revenue and profit (Burgelman, 1983b; Burgelman & Grove, 2007).

The success of project portfolio management in Cinnamon can be judged by asking whether the management did the best with what they had at hand. One can estimate if the processes in Cinnamon were efficacious. Ray, Barney & Muhanna (2004) suggest that observations from process effectiveness related to business processes, activities and routines can be used to construct a measure of firm performance. Three classical studies address processes in product development. Brown & Eisenhardt (1997) propose three success factors for product development. Firstly, organizational committees should have clear responsibilities and communicate priorities. Secondly, projects should be probes for the future. Finally, projects must also link with current business. Dougherty & Hardy (1996) state three criteria for sustained innovation. Firms should maintain adequate resourcing, they should design collaborative structures and processes, and they should connect innovations with existing business. Cooper, Edgett and Kleinschmidt (1997ab) present three normative interdependent objectives for the management of portfolio of new product development projects. Managers should maximize portfolio value, should balance the portfolio against different types of risks, and should align the project portfolio with firm strategy.

Measuring new product development project performance beyond tactical success – in terms of time, cost, and quality – is still in its infancy due to problems in conceptualization and measurement (Tatikonda, 2008). Prior research has reported only partial results on the factors explaining actual performance in project portfolio management (Cooper, Edgett & Kleinschmidt, 1997ab, 1999, 2000, 2004; Nobeoka & Cusumano 1995, 1997: Fricke & Shenhar, 2000; Loch, 2000; Martinsuo & Lehtonen, 2007b). Some correlation between the extent of using the control methods of portfolio management and project performance has been reported (De Reyck et al, 2005).

The effect of control on performance has been questioned since project control systems in project based firms stifle innovation (Keegan & Turner, 2002). Too much control weakens the performance of new product development. Even interactive control negatively affects project performance (Bonner, Ruekert & Chao, 2002). Evidence from the USA suggests that formal portfolio management processes relate to success (Cooper et al, 2004). European evidence indicates that the formalization of a portfolio management process beyond alignment to strategic intent does not relate to success (Griffin & Page, 1996). Improving management processes has resulted in new product development (NPD) narrowing to incremental innovations (Kavadias & Chao, 2008). If the firm has not defined its strategy in the way that can be of operational guidance for project resource allocation, then the effect of the methods is weak. A high level of exploration in projects benefits from autonomy, whereas a low level does not (McGrath, 2001). Portfolio management success factors also depend on a firm's environment (Eisenhardt & Tabrizi, 1995). Top managers' teamwork as a way of deciding the process criteria for portfolio management is a success factor of project and portfolio through the process of linking projects to strategy (Englund & Graham, 1999). A cross-functional portfolio committee improves effectiveness (Leenders & Wierenga, 2002).

Criticizing the "best practice" approach of portfolio management, Loch (2000) points out that firms are unique with regard to the specific new product developments and strategic options that result in that firm's specific project clusters. Because of the mixed results reported in the previous literature, the effectiveness of business processes on performance should be studied further (Ray, Barney & Muhanna, 2004; Tatikonda, 2008).

There is conflicting opinion on how the performance of a single firm like Cinnamon should be judged against portfolio success. In the pharmaceutical industry, innovation management amounts to a large and important part of strategy. In this industry, firms maintain a high amount of slack for searching new solutions for institutional reasons (Chen & Miller, 2007), so firms maintain large R&D budgets in a path dependent manner. The business performance of these firms is dependent on how they manage their R&D projects. To an extent, managing research projects as businesslike investments resembles other types of project businesses (Artto & Wikström, 2005; Artto & Kujala, 2008). Therefore, it is appropriate to treat Cinnamon's investment portfolio of R&D projects as a major determinant of the firm's success in the long run.

The project and portfolio management processes in Cinnamon fulfilled the criteria of three different scholarly studies. First, they were ostensibly in line with success factors outlined by Brown & Eisenhardt (1997) with regard to product development. In Cinnamon, organizational committees had clear responsibilities and priorities were communicated. Projects in the firm were probes for the future. Business units linked present products with at least some stage S5 and S6 projects. Second, Cinnamon projects fulfilled three criteria for sustained innovation defined by Dougherty & Hardy (1996). Considerable resources were available for new products. The organization had collaborative structures and processes. Some projects at stages S5 and S6 connected innovations with existing business. Innovations were a meaningful component of the firm's strategy. Third, new product development in Cinnamon fulfilled the three normative interdependent objectives for managing a portfolio of new product development projects (Cooper, Edgett and Kleinschmidt, 1997ab). The selection rule for prioritization tended to maximize portfolio value. In effect, the selection rule was tailored to make overall firm profit high through full use of marketing organization. A system of balancing the portfolio by allocating R&D funding by business unit was used. The project portfolio was aligned in order to realize firm strategy through the number of new project initiations. I was unable to find out whether the right projects were prioritized in the end. This could be studied only in comparing the final performance of all projects which were prioritized with the ones which were not.

Based on the comparison of processes in Cinnamon and their descriptions in the literature I conclude that managers in the organization did their best with respect to process efficacy and efficiency of R&D project portfolio management. And yet, in the prioritized projects this was seemingly not enough under instances of co-selection. Studying the dependencies between the amount of variation and selection mechanism in the context of evolutionary framework provides further insight about the management of the portfolio.

6.2 Variation, portfolio evolution, and uncertainty

6.2.1. Sources of variation

In Cinnamon, initiating new projects and passing projects to new development stages introduced variation to the portfolio. Initiations and terminations determined the portfolio size and much of the total variation. When unexpected terminations occurred, variance was reduced. Variance in the R&D portfolio was especially volatile, since Knightian uncertainty (Knight, 1921) was a feature in terminations. Although the portfolio board did not restrict variation as such, variation was restricted by the R&D budget quota for the business units. The dynamics of the R&D project portfolio in

Cinnamon revealed that managers had difficulties sustaining the innovative process, especially in the focal business unit Lavender.

One can test if Cinnamon had adequate funding of R&D projects for future success in two examples where discontinuities appeared. First, internally, the R&D portfolio suffered from the unexpected terminations of prioritized projects in the focal business unit. Second, externally, the overall R&D funding was affected by sales decreases in the latter part of the observation period.

In the first instance, managers did not compensate sudden project terminations with new initiatives in a timely manner. The increasing age of R&D portfolio in Cinnamon suggests that both selection structures allowed projects to go on for lack of new candidates. Sudden terminations still had one consequence on R&D funding and adequate variation. Very few R&D portfolio projects were completed until towards the end of the observation period. True, some projects in stage S6 had been launched in some applications in some markets. They already generated revenues and product development went on to secure new applications and launches in new territories. However, unforeseen terminations of prioritized Lavender projects removed the candidates that were expected to be future revenue generating products. This may also partially explain the decrease in sales growth.

In the second instance, shortly after the peak of initiations, sales and R&D spending in Cinnamon went flat (Appendix 11). Managers could no longer provide a sufficient number of new project initiatives to increase variation. R&D spending slightly decreased in years 7 and 8. Nevertheless, in years 7 to 9 a massive selection effort to complete projects and to increase prioritized projects took place in the portfolio committee.

As to variation in Cinnamon, there was no public financial data on R&D spending by business unit. I analyzed R&D funding at a portfolio level and took the number of projects in each business unit at any year to be a rough proxy for the allocated funding for the business unit. Focal business unit Lavender had more projects than the other business units. There was also a peak of new project entries in the middle of the observation period, together with a minimum number of terminations. However, there was no radical increase in the R&D budget at that time. On the contrary, the R&D budget increase was tightly aligned with revenue increase.

New product development needs continuous high risk funding to maintain an adequate number of projects. Sufficient variation to allow for both successes and failures makes it possible for a selection mechanism to operate. There is no consensus in project portfolio management about the optimal number of projects for given resources (Lieb, 1998; Adams et al, 2006). Generally, best performing firms tend to focus much more resources on new product development than on other projects (Cooper et al, 2004). The level of funding for an innovation project or portfolio relates to the amount of variation needed to cope with uncertainty. To calculate portfolio size, termination risks can be estimated under ideal conditions (Chapman & Ward, 2002, 2003), but not in the presence of Knightian uncertainty. In drug development, uncertainty is remarkably high. Under the conditions of Knightian uncertainty, variation is simply unknown (Klein & Meckling, 1958). The wide acceptance of portfolio balancing with bucket models in practice indicates that mathematical models do not capture Knightian uncertainty.

The results of the test to find out if Cinnamon had adequate funding are now summarized. First, there was not sufficient variation to compensate the losses in the Lavender business unit. Second, there was not sufficient variation in Cinnamon to compensate for portfolio aging by the funding available for R&D. This suggests that timely new project entries were made difficult for two essentially external reasons: very sudden terminations and slow traction in sales. There was a decoupling between the plans for increased R&D funding for future business, and the reality of a sudden slowing of sales growth of the current business.

6.2.2. Variation and slack

In Cinnamon, managers had problems with adequate funding of their R&D pipeline. Unexpected terminations ruined prioritized projects in the Lavender business unit and slow sales growth restricted R&D funding. Hence, both the number and timing of additional variation were affected. To increase variation beyond the minimal planned level organizations must have resource slack. Slack refers either to resources or timing.

Financial slack is defined as the difference between total resources and total necessary payments (Cyert & March, 1963). Measuring slack in innovation project portfolio management has traditionally focused on indirect financial measures (Bourgeois, 1981), and has neglected temporal measures (Adams et al, 2006). Scholars use slack to denote either an absorptive buffer within the organization against “bad times”, or as a means for top management to initiate and execute strategic change (Bourgeois, 1981).

Good performance correlates with high financial slack (Singh, 1986). However, studies on the effect of slack on performance are inconclusive (Daniel, Lohrke, Fornaciari, & Turner, 2004; George, 2005). Scholars regard slack as beneficial to facilitating innovation and strategic exploration (Cyert & March, 1963; Greve, 2003ab), or adaptation to new environmental landscapes (Levinthal, 1997). Some consider slack to be harmful since resource use is then unproductive (Jensen, 1988). A little slack encourages, whereas too much slack is harmful to innovation (Nohria & Gulati, 1996). In their meta-analysis, Daniel et al (2004) conclude that there is mostly positive evidence of the effect of financial slack on performance. In more recent studies, scholars have found support for the idea that the effect of financial slack on R&D investment is an inverted U-shape, moderated by ownership as a contingency factor (Kim, Kim & Lee, 2008), but also that a higher level of slack steadily brings a higher level of innovation (Oerlemans & Pretorius, 2008). Therefore, studying slack should be more resource specific (Geiger & Makri, 2006), and a firm’s environment should be taken into consideration (Voss, Sirdeshmukh, & Giraud Voss, 2008). Both unabsorbed slack, defined as non-liquid administrative slack, and liquid financial slack, enable more exploration and variation in the form of innovative R&D projects (Singh, 1986; Greve, 2007).

At an operative level, budgeting slack resources in advance has been shown to be consistent with successfully managing goals that go beyond keeping within the limits of cost budget. According to Davila & Wouters (2005), designing explicit budgeting slack over some years helps the firm to cope with an increased demand on service quality. They consider planning for slack to be not dysfunctional but rather as facilitating managerial flexibility for more demanding and multiple goals under uncertain conditions. As Davila & Wouters (2005) show, an intentional management reserve could benefit the managing of a R&D project portfolio.

Most academic scholars have not discussed temporal slack as a resource constraint (Gupta, Smith & Shalley, 2006; Baker & Nelson, 2005). Workflows in organization also need internal absorbers (Bourgeois, 1981). Although recognizing workflow slack, Bourgeois (1981) does not provide an indicator for it. The notion of transient slack tries to capture its temporal aspect, but it is made operational only in short term financial indexes (George, 2005). Studies on the speed of product development do not directly address slack (for example, Kessler & Chakrabarti, 1996). Reduced time to market by compressing a rational process with better planning and computer-aided design is suggested to be effective only in mature industries (Eisenhardt & Tabrizi, 1995).

In contrast, the project management literature and practitioners consider time as a very important constraint to new product development (Milosevic, 2004). Nobeoka & Cusumano (1997) emphasize speed with reference to new multi-product development. Scholars of project management suggest there are trade-offs between both cost and cycle time (Cleland, 2004; Krishnan & Ulrich, 2001; Clark & Fujimoto, 1992; Crawford, 1992), and product performance and cycle time (Cohen, Eliashberg & Ho, 1996). A level of uncertainty modulates the trade-off between product success and time to market (Chen, Reilly & Lynn, 2005). Delays in timing due to resource slack can be overcome with financial slack.

The notion of a critical path as a means to shorten development or production time to market is temporal slack operationalized (Gantt, 1919; Goldratt, 1999; Leach, 2004; Chapman & Ward, 2002; Rolstadås, 2004). A critical path method aggregates contingency reserves to achieve performance in time under uncertainty (Rand, 2000; Steyn, 2000). In addition to time and cost buffers, Pich et al (2002) conceptualize flexibility as yet another form of slack to accommodate many different, yet possible, outcomes of risk and uncertainty. This flexibility is useful under conditions of uncertainty. Temporal buffers eliminate process overloading relating to capacity (Steyn, 2000). Chapman & Ward (2002) are not explicit about how to utilize an unused time buffer. Conceptualizing a critical chain helps to seize an opportunity for early completion of steps in a critical path. Critical chain thinking does not recognize an "optimal" project schedule. On the contrary, there are perhaps more than one "good enough" scheduling solutions (Steyn, 2000).

Attaching extra resources or time beyond the “optimized need” in order to achieve R&D goals seems counterintuitive. High level of variation is likely to induce additional cost with no extra benefit (Madsen, Mosakowski & Zaheer, 1999). Viewing the portfolio through “optimizing” lenses leads one to think that only successful R&D outcomes require funding. One easily forgets that these successes arose only because all the other candidates in the race were also funded, although they failed. Optimizing (Klein & Meckling, 1958) assumes that forecasting works all the time. But there are no real forecasts for even the most important projects if the variation of these forecasts is both huge and indeterminate (Taleb, 2008; Mandelbrot & Hudson, 2004). Not every R&D project is successfully completed; indeed, many projects are terminated. Due to unforeseen Knightian uncertainty, these terminations are sudden. The need for slack to increase variation for new projects is closely connected with the presence of unforeseen events. If a firm has both resource and temporal slack available, the additional variation can be achieved. To achieve this, some additional reserve to provide additional projects, and thereby increase variation, should be at hand.

Many scholars suggest using slack to increase variation. Minimizing both total cost and time in new product development is sensitive to uncertainty (Loch, Terwiesch & Thomke, 2001). Managers should build an element of slack resources to cope with the unexpected (Loch et al, 2006). Slack is needed to persist on a course of action in trial and error learning (Garud & van de Ven, 1992), and allows failures to be absorbed (Adams et al, 2006). Extensive variation for parallel projects, some of which do not survive, is needed to successfully manage a R&D portfolio under unforeseeable uncertainty (Pich et al, 2002).

Financial data shows that Cinnamon’s reserve resources were not used for funding R&D to increase variation. As a consequence, the R&D portfolio aged for lack of new projects. References to measurements as a way to estimate the amount of slack in Cinnamon R&D beyond financial indicators from balance sheet were not found in the documents. I found no written evidence of using slack resources at the organization.

In Cinnamon, prioritizing resulted in the aging of prioritized projects. Managing the portfolio with critical chain would have meant building reserves in the scheduling so that projects which were prioritized would not be affected by congesting workflow. This would have been assigned to project committee from portfolio committee. Since the distribution of projects by phase remained constant and the portfolio was aging, this suggests that the management of critical path in product development was not system of improvement.

The history of Cinnamon suggests that budgetary slack for additional new project variation and temporal slack to resolve bottlenecks at development phases were not in use. There was little or no resource or temporal slack available for making adjustments. However, this conclusion remains conjectural, since no interviews with top management were undertaken to reveal the internal financial activities.

6.2.3. Variation and selection

Selection mechanisms influence variation. Increasing variation widens the subset of possible survivors of selection (Dobbs & Molho, 1999). If selection structures inside a firm are heavily top down oriented (Burgelman, 1983ab, 2002ab), this reduces variation that feeds in as new R&D initiatives. On the one hand, selection rules should allow projects to survive more easily to maintain variation. On the other, selection should be effective in order not to be too expensive.

Since not all combinations of attributes were co-selected, co-selection decreased the variation at least initially among prioritized projects A dominant design restricts variation. Variance was also reduced due to the interactions between selection levels when prioritized projects did not proceed through the milestones to the next development phases, but rather became older.

Scholars do not agree on how to control evolutionary mechanisms. In agreement with March (1994a), Warglien (2002) observes that evolution is used as a design tool in animal husbandry. We can tune parameters of variation and set up selection mechanism, but have no firm control over the outcome. Variation control is possible by controlling the amount of slack resources. With selection control it is possible to affect retention. The tools could be population search heuristics and organizational policies. Evolution allows intentional experimentation and adjustment. Executive teams can influence variation and selection in product design (McGrath et al, 1992). Although perhaps possible for the short term, it is very likely to be quite hard to "engineer" the conditions for evolution for the long term (March, 1994a). The fact that levels of selection exist and they interact is emphasized by Aldrich & Ruef (2006). Selection may occur at an aggregate level population level attributes and selection mechanisms may interact with different levels (Aldrich & Ruef, 2006).

Experimenting with vicarious variation and selection still does not guarantee success in external competition against environmental selection. For vicarious selection, the selection mechanisms inside a firm are different from those in the outside environment (Campbell, 1994). The problem is to mimic the environmental selection criteria with the vicarious criteria, selection structure and process. To compensate for terminations, variation ought to be increased. Selection mechanisms need reserve variation to cope with the unexpected. In the evolutionary framework, managers can, in principle, influence variation and selection to modify retention. They can design selection structures and decide selection rules, and they can influence the amount of variation. Scholars have both advocated and shown skepticism about the management of evolution by actively adjusting variation and selection. They differ with regard to how much variation and adaptation they consider possible (Turnbull, 2000; Gould & Lewontin, 1979).

Managing evolution addresses the problem of exploration and exploitation. Exploration increases variation, whereas exploitation reduces variation. Increasing variation is considered beneficial to create successful new ventures (Brown & Eisenhardt, 1997; Burgelman, 1983ab, 1994). Expanding variation in product development requires more funding for new project initiatives. It has been documented that top managers give more time to current business than new business and value it more highly (Dougherty & Hardy, 1996; Greve, 2008). R&D activities contain both more exploratory (entirely new products) and more exploitative (product life cycle improvements) types of projects. At the firm level, all R&D investment is explorative in comparison with other investing activity, the improvement of internal processes or more general operations management.

The notions of exploration and exploitation and tradeoff between them, have been elaborated upon by March (1991) and Levinthal & March (1993). Many scholars agree that balancing exploration and exploitation is beneficial, but also recognize the difficulty of achieving and maintaining a balance (Christensen & Bower, 1996; Burgelman, 2002ab; Gupta, Smith & Shalley, 2006; Greve 2007). In the evolutionary framework (Hannan & Freeman, 1989; March, 1991), the choice between exploration and exploitation has been described as the balance between the processes of variation and selection. In Burgelman's (1991) analyses, induced strategic behavior that decreases variance and selection is powerful, whereas autonomous strategic behavior that increases variance and selection is less powerful. Whether exploitation and exploration are exclusive or occur together remains controversial (Gupta et al, 2006). For example, Burgelman (1991) argues for ambidextrous firm structure, and, later, for a punctuated equilibrium structure (Burgelman, 2002a), depending on the firm under study. Exploring and exploiting can be analyzed on different levels (Gupta et al, 2006).

In terms of R&D portfolio management, following March (1991) and Hannan & Freeman (1989), firms in an exploring mode increase portfolio variation and they are lax about portfolio selection criteria, whereas in the exploitative mood they carefully select to reduce variation. In uncertain environments, product variety is important (Sorenson, 2000). Pursuing ambiguous and contradicting tendencies jointly has survival value (Weick, 2004). Many scholars suggest that increasing variation in order to allow more trial and error type exploration is beneficial to managing the evolutionary mechanism (Brown & Eisenhardt, 1997; Burgelman & Grove, 2007; Klein & Meckling, 1958; Loch et al., 2006; March, 1991; March, 1994a; McGrath, 2001; Nightingale, 2008). Managers can influence variance and selection in the evolutionary system of R&D development projects to some extent, but not wholly modify retention, that is, portfolio outcome.

Scholars who are optimistic about managing the future such as Lovas & Ghoshal (2000) put more emphasis on the active role of top management. They maintain that by making "small timely interventions" managers can influence history. Managers' understanding about when and how to intervene comes from their ability to utilize human and social capital. In other words, more acuity in vicarious selection drives better choices, and better organizational skills facilitate internal organizational changes. Managers have to adjust this internal balance against what is going on outside the firm. In Burgelman's (2002a) account of Intel, the building of a strategic vector resulting in successful exploitation came about from a onetime lucky circumstance. Recently, Burgelman & Grove (2007) have shown that Intel was able to shift the mode of operation between exploring and exploiting forms. However, foresight cannot be generally replicated. Hidden cyclical changes and historical time epochs may be of importance. Managers may sometimes choose between modes of exploring and exploitation for a suitable period of time, if they are careful in their search of environmental clues for which they provide an interpretative framework (Burgelman & Grove, 2007). This idea comes close to relying on the efforts of managerial cognition in framing opportunities and shaping new business models (Porac et al, 1995).

Other scholars, for example March (1994a), think that managing evolution is illusory. Managers can definitely change their behavior and make “small timely interventions”. Lacking good enough clues about the consequences of their behavior, the outcomes of changes made by managers are likely to be not quite, and sometimes not at all, what they wanted. This logical argumentation is hard to crack. However, it still allows successes and leaves room for learning. Recently, de Rond & Thietart (2007) promote the view that managerial choices are insufficient to account for strategy. Knowing when to explore or exploit is a diagnostic problem clouded by uncertainty (de Rond & Thietart, 2007), in spite of the occasional one time success in doing the right thing. The views of de Rond & Thietart (2007) and Burgelman & Grove (2007) make an interesting and unresolved contrast. Interestingly, strategic consistency in competitive behavior has also been suggested to be important for long term survival (Lamberg et al, 2009). Exploration to increase variation would help to meet the uncertain future and increase learning (March, 1991). Exploitation to decrease variation would be dangerous if the unexpected happens. Burgelman (2002a) notes that an exploitative “lock in” type of evolution leads to competency traps because variation is reduced.

Co-selection during prioritization decreased variation in Cinnamon since not all possible combinations of attributes were selected. These constraints made variation asymmetric. The prioritization criteria in the portfolio committee could have been used to adjust the portfolio. However, managers kept selection structures and selection rules constant in Cinnamon. In the organization, selection structures and selection rules also interacted. Selection rules for milestones at project committee levels were not flexible. Managers did not increase variation due to sudden terminations and the R&D funding crisis. Experimenting with variation and selection mechanisms in Cinnamon could have made a difference.

By prioritizing stage S5 and S6 projects and refraining from making new initiations to fully compensate losses due to terminations managers in Cinnamon were taking more exploitative than explorative actions. The productivity gap in Cinnamon and sustaining projects in stage S6 after launch to document new applications were indicative of exploitation rather than exploration. In Cinnamon, prioritized projects at stages S5 and S6 increased over time. This is a sign of exploitation because these projects were either close to launching or were the subject of an expansion program for products already launched.

In Cinnamon, selection for priority was vicarious. Terminations were managerial acts but basically resulted from technological hurdles, that is, events in the external environment. Although vicarious selection may have reflected the external environment quite well, it could not anticipate sudden terminations. A critical question for Cinnamon was to ask how long to wait before terminating a project for commercial reasons. This either did not happen at all, or only very seldom. The discrepancy between vicarious and external selection remained an unsolved problem.

6.2.4. Evolutionary R&D portfolio management

Attempts to treat project portfolios holistically have not been very successful (Elonen & Artto, 2003). Companies continue to suffer from resource allocation problems (Engwall & Jerbrant, 2003) and complexity caused by resource interdependencies (Dammer & Gemünden, 2007) in their project portfolios. There are problems of measurement in the study of R&D projects which have not been resolved (Adams, Bessant, & Phelps, 2006). Project portfolio decision aids are inadequate (Iamratanakul & Milosevic, 2007). Many questions in new product development project management are still open problems (Kavadias & Chao, 2008).

Darwinian variation and selection logic applies best when diversity of goals and preferences are high and there is uncertainty about means-ends connections (Hannan & Freeman, 1984). Recognizing the importance of evolutionary logic, some scholars have addressed the management of a portfolio under conditions of uncertainty (McGrath, 2001; Pich, Loch & De Meyer, 2002; Sommer & Loch, 2004; Loch, Terwiesch & Thomke, 2001; Leonard-Barton, 1992; Loch et al, 2006; Loch & Bode-Greuel, 2001; Loch & Kavadias, 2008b). They pursue selectionism to manage portfolio by means of adjusting variation and selection mechanisms. When engaging in evolutionary portfolio management, one faces the seemingly "unnecessary" costs of projects that had to be later abandoned. However, some events in the future are fundamentally unpredictable (Cooksey, 2000; Knight, 1921; Klein & Meckling, 1958). Selectionism (Loch & Kavadias, 2002) recognizes that the cost of successful R&D projects must also include the cost of the failed projects.

Maintaining control through intolerance to any deviations from an operating process is a high resilience procedure to avoid major damage from unknown causes (Weick & Sutcliffe, 2007). High resilience is a possible key to detecting co-selection. However, exploration for strategic renewal is the opposite of managing deviations by maintaining control. Calculative strategic experimentation in solving ill-structured problems under ambiguity is seen as the most profitable use of a firm's R&D assets. Here content is overcome by process (Mosakowski, 1997). For the lack of a good causal picture, small scale low-cost probing is recommended (Brown & Eisenhardt, 1997) as the preferred way of coping with ambiguity. Project organization is suitable for trial and error learning (Lindkvist, 2008).

The evidence from Cinnamon suggests that attempts to anticipate or detect co-selection were not made. At least, actions to compensate it were not observed. Detecting co-selection faces the realm of unknown unknowns. Following resilient management practice, this would mean cautious monitoring of the portfolio for any anomalies, which could be caused by co-selection or unexpected terminations, and immediate action if anomalies are observed. Following portfolio management practice, this would amount to looking for externalities, internal constraints, and interactions between projects and selection mechanisms.

6.3 Co-selection as an explanation

6.3.1. Co-selection mechanisms and portfolio evolution

The discussion above shows that the evolutionary patterns of strategy in Cinnamon displayed in Table 13, (chapter 5.3), become plausible when the conjecture of co-selection is applied to explain the observations. Managers pursued a policy that was aimed to reduce time to market. Prioritized projects increased in number but they also aged (pairs 1 and 2, Table 13). That there was an increasing number of old co-selected Lime projects which were not completed but were retained explains these trends. Managers focused project initiations and prioritizations in the Lavender business unit (pair 3, Table 13). They did not succeed in prioritizing enough of the Lavender projects. Unforeseen terminations cut many of the prioritized Lavender projects, but not Lime projects which were retained and carried co-selected attributes (pair 4, Table 13). This resulted in the increase of prioritized projects (in Lime) at development stages S5 and S6 (pair 5, Table 13). These projects possibly acted as constraints for other projects to enter stages S5 and S6.

In initiating and prioritizing more Lavender project against retaining old prioritized Lime projects managers faced a tradeoff. Pursuing both strategies would increase the number of prioritized projects and their age, leading to congestion at the end. Managers were unable to cope with the productivity gap arising from terminations of Lavender projects for lack of sufficient new initiations (pair 6, Table 13). Due to co-selection, the R&D resources were partially locked in to the prioritized Lime projects at stages S5 and S6. These projects were not terminated, not deprived of priority status and not completed. Managers did not detect this effect of co-selection and were unable to cope with it.

I conclude through a process of abduction that co-selection as a mechanism explains the observed conflicting pairs of evolutionary outcomes in portfolio retention. What happened in Cinnamon and why is presented as a short narrative to answer the research question.

6.3.2 Explanatory narrative

The story of R&D portfolio evolution in Cinnamon starts from a specific historical situation. At the beginning, the majority of R&D development projects in the firm were held by business unit Lime. Lime also held the majority of prioritized projects. Managers intended to increase projects especially in the focal Lavender business unit and focused the majority of new project initiations in that unit. This is visible by the huge number of project initiations in Lavender. As a consequence, the Lavender business unit soon gained dominance in the R&D project portfolio.

To increase efficacy in R&D by more precise targeting of the available limited funding, managers started to increase prioritizations as a means to decrease the time to market of selected prioritized projects. The selection rule for prioritizations was to favour projects with high revenue potential and global coverage. When managers pursued more initiations in the focal business unit Lavender, managers also prioritized more projects in focal business unit than elsewhere. The number of new or prioritized projects was not restricted. Applying the selection rule for priority, projects that were from different business units, not only from Lavender, were co-selected. The mechanism of co-selection caused the retention of ancillary attributes, such as development stage, of the prioritized projects in Lavender. These projects were often at development stage S4 and, later S5. But the mechanism of co-selection also retained the ancillary attributes of prioritized projects in Lime and Blue. These projects were often in development stage S5 or S6, and therefore generally older in age. As a consequence of co-selection, projects with distinctively different project development stages and age from the different business units were retained in the prioritized portion of the portfolio.

During the development of the portfolio over years, the prioritized projects in the Lavender business unit were terminated due to unexpected, often technological causes, more frequently than prioritized projects in the other business units, especially Lime. This resulted in “missing” prioritized projects in Lavender. The prioritized projects in Lavender that were terminated were somewhat younger than the Lime projects. New projects were initiated to mend the gap. Consequently, prioritized projects in Lavender were in an earlier development stage relative to Lime. Older prioritized projects in the Lime and Blue business units at development stages S5 and S6 were retained together with Lavender projects. On a portfolio level, this dominance resulted in a further increase in the average age of projects, especially prioritized projects. The project portfolio continues to age. In the end, there were not enough slack resources to increase variation in order to fully compensate these losses in Lavender. Managerial action to increase prioritized project in Lavender did not result in the dominance of prioritized Lavender projects in the portfolio as a whole.

Project development stages were executed sequentially due to the project dominant design. Development times by stage were hard to compress. Consequently, total development time did not decrease beyond a definite minimum time. The selection rule for prioritizing in the portfolio committee interacted with the selection rule for milestone decisions in project committee in a way that was not anticipated. Milestone decisions were independent of prioritizations. Milestone decisions could not be accelerated unless the specifications of sub goals by consecutive development phases were met. For this reason, the project committee delayed rather than accelerated the projects prioritized by the portfolio committee. In the portfolio, the proportion of projects at different stages remained largely constant.

Completing different stages required different types of resources; so free resources from one development stage were not transferable to another project at another development stage even if projects were prioritized. Only resources within a single development stage were readily transferable. There was insufficient unabsorbed slack to meet additional demand by providing resources to the project development stage. In addition, there were insufficient temporal buffers to overcome the temporal constraints in the critical chain. Therefore, the prioritized projects in business unit Lime did not necessarily proceed to the next development stage or to the market. Many prioritized projects in Lime were locked at stages S5 or S6. This constraint restricted the advancement of other prioritized projects, such as Lavender projects, to stages S5 and S6. Since many Lime projects were above average age, the aging of the prioritized portfolio increased. Projects in the Lime business unit that were at advanced development phases continued absorbing prioritized resources. This delayed the dominance of Lavender. Lavender had fewer projects prioritized than the proportion of its share in the total portfolio.

Contrary to managerial intent, prioritizing did not decrease the time to market. Managers did not terminate prioritized Lime projects for commercial reasons either. These projects went ahead. Managers had to consider whether to go ahead with old prioritized Lime or new prioritized Lavender projects. Co-selection of Lime projects in late development stages S5 and S6 during prioritization had created this problem. In the end, managers pursued both strategies, which eventually led to congestion in portfolio performance. In summary, the co-selection mechanism and interactions between the two selection structures with different selection rules influenced the portfolio dynamics to produce realized strategies in conflict with those that were intended, and with each other.

6.4 Alternative explanations

The conjecture of co-selection can be challenged. I shall present some possible criticism. I shall examine some alternative explanations to show that they are less compatible with the observed facts than the proposed conjecture, that of co-selection.

Statistical tests for correlation between project attributes were not used. The correlations of statistical tests measure closeness and co-variation. They do not justify causal explanations, since the direction of cause and effect is not specified. However, QCA analysis provides the necessary causes as the antecedents to the observed events. If an attribute of a project was a necessary cause for prioritization in Boolean analysis, then it was also present at the selection event – when the selection rule for prioritization was applied – and was co-selected. This gives a logical justification that a co-selection mechanism explains observed retention in prioritized projects.

Decision making was not shown to uncover the roots of co-selection. Analyzing Cinnamon, I did not attempt to use the decision theory to uncover the mechanism through which managers arrive at actions. I only pointed out where rational consequential logic breaks down and other means of solving problems appear; for example, the logic of identity (March, 1994b). The influences of top management team heterogeneity, composition, tenure, education or other demographics, on actions were not studied. Reviews were considered a proxy for focusing attention on specific projects. The influence of attention was not studied further. The top management remained fairly stable during the years of analysis. In Cinnamon, selection for priority was based on consensus. This was also the case for other decisions in the portfolio committee. In the project committee, decisions were based on the following of rules. The selection rule for priority was well documented and did not change.

An objection could be that decisions are based on factual substantial criteria, which would explain every separate decision. It is true that factual content issues – preference criteria – accounting for these decisions at the project level (for example, the ranking order of projects by modeling financial expectations) were not analyzed in detail. But the archival event data from the selection structures suggests that content data was not analyzed at the portfolio committee, although this was carried out at the project committee. When choosing projects for prioritization, top managers took into consideration aspects that reflected both signals from the external market and from the internal organizational environment. This was their basis for applying the priority selection rule. A detailed analysis of substance issues confronts the problem of which substance issues were neglected and which were totally unknown. Substance issues would have to cope with information overflow and misplaced illusory preciseness. Managerial judgment would still vary over changing times. Proposing that failure to apply project portfolio management model caused the observed correlations is unfounded because even the process model allows independent judgment against any model tools or norms at will. Although project features are likely to affect choices, they do not account for negative externalities arising from dependencies between projects and the opportunity windows. Content issues were handled with selection rules.

In Cinnamon, the unit of explanation was the project portfolio, not a single project. Using selection mechanisms to provide an explanation meant that the analysis did not go into the details of the decision making process beyond selection rules. The concept of co-selection denotes a non-adaptive selection mechanism that collects the project attributes present at the time when the selection rule for priority is applied. Therefore, the consequences of co-selection totally come about from the prioritization in the first place. There is no need for further cognitive explanations for co-selection since it derives from both the selection rule and the project dominant design. In a sense, co-selection cannot be avoided, once the selection rule and dominant design are a given.

It may be argued that sunk cost or escalation of commitment prevented the de-prioritizing of some projects. This may be correct, but it does not exclude co-selection. Managers depend on their prior choices and may need to repeat their commitment to prior investments, and at the same time they allow the portfolio to age.

With regard to milestone decisions, content analysis is not needed, since the decisions were based on the rule of fulfilling milestone criteria, mostly of external origin. The internal dependencies between the attributes of any single project, which were neither anticipated nor analyzed in portfolio models, were the effects of co-selection.

There was either not enough or too much variation to apply evolutionary logic at all. When there is too little variation, like in a homogeneous population, the selection mechanism has nothing to work upon. When there is too much variation, the selection mechanisms do not differentiate between variable attributes, or the mechanisms become extremely complicated. There is no methodological or theoretical yardstick to relate the amount of variation to a specific selection mechanism. The evidence must be of a practical nature. In Cinnamon, the amount of variation increased due to new project initiations and successive milestone decisions. The portfolio size almost doubled. The portfolio changed and contained diverging trends. Since portfolio retention changed, it is likely that selection did operate and there was sufficient variation not to dampen the selection mechanism.

Selection mechanism may be so strong that very few projects survive and may not contain sufficient attributes favored by selection. In Cinnamon, the portfolio size doubled, indicating that selection was not overly strong. The selection mechanism may also be too weak to select attributes present in only a small quantities in a much larger project population. This results to the retention of average attributes rather than those favored by the selection mechanism (McKelvey, 1999; Kauffman, 1993). Rapid adaptation may weaken a selection mechanism (Levinthal & Posen, 2007). Path dependence may restrict variation and selection (Lewin & Volberda, 2003b). In Cinnamon, the number of prioritized projects increased, supporting the view of an effective path dependent selection rule. High or low variation (Kauffman, 1993) does not make a difference to an evolutionary selection mechanism as such, although it is relevant to the survival quota via rates of reproduction. In summary, the portfolio dynamics in Cinnamon indicates that variation and selection worked to achieve changes in portfolio retention.

Shifting selection criteria cause the observed evolution. Researchers do not always report selection criteria clearly. In Cinnamon, the selection mechanism, selection structures and selection rules for prioritization remained constant. This is consistent with the demands proposed by Campbell (1969, 1974). Generally, providing an explanation with co-selection is not tied to a specific selection rule about the prioritization that was in use. The particular baggage attached to ancillary attributes would correspond to a specific selection rule resulting from the project dominant design.

In Cinnamon, the project dominant design did not change over time. Variation was increased through new project initiations and project development by stages. Selection mechanisms were shown to be at work. The growth of the portfolio was extensive rather than intensive. The size of the portfolio both increased and decreased.

Termination criteria are market and technology dependent (Balachandra & Brockhoff, 1995). Decision simulations show that project terminations are more difficult for respondents if they themselves have started the project, or the level of innovativeness is high (Schmidt & Calantone, 2000). Decisions to terminate new product development (NPD) projects tend to occur at the middle phase of development (He & Mittal, 2007). The majority of terminations occur for technological rather than market reasons (Christensen & Bower (1996). Managing innovations benefits from escalated commitment (Garud & van de Ven, 1992). In Cinnamon, for terminations to occur it was necessary that the project failed to meet financial or technical criteria.

Co-selection effects are marginal when development times are short. One could claim that co-selection is industry specific due to long drug development times. Since co-selection has been documented in a single case study, an industry specific effect cannot be ruled out. In Cinnamon, the lifetimes of prioritized projects varied between 1 and 9 years. Co-selection was detected in projects of different ages. A long development time as such would not be necessary for co-selection to appear. Co-selection inevitably arises due to the dominant design. Many authors have argued for the existence and importance of a dominant design in other industries (Murmann & Frenken, 2006; Mokyr, 2000; Ziman, 2000; Dew et al, 2004; Villani et al, 2007; Grandori, 2007). This should encourage the investigation of whether dominant design could also cause co-selection in other industries.

Co-evolution explains the developments in the case firm. Co-evolution refers to a path-dependent development dynamic. Co-evolution is defined by Lewin & Volberda (1999) as "the joint outcome of managerial intentionality, environment, and institutional effects. Change can be recursive and need not be an outcome of either managerial adaptation or environmental selection but rather the joint outcome of managerial intentionality and environmental effects." This definition describes a broad principle of recurrent mutual train of path-dependent interactions. The definition does *not* refer to a specific selection mechanism or co-selection. To explain particular outcomes with co-evolution one needs to identify both a source of variation and a specific selection mechanism. For example, specific co-evolutionary lock-in processes may select "in" one technology and select "out" a number of others (Arthur, 1989). The co-evolution perspective combines the population ecology and adaptive intention research streams (Astley, 1985; Lewin, Long & Carroll, 1999; Burgelman, 2002a; Lewin & Volberda, 2003ab). Co-evolution is not optimal but just "good enough" (Arthur, 1989).

Co-selection refers to a non-adaptive, and often probably non-intentional, and dominant design driven selection mechanism that may be present in any evolutionary selective process that follows a rule. It may or may not occur during a co-evolutionary process. The history of the Cinnamon R&D portfolio shows evidence of a co-selection mechanism and not of adaption driven co-evolution. Hence, co-selection and co-evolution describe two important and distinct phenomena.

No selection is needed for evolution. If complexity increases over time, populations could develop increasing diversity without a variation and selection mechanism (Kauffman, 1993). But self-organization and complexity do not explain evolution (Anderson, 1999). Complexity does not overrule the logic of evolutionary mechanisms (Hodgson, 2002). Rather, complexity increases variation. The origins of increasing variation and the mechanism of selection are two things to be carefully defined and kept apart. Selection is irreducible to phenomena arising from complexity (Hodgson, 2002; Knudsen, 2002; Hodgson & Knudsen, 2006). Selection effects may be masked or blurred under certain conditions, but not generally undone (Kaufmann, 1993; McKelvey, 1999, Hodgson, 2004). Complexity does not always increase, deterioration and evolution towards simpler specimen also occurs (Gould & Lewontin, 1979). In the realm of biology, most living creatures are simple unicellular beings or bacteria (Gould, 2002).

In Cinnamon, the interplay between variation and the selection mechanism is needed to explain the portfolio dynamics that were observed. The Cinnamon portfolio was fundamentally no more complex at the end than it was at the beginning. The interactions between the two levels of selection structure were present the whole time. The complexity of the R&D projects did not substantially increase during a decade in the pharmaceutical R&D. Regulatory requirements did not fundamentally change. The number of patients in clinical studies tended to increase due to regulatory requirements but this would not increase complexity as such.

Other firm specific explanation is possible. One might argue that some entirely different cause in Cinnamon's history rather than co-selection accounts for the portfolio dynamics that were observed. Based on external and company documents, no other surprising trends or events are apparent. The profit level of the firm remained steadily in the mid-range for the industry. The stable investment level on R&D was declining compared with an increase in the industry average. These performance statistics could justify the shift towards increased prioritizing in management of the portfolio. The company was publicly sold in Europe and at the New York Stock Exchange (NYSE). Shareholders and other stakeholders accepted the observed managerial performance. According to internal and public annual reports, notable changes in business unit charters did not occur. It is also stated in the annual reports that executive turnover was quite low so that suggests that new executives did not make later decisions incomparable with former executives. According to firm sources, there were only minimal changes in organizational structures and procedures that could affect the portfolio dynamics. The project and portfolio committees, the selecting structures, did not change during the period. In all, there was nothing very exceptional noted in the public records of Cinnamon that could explain the observed dynamics.

It is a recognized historical trend in the pharmaceutical industry that regulatory authorities have increased requirements by asking for more extensive evidence from pre- and post-marketing clinical studies, and that this tends to lengthen development times (Cockburn, 2004); this would explain portfolio aging in Cinnamon. As a consequence, the mean project age would tend to increase over time. But the Cinnamon data shows a clear decrease of mean project age at the end of the observation period. Hence, it is not likely that this industry-specific trend would alone account for all the observed outcomes. It would not explain the constancy of project stages in portfolio over the years. One would rather expect to see an increase in all projects at stages S5 and S6, not only in the prioritized projects at these stages. It would also fail to explain the conflicting trend in the number of prioritized versus all projects arising from co-selection in the Lavender business unit.

The list of alternative explanations is open to further additional suggestions. However, it seems that co-selection can better address the anomalies detected in the portfolio than the other explanations discussed above. If we accept the concept of a co-selection mechanism, we can causally explain the portfolio dynamics. Applying this train of thought gives an integrated understanding of what was going on in Cinnamon.

6.5 Study limitations and further research

6.5.1 Limitations of the study

The study builds on observations from only one firm in one industry during a specific historical period. Evidence for co-selection in a population comes from a single R&D project portfolio. Clearly, in order to reproduce the findings, one should search for signs of co-selection in project portfolio evolution in other firms across different industries.

The archival records of portfolio and project committee meetings were sometimes open about specifying the causes for termination. To gain more information, project team level archival data could have been used as a source. The choice was made to limit the size and scope of the study to the documentation emanating from the portfolio and project committees. Expanding data gathering to project team minutes would have increased the number of archival documents to an unmanageable level. Therefore, no detailed project level analyses were presented.

Interviews of top management were not carried out. This could have helped to link financial performance and R&D portfolio funding, portfolio size and the prioritization rule together more closely. However, this was a deliberate choice that was selected in order to avoid the bias of retrospective reporting that would have interfered with the dynamics emerging from the coded data. Financial and temporal slack were not measured.

6.5.2 Future research

This work is an exploration of the almost completely uncharted terrain of a thorough study of evolutionary selection mechanisms in the context of a project portfolio. Studies of evolutionary mechanisms, where selection objects are material entities or habits and routines, could improve our understanding of the Darwinian causal logic of variation, selection and retention. Explaining events with causal mechanisms should be continued when investigating economic phenomena. Other firms and their portfolio dynamics should be studied. New ways to address research problem in new product development projects should be tried.

The relation between co-selection and dominant design would be an important research topic. Because co-selection is likely to occur when objects of selection have a dominant modular design, one should try to clarify how to detect co-selection. One should study whether it is possible to manage co-selection through adjustment of the dominant design, and modularity or adjusting variation and selection mechanisms. More studies designed at investigating the relationship between selection mechanisms and variation would be needed. Due to its non-adaptive nature, co-selection induces restrictions in variation on a project portfolio. It would be important to study its impact on managerial choice.

In order to improve the understanding of project portfolio processes, one should study the interplay of various events in sequences or clusters. Techniques of sequence analysis would be a suitable methodology to disclose more structure and interaction in event streams. The study of dynamic interactions between the two managerial levels did not fully reveal the nature and causes of these interactions. The evolution of prioritized project when co-selected development stages change at subsequent milestone decisions should be studied further. The sequencing of review events could also be analyzed. The interaction of the R&D portfolios of two different firms would be a way to observe the competitive dynamics in the field of innovation management.

One could further uncover through QCA whether the attribute that was co-selected was acquired recently or more distantly in time. This could be studied to establish the possible sequences of causal antecedents to events.

A fruitful avenue of inquiry would be to study project level attributes and interactions and not only project level attributes. It is not known whether, and how, managers respond to portfolio properties and their changes. It is also not known how managers cope with portfolio size in comparison to available resourcing.

The relationship between managers' vicarious selection in R&D innovation portfolio success and the external environment selection of firm success could be investigated further; although the methodological challenges to measure the causal relationship are huge. More detailed analyses of managerial intent could also be studied. To achieve this, a larger number of public documents relating to the goals of firms together with interviews of managers could be used to better document managerial intentions. The interactions of reviews and events could enlighten the role of attention, aspirations or information search in portfolio management.

7. Implications

7.1 Implications for project portfolio management

7.1.1. R&D project portfolio models

New product development projects differ with respect to levels of uncertainty, and time to market (Archer & Ghasemzadeh, 2004). Development projects vary across industries, in degree of innovativeness and in the ways to manage projects (Artto & Dietrich, 2004). New product development, especially in the pharmaceutical industry, is technologically novel and carries high risk. Studies of project portfolio management have largely consisted of evaluating, prioritizing, and selecting projects based on strategy (Hall & Nauda, 1990; Henriksen & Traynor, 1999; Comstock & Sjolseth, 1999; Graves, Ringuest & Case, 2000; Ringuest & Graves, 1999; Spradlin & Kutoloski, 1999; Killen, Hunt & Kleinschmidt, 2007), and allocating resources to projects in line with strategy (Hansen, Weiss & Kwak, 1999; Cooper & Edgett, 2003).

Some scholars consider project portfolio models as empirically validated heuristic aids (Archer & Ghasemzadeh, 2004; Ghasemzadeh & Archer, 2000; Cooper et al, 1997ab, 2004) that form an “adaptive toolbox” (Todd & Gigerenzer, 2003). More typically, according to Elonen & Artto (2003), some scholars (for example, Cooper et al, 1998; Chapman & Ward, 2003; Standard for Portfolio Management, 2008), regard models of project portfolio management as mathematically “right” and therefore normative and prescriptive. The prescriptive view is aligned with mathematical modeling in economics. Options theory is considered normative (Davidson, 1996; Merton, 1998).

Although the literature on new product development is extensive, it seems that many research questions in managing a portfolio of new product development projects are open (for a recent review see Loch & Kavadias, 2008a). According to Kavadias & Chao (2008), research concerning decisions about resource allocation for a portfolio of new product development projects, should address problems such as:

- cross interactions of factors that define portfolio performance
- the impact of organizational levels and the modes of exploring and exploiting on resource allocation

- extending the study of isolated project level decisions in development funnels to a holistic process view that aggregates project level information to reflect the total portfolio value
- comparing different portfolio strategies in event studies

Empirical evidence from managerial selection and R&D project portfolio evolution in Cinnamon opens new perspectives for project portfolio management research. The findings in Cinnamon, somewhat surprisingly, address, to some extent, all of the above topics. In Cinnamon, the effects of co-selection in portfolio evolution are a new example of cross interactions in a project portfolio. Co-selection in the presence of unforeseen terminations sheds light on the internal interactions within a project and the outcome of portfolio strategies and performance. The importance of organizational levels in selection structures, with their different interacting selection rules that reinforce the effects of co-selection, has become visible in Cinnamon. The amount of variation in comparison with the selection mechanism, including co-selection, and the available slack has been identified as an important issue in Cinnamon. This problem has not been completely solved. The different approaches to project portfolio management have been compared, and to some extent, criticized.

The evolutionary approach to R&D project portfolio management is helpful at directing the level of analysis to the portfolio instead of relying only on the level of an individual project. This is especially true of long-lasting new product development initiatives, where both new technology and new market often appear together. The internal interactions of projects, due to co-selection and the dominant project design, are a novel finding in portfolio research. Based on the findings of this study, I shall address some aspects of normative portfolio management models which build upon concepts such as rational decision making, ordinal utility, and optimizing.

7.1.2. Rational decision making

In Cinnamon, the settings for portfolio decision making were ambiguous. Top managers employed both a strategic and a structural contextual setting to establish meaning to managing the portfolio. In Cinnamon, processes were defined and issues of content taken into account by selection rules. Strategic decision making about project prioritizing did not slip out of the hands of top management.

In the organization, managers made portfolio decisions in committee according to a scheduled procedure. The logic of portfolio decisions in Cinnamon was more appropriate to a rule base, than a choice base. Choices of preferred projects were based on selection rules regarding priority. The portfolio committee in Cinnamon relied on consensus decisions. Executives avoided formal portfolio selection criteria that were based on models. Project terminations were unexpected, and R&D projects carried a high risk.

The project committee made more content driven decisions in the course of fulfilling the milestone criteria. The selection rule for milestone decision could overrule the selection rule for prioritizing but prioritizing could not disregard the milestone selection rule.

Both decision content and decision process are important for innovation decision making (van de Ven, 1986). Many decisions in projects are made by default according to a plan rather than by intent (Krishnan & Ulrich, 2001). Even quite unique strategic decision contents are reduced to a few categories (Mintzberg, Raisinghani & Théorêt, 1976), because primary perceptions of managers yield to framing and channeling into categories (Nutt, 2002). Framing a problem (Nutt, 1998a) and also the degree of uncertainty in the decision context (Allaire & Firsirotu, 1989; Pich et al, 2002) have impact on decision effectiveness.

The dominant paradigms in strategic decision making are the rational, the rule based, the power political and the garbage can model streams of research (Eisenhardt & Zbaracki, 1992). In the anarchic garbage can model context, not content is important (Cohen, March & Olsen, 1972). Institutional forces sometimes constrain garbage can anarchies (Levitt & Nass, 1989). Strategic decisions are of limited rationality (Simon, 1947, 1955; Lindblom, 1959). In the rational decision models, decision making and information gathering is emphasized by the cost of neglecting action (Brunsson, 1982). Strategic decision making theory lacks good conceptualization which unifies the rational, action and interpretative perspectives and covers strategy process (Hendry 2000), classifies decision processes or behavior (Cray, Mallory, Butler, Hickson & Wilson, 1988), and explains, how and why non-decisions arise (Hickson, 1987).

In a team that has to consider complex issues, there is too much rather than too little information at hand. Hence, managers try to establish meaning. They try to make sense of what is going on rather than merely solving well formulated problems (March, 1994b; Weick, 1995), or focus attention (van de Ven, 1986; Ocasio, 1997; Greve, 2008). In a reanalysis of Thomson's (1967) predictions of effective decision making, , Nutt (2002) suggest that for effective strategic decision making in teams, judgment is used unless powerful actors interfere. In this latter case, bargaining is introduced. Analysis is avoided, since it is affected by biased data gathering or biased "clean" statements about issues that are inherently emotional and complex. In some instances, analysis is more effective than judgment (Nutt, 1998b). Some scholars (for example, Eisenhardt, Kahwajy & Bourgeois, 1997) claim that heterogeneous teams make more successful decisions. Others (for example, Dean & Sharfman, 1996) maintain that focusing on procedural rationality, where the process of information gathering is considered relevant and pursued systematically, makes teams effective, but focusing on a political decision makes teams less effective. A study on team effectiveness in a wide variety of teams shows no coherent overall findings which undermines the importance of context and team type in discussing group effectiveness (Cohen & Bailey, 1997).

Managers are not committed to normative decision models because they suspect that models do not reflect the problems they are facing in their work in an adequate way (Bower, 1970; Nutt, 1984; March & Shapira, 1987). Rational normative axiomatic economics has been increasingly criticized for oversimplifying and other defects in its theoretical foundations (see for example Nelson & Winter, 1982; Lawson, 1988; Simon, 1979; Vanberg, 2004; Hodgson, 1993, 2004). For example, habits and rules, omnipresent in organizations, have been explicitly neglected in economic analysis of decisions by agents for over half a century (Hodgson, 1997). I will not attempt to review this wide discourse in detail. I just observe that this criticism has revealed a problem in the foundations of traditional financial models of the optimizing of portfolios (Markowitz, 1952, Sharpe, 1962, Merton, 1998). Their axioms, according to critics, do not apply if true uncertainty is present. As narrated by Nightingale (2008), the "skeptical" project manager described by Klein & Meckling (1958) recognizes that future performance of a project that has been specified today is often unknowable. Hence, there is no justification for one time historical optimization to succeed, as is assumed by the "planner" project manager. Events in the future are not foreseen clearly enough to allow any numerical estimates about the probabilities of some important future outcomes, internal or external to the project or the firm. Moreover, not even the types or categories of some instances in the future are foreseeable. Alas, project portfolio management leans on rational decision theory and optimizing models of new product development for the unknown future (Standard for Portfolio Management, 2008). Attempts to model uncertainty still assume that categories of future events are known (Orszag & Yang, 1995). What Knight (1921) called "true uncertainty" and Thompson (1967) "unknown unknowns" have no place in these models. Since true uncertainty does not fit the modeling approach, models do not recognize it.

In Cinnamon, the features of project portfolio selection to prioritize did not support the idea of purely rational decision making. Normative project portfolio management models pursue rational decision making as a model for optimizing a project portfolio. Both the findings in Cinnamon and the general literature on decision making clearly regard rational decision making as highly insufficient to account for real life portfolio management.

7.1.3. Ordinal utility

In Cinnamon, projects were not ranked in absolute scale of measurement when they were prioritized. The two criteria in the selection rule for prioritization – high revenue and global access - were interdependent, but not reducible to a single one-dimensional measurement of utility. For example, achieving global access is important in order to guarantee that new products utilize the global marketing machinery which the firm wants to sustain. In Cinnamon, a funding quota for different business units prevailed. Balancing projects was needed because all attributes could not be ranked by an ordinal measure.

Co-selection in Cinnamon also changed the portfolio over time. Project comparison models do not recognize internal project interdependencies that occur due to a dominant design and manifested by co-selection. Project comparison techniques for rank ordering or balancing tacitly assume that the attributes of single projects are always separable. This is unwarranted because of the dominant design of R&D projects. One cannot independently choose different project attributes to any balancing heuristics and then compare them, since some project attributes are connected inside a project. Project comparison models also neglect the interactions between projects, which are negative externalities and affect balancing. In Cinnamon, the milestone selection rule interfered with the priority selection rule.

Historically, the notion of utility in economics degenerated from the multi-dimensional and incommensurable utility considerations of Jeremy Bentham to a one dimensional marginal utility analysis found in the writings of Jevons, Walras and Marshall (Warke, 2000). Classical ordinal utility theory is now being questioned (Simon, 1979; Tversky & Kahneman, 1986). The empirical heuristics for portfolio balancing (Cooper et al, 1998) tries to reinstate the lost delicacies of Bentham's incommensurable utilities that collapsed to a one-dimensional ordinal valuation.

Some portfolio management models state that there cannot be prioritizing without ranking (Standard for Portfolio Management, 2008). This is a manifestation of the "ordinality fallacy" found in these optimizing models. The assets in a R&D project portfolio are assumed to have one-dimensional utility so they can be compared like numbers in an ordinal transitive array. In fact, balancing with buckets and scoring models prioritizes without ordinal ranking (Cooper et al, 1998).

Taking account of interdependency requires organization-dependent weighting of goals (Dickinson et al, 2001). Empirically oriented scholars suggest there is no one single technique that satisfies the needs of a practical R&D project selection technique (Ringuest, Graves & Case, 2004).

Data from Cinnamon does not support the use of mathematically oriented ordinal utility models. Balancing was in use. As is evident in decision research results, choosing for preference is not necessarily ordinal, well-ordered, or transitive, and sequence preserving. The whole idea of balancing a portfolio in the practitioner-oriented literature goes against one-dimensional ordinal project ranking. Managerial judgment recognizes a multi-dimensional utility in portfolio selection.

7.1.4. Optimizing and path dependence

The findings in Cinnamon do not support an exhaustive search procedure resembling optimizing in the selection to prioritize projects. Review events in the portfolio committee without decisions were rare compared to decision events. The empirical reality around portfolio management in Cinnamon was that of rule following selection, which operated within the selection structure of the organization. Decisions were part of a systemic interactive ecology. Interactions between selection structures took place. Cinnamon, like all firms possessing R&D portfolios started from a specific path-dependent historical situation, both externally and internally.

In Cinnamon, path dependence was created by persistent selection rules for prioritized projects. Some were terminated due to unforeseen technological hurdles. Path dependence was reinforced due to co-selection and the advancement of product development by stages, which changed portfolio retention. Prioritization decisions resulted in an accumulation of prioritized projects and their attributes over time in a path dependent way. New projects induced variation. Co-selection reduced variation. The development of projects to further stages changed variation. Co-selection resulted in a path dependent change of properties in the portfolio. These mechanisms created a new non-ergodic future.

A mathematical portfolio model assumes rational decision making under ordinal utility by optimal choice. Optimization is about finding, through mathematics, a maximal or minimal utility value to a set of equations with several variables (for details see Luce & Raiffa, 1957; Ackoff, 1962; von Neumann & Morgenstern, 1944). The first critique of "optimizing" normative project management was presented quite some time ago (Klein & Meckling, 1958). Managers search solutions rather than optimize them (Nelson & Winter, 1982). Decisions are made by aspiration level to find "good enough" solutions rather than by maximizing some equations (Cyert & March, 1963; Greve, 2007, 2008). Decision research reveals that people follow rules rather than optimize (Page, 2008).

Mathematical optimization models do not account for historical specificity. In technical terms, they are ergodic. Path dependent processes are neither Markov nor ergodic processes (Page, 2006). The sequence in which selections are made over time does matter. Path dependence goes against the ergodic assumption. Optimizing is not path dependent (Page, 2006). An evolutionary framework is path dependent (Carroll & Harrison, 1994). The escalation of commitment need not be just harmful; it is present and also needed when managers persist in funding projects through trial and error selection to achieve learning (Garud & van de Ven, 1992; Turner & Keegan, 2004).

Option theory is a further development of mathematical optimizing. The mathematical model for option pricing began as a theory of speculation put forward by Bachelier in 1900 (Merton, 1998; Mandelbrot & Hudson, 2004). It was reintroduced in order to build a normative theory to evaluate the value of a financial portfolio by Markowitz (1952) and Sharpe (1964). Combining asset price variance to determine risk level, these authors formulated a capital asset pricing model. Portfolio theory relies on one-dimensional ordinality of any attribute's utility, which is incorporated to estimate portfolio value.

The tradition of economic theory, including the theory of financial options, is axiomatic in structure and normative in the way it interprets the results of its scholarship (Davidson, 1996; Merton, 1998). The axiomatic approach has been recently challenged by many scholars (Davidson, 2003; Hodgson, 1997, 2004; Vanberg, 2004). An increasing amount of experimental evidence shows that theory derived from these axioms is not compatible with the data. R&D project portfolio management using the real options approach has been proposed by numerous authors (Merton, 1998; McGrath, 1997; Luermann, 1998; Lint & Pennings, 2001; Rogers, Gupta & Maranas, 2002; McGrath, Ferrier & Mendelow 2004; McGrath & Nerkar, 2004). According to McGrath & Nerkar (2004), managers in pharmaceutical firms actually reason by real option logic. Huchzermeier & Loch (2001) and Hartmann & Hassan (2006) consider there is little evidence of their use by managers.

Using real option reasoning in innovation project portfolio selection has been extensively criticized. Optimizing is computationally intensive, especially when systems are complex (Blau et al, 2004; Seider, 2006). Unforeseen uncertainties (Knight, 1921; Keynes, 1937; Thompson, 1967) cannot be modeled with real options for lack of categories for unknown risks, or sensible probability estimates for uncertain events. After rejecting a development project, it is not possible to revitalize it if opportunities arise (Adner & Levinthal, 2004ab). Real option theory does not take procedural elements in decision making into account. Real option theory in the case of R&D investment decisions would require estimates of value which are not available in practical business contexts and the oversimplification of calculations, which is theoretically deleterious (Lander & Pinches, 1998). Financial theory on option modeling needs exact data to allow forecasting, much of which is not available due to uncertainty (Knight, 1921). Real option reasoning over different time spans requires attention. One should recall that financial portfolio tools evaluate asset returns for the time span of weeks or months (Levy & Duchin, 2004). Compared to the time span of R&D investment over years, and cash flow generation over decades, the models are myopic. It is an open question regarding the extent that option modeling can be improved by relaxing assumptions on risk distribution to include asymmetric distributions beyond Gaussian ones with fat tails and long term path dependencies (Mandelbrot & Hudson, 2004). It is also an open question, whether multi-dimensional measures of utility can be accommodated in real option theory (Lander & Pinches, 1998). In current practice, real option models use ordinal utility.

Ultimately, mathematical portfolio models assume that the future resembles the past (Carlson, Fullér, Heikkilä & Majlender, 2004; Golosnoy & Okhrin, 2008). Market valuation of a firm's R&D capital separating technological and market uncertainty have been presented (Oriani & Sobrero, 2008). It is evident from the discussion between Adner & Levinthal (2004a) and McGrath, Ferrier, & Mendelow (2004) that scholars do not always differentiate clearly between real option and more general iterated decision making (Noda & Bower, 1996). The heuristic and normative aspects of real option reasoning are also sometimes confused (Adner & Levinthal, 2004b). If real option reasoning is used in practice, it is only done so for projects where quantifiable benefits are small (Tiwana, Wang, Keil & Ahluwalia, 2007). The possible gains of practical NPD projects are huge.

I have found no evidence in Cinnamon to support the claim that managers selecting a R&D portfolio use real options reasoning. Selection rules were applied. New products were not introduced to mend the performance gap of missing Lavender projects. Regarding real options as normative in R&D development may have resulted from first regarding financial options as normative in economic theory. Innovation portfolio management faces many-dimensional utility, for example, balancing a portfolio between strategic business units or prioritizing projects in different geographical locations. Therefore, real option models should be applied with caution to phenomena beyond ordinal utility.

7.1.5 Summary

With regard to rational decision making, ordinal utility and optimizing, the findings in Cinnamon are not compatible with the model-centered view of portfolio management. The findings rather support a view of an empirical and heuristic approach, emphasizing the uncertain future, managerial judgment, procedural contingencies and firm specific solutions to multi-dimensional problems within portfolio management.

7.2 Implications for practitioners

7.2.1. Co-selection limits R&D portfolio management

Managerial intention regarding decisions about R&D portfolio selection as a means to adapt the firm in the best possible way for future success is limited by co-selection. Co-selection interferes with the prioritizing of projects in a portfolio. Practitioners should recognize that their lists of preference regarding R&D projects selected for prioritization bring about other choices they have not been intentionally made. There are previously unrecognized limits to managerial choice. These arise from internal dependencies within the projects. The project attributes that were not intentionally chosen still change the total portfolio. These changes may become visible more easily if unforeseen terminations kill some of the most favored projects, and projects with unexpected attributes are retained. Co-selection does not become visible only when portfolio models using one-dimensional ordinal utility measures are used. It may become visible with empirically derived portfolio balancing models.

7.2.2. Experiment with selection mechanisms

When managing a portfolio of new product development projects one should examine carefully how their current selection system operates and what it delivers. Since managers cannot anticipate every instance of co-selection, they should be encouraged to experiment with vicarious internal selection mechanisms. They should experiment with different sets of selection rules and selection structures and observe the outcomes of these choices. This is a way to learn about internal project constraints. Managers should be alert to the interactions between different selection structures and their selection rules.

7.2.3. Adjust variation for co-selection effects

Increasing new R&D project initiatives helps to complete the development of future products that are drivers of the business. Managers should either initiate a larger number of projects or maintain a larger pre-project pool of discoveries that would make faster new project entries possible. Co-selection is a manifestation of constraint in project dominant design. Hence, it also constrains the scope of variation. Increasing variation creates more opportunities to circumvent the instances of co-selection which become amplified by sudden losses in the project portfolio. Managers should study carefully the interplay of variation and selection under the specific conditions of their firm and industry.

In addition, managers should perceive that they are funding the totality of the R&D project portfolio, which includes both successes and failures. Both restrictions to managerial choice due to co-selection and instances of Knightian uncertainty change the project portfolio in an unanticipated way. Some of the R&D funding for future success gets allocated to future failures. However, these failures are not known until they materialize, sometimes even very late.

7.2.4. Maintain financial reserve to achieve variation

To increase variation managers should make allowances for slack resources. The previous prescriptions to increase variation and adjust selection rules and selection structures may be not possible to realize unless managers recognize the need to budget slack, both material and temporal. Slack resources in R&D project portfolio management are the means to finance increased variation and relieve temporal congestion. Variation makes exploratory search of new ideas possible. An unallocated reserve in resourcing enables managers to cope proactively with unforeseen co-selection and sudden performance gaps in the R&D project portfolio. Building temporal slack and, when allocating resources, being more specific on the types of resources help to synchronize workflows when decisions about different levels of the organization interact. Evolution favors the prepared mind.

7.3 Conclusion

With the help of rich empirical data from the case firm, I have longitudinally analyzed a multi-level intra-firm selection environment. This study has a number of specific contributions.

First, I have conceptualized co-selection as a non-adaptive evolutionary mechanism in a R&D project portfolio driven by dominant design. I have presented empirical data from a new product project portfolio in a global R&D intensive firm to support the conjecture of co-selection.

Second, I have causally explained deviant R&D project portfolio evolution with the help of the co-selection mechanism and thereby provided insight to the question of why the realized R&D strategies of a firm were in conflict with each other.

Third, extending the work of Robert A. Burgelman, I have explicitly refined the analysis of vicarious selection mechanisms. I have differentiated between two organizational selection structures and a number of selection rules acting on different entities. I have described the interactions between hierarchy levels of selection structures using different selection rules. An improved classification of selection mechanisms benefits their analyses in scope, clarity and causal relevancy.

Fourth, the study enriches the portfolio management literature with new empirical findings. When managing a R&D project portfolio, internal project constraints force decisions. Interactions between organizational levels regarding portfolio selection for priority and project milestone decisions occur. The amount of variation and the portfolio selection rules are connected; this can be detected by observing the total portfolio dynamics.

Fifth, the results of the study suggest that a R&D project portfolio should be managed with the help of adjusting variation and experimenting with selection mechanisms in order to cope with co-selection and Knightian uncertainty. The study supports the view that sufficient financial slack to allow new product variation is beneficial to the development of innovation. The study supports the idea that temporal slack as a means to cope with interconnected selection structures is a helpful way to manage the critical path.

Sixth, the study addresses some limitations found in normative project portfolio management models and managerial practices based on, or relating to, financial optimizing theory of ordinal utility. The use of empirical heuristic models that permit multi-dimensional utility is encouraged.

Finally, study results point towards some practical prescriptions for managing R&D development project portfolios.

The results of my study show that the concept of co-selection widens and sharpens the evolutionary logic of variation, selection and retention. This should encourage scholars to look for other features of selection logic not previously characterized, but possibly within reach of evolutionary inquiry. Co-selection arises from the fact that entities under selection are not put together in a way that allows illimitable modification and change in their structure, and unbounded adaptation. Non-adaptive, forced selection is likely to occur when adaptive selection rules are applied. My research suggests that non-adaptive co-selection may compel us to revise our understanding of managerial choice in a profound way.

There are an increasing number of scholars who agree that economic and managerial theory benefits from pursuing research within the evolutionary framework; in Darwin's (1859) and Veblen's (1898) tradition (Aldrich et al, 2008; Beinhocker, 2006; Gavetti & Levinthal, 2004; Hodgson, 2007bc; Pich et al, 2002). In the field of biology, forced non-adaptive selection has received immense and ongoing attention through the work of the late Stephan Gould. In establishing the material and temporal limits to Panglossian adaptation (Gould & Lewontin, 1979; Gould, 2002) he developed Darwin's theory. It is increasingly recognized that adaptive changes at many levels are far more restricted than previously assumed. The restrictions arise, first, from the structural constraints of internal design and, second, from the temporal constraints of the path-dependent historical constitution of organisms. However, adaptive constraints produce asymmetric variation in biological evolution. These constraints may therefore provide efficient opportunities for new growth based on limited variation. When variation is immense yet miniscule, this causes the congestion of selection mechanisms. Gould's conceptualization has new explanatory power beyond the traditional adaptation-centred approach.

By introducing co-selection, this study helps to understand selection mechanisms in R&D project portfolio management in project based firms. Consider sowing and reaping as a metaphor for fostering projects in a portfolio. One does not know ahead, which exactly seeds will germinate. Some will sprout, others will not. They all are spread, and their totality yields the crop to harvest. Describing managerial action with Darwinian evolutionary logic, the effects of co-selection may become increasingly important in searching for the constraints to firms' adaptation, guided evolution, exploration, variation or to managerial intent. This would lead to an improved strategic understanding of the limits and possibilities of the managerial pursuit for success. The discovery of internal, structure driven, modular and design related constraints, and temporal, path dependent and historically specific constraints may well go hand in hand with the detection of new instances of co-selection.

The phenomena of dominant design and modularity are well established in the management and innovation literatures. Co-selection reveals these internal structural constraints to managerial choice in R&D portfolio management. These constraints may, hopefully, also provide signals of opportunity for managers to build upon what they have. The study of routines and habits to explain managerial choice is being revitalized (Hodgson, 2009). Routines can be connected with projects which are artefacts. The idea of co-selection among routines and habits is fascinating. Ideally, research on routines and habits could be conducted in the empirical context of project business firms. Future scholarship will judge the significance of the construct of co-selection in explaining the undetected consequences of managerial action.

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Archival sources

Internal records

Portfolio Committee Meeting Minutes
Project Committee Meeting Minutes
R&D Handbook

Public records

Annual Reports

9. Appendices

Appendix 1 Abbreviations

Abbreviation	**Full text**
EMEA	European Medicines Agency (European Union)
FDA	Food and Drug Administration (USA)
NPD	New Product Development
NYSE	New York Stock Exchange
PMDEC	Pharmaceuticals and Medical Devices Evaluation Center (Japan)
QCA	Qualitative Comparative Analysis
R&D	Research and Development

Appendix 2 Data coding dictionary for Excel table

Code	Definition	Explanatory notes
LAV	Business unit color code	The project is assigned to business unit lavender. For confidentiality, actual names are not disclosed.
LIM	Business unit color code	The project is assigned to business unit lime. For confidentiality, actual names are not disclosed.
BLU	Business unit color code	The project is assigned to business unit blue. For confidentiality, actual names are not disclosed.
TAN	Business unit color code	The project is assigned to business unit tan. For confidentiality, actual names are not disclosed.
PRI	Prioritized project	Divides the class of projects into two mutually exclusive categories. All other projects are non-prioritized. Prioritization occurs either through allocating more resources, or establishing priority in bottlenecks.
NEW	Initiate a new project	Development stage code S(n) can vary at the start
P	Grant priority status to a project	
DEP	Remove priority status from a project	Negation to PRI
ACC	Accelerate project	Put resources into project to increase the speed of development. Always coded to PRI.
HLD	Put a project on hold	Stop all activities and wait for new information or resources, restart possible. Always coded as DEP.
TER	Terminate a project	Project goal is not attained, problems of development or change in market situation.
END	Complete a project after the product has received regulatory approval or launched	Contrary to termination, the completed product delivers revenues.
OUL	Out-license a project	Always coded as END.
REV	Review a project	Number of reviews is a measure of managerial attention.
A(n)	Age of project	Recorded as time difference from initiation to current time.
T(n)	Running time	Calendar dates from individual minutes in ordinals (not intervals) from 1 to 83.
D(n)	Milestone decision	Milestones decisions move projects to the next stage when goals of the previous stage have been reached. Number (n) varies from 2 to 6.
S(n)	Project development stage	Projects are at a development stage. Number denotes the stage of the project Number (n) varies from 2 to 6.

Appendix 3 Definitions of variables in terms of measurable entities

Decisions
Project initiation
Project prioritization
Project de-prioritization
Project termination
Project completion
Project stage milestone decision (D2, D3, D4, D5, D6)
Decision patterns
Distribution of project initiations
Distribution of project prioritizations
Distribution of project de-prioritizations
Distribution of project terminations
Distribution of project completions
Distribution of project milestone stage decisions (D2, D3, D4, D5, D6)
Project attributes
Prioritized project
Not prioritized project
Project membership in a business unit (Lavender, Lime, Blue, Tan)
Development stage (S2, S3, S4, S5, S6) of project
Age of project
Portfolio attributes
Number of projects
Number of prioritized projects
Number of projects by business unit (Lavender, Lime, Blue, Tan)
Number of projects in a development stage (S2, S3, S4, S5, S6)
Age of portfolio
Portfolio patterns
Distribution of projects
Distribution of prioritized projects
Distribution of projects by business unit (Lavender, Lime, Blue, Tan)
Distribution of projects by development stage (S2, S3, S4, S5, S6)
Distribution of projects by age

Appendix 4 Chronology of project and portfolio committee meetings

year	unit of time	type of meeting	Year	unit of time	type of meeting
year 1	1	project committee	year 5	43	*portfolio committee*
year 1	2	project committee	year 5	44	project committee
year 1	3	*portfolio committee*	year 5	45	project committee
year 1	4	project committee	year 5	46	*portfolio committee*
year 1	5	project committee	year 5	47	project committee
year 1	6	project committee	year 5	48	*portfolio committee*
year 1	7	*portfolio committee*	year 6	49	project committee
year 1	8	project committee	year 6	50	project committee
year 1	9	project committee	year 6	51	*portfolio committee*
year 2	10	project committee	year 6	52	project committee
year 2	11	project committee	year 6	53	*portfolio committee*
year 2	12	*portfolio committee*	year 6	54	project committee
year 2	13	project committee	year 6	55	*portfolio committee*
year 2	14	project committee	year 6	56	project committee
year 2	15	*portfolio committee*	year 6	57	project committee
year 2	16	project committee	year 6	58	*portfolio committee*
year 2	17	project committee	year 7	59	project committee
year 2	18	*portfolio committee*	year 7	60	*portfolio committee*
year 3	19	project committee	year 7	61	project committee
year 3	20	project committee	year 7	62	project committee
year 3	21	*portfolio committee*	year 7	63	project committee
year 3	22	project committee	year 7	64	*portfolio committee*
year 3	23	*portfolio committee*	year 7	65	project committee
year 3	24	project committee	year 7	66	*portfolio committee*
year 3	25	*portfolio committee*	year 7	67	project committee
year 3	26	project committee	year 8	68	project committee
year 3	27	project committee	year 8	69	project committee
year 3	28	*portfolio committee*	year 8	70	*portfolio committee*
year 4	29	project committee	year 8	71	project committee
year 4	30	project committee	year 8	72	project committee
year 4	31	*portfolio committee*	year 8	73	project committee
year 4	32	project committee	year 8	74	project committee
year 4	33	*portfolio committee*	year 9	75	project committee
year 4	34	project committee	year 9	76	project committee
year 4	35	project committee	year 9	77	*portfolio committee*
year 4	36	*portfolio committee*	year 9	78	project committee
year 4	37	project committee	year 9	79	*portfolio committee*
year 4	38	*portfolio committee*	year 9	80	project committee
year 5	39	project committee	year 9	81	*portfolio committee*
year 5	40	project committee	year 9	82	project committee
year 5	41	*portfolio committee*	year 10	83	*portfolio committee*
year 5	42	project committee			

Appendix 5 Organizational selection structures

Selection structure	**Membership**	**Mandate**
Project committee	business unit, R&D, and functions leadership	approve milestone decisions D2, D3, D4, D6, but propose decisions D5 to portfolio board
Portfolio committee	top management, business unit and regional business leadership	approve milestone decision D5, approve project initiations, prioritizations, de-prioritizations, terminations and completions

Appendix 6 Project development stages, milestones and regulatory phases

Stage of development	**Milestone**	**Type of development activity**	**FDA, EMEA and PMDEC regulatory scheme phase**
Project candidate	n. a	Drug discovery process	
S2	D2	Chemical and biochemical characterization, animal models, manufacturing scale up	phase 1
S3	D3	Pharmacological, toxicological, proof of concept in humans	phase 1- 2
S4	D4	Proof of efficacy in humans	phase 2
S5	D5	Large scale clinical trials	phase 3
S6	D6	Follow up clinical trials of marketed product, new clinical trials for new applications or product claims	phase 3 - 4

Appendix 7 Selection events by selection structure

Year	1	2	3	4	5	6	7	8	9
Portfolio committee									
Project initiations									
Lavender	10	9	11	14	6	9	6	12	6
Lime	10	7	5	7	7	2	4	4	4
Blue	7	2	1	11	0	6	6	7	1
Tan	2	1	0	5	6	1	3	0	0
Project prioritizations									
Lavender	5	5	2	2	4	4	4	13	12
Lime	5	4	2	2	3	1	5	2	13
Blue	6	5	0	4	3	0	1	1	7
Tan	0	0	0	0	0	1	1	0	0
Project de-prioritizations	2	4	2	5	0	1	0	1	7
Lavender	1	2	0	0	0	0	0	1	5
Lime	0	1	2	4	0	0	0	0	1
Blue	1	1	0	0	0	1	0	0	1
Tan	0	0	0	1	0	0	0	0	0
Termination all projects									
Lavender	2	5	6	1	5	5	7	4	5
Lime	1	7	5	0	1	1	4	4	3
Blue	0	1	3	1	0	6	4	2	5
Tan	0	1	1	1	0	5	1	4	0
Terminations prioritized projects									
Lavender	0	2	2	0	1	1	1	1	4
Lime	0	0	0	0	0	0	1	1	0
Blue	0	0	1	0	0	2	1	0	1
Tan	0	0	0	0	0	0	1	1	0
Ends all projects									
Lavender	0	0	1	0	0	0	0	3	0
Lime	0	0	0	0	0	0	0	5	2
Blue	0	0	0	0	0	0	0	6	0
Tan	0	0	0	0	0	0	0	1	0
Ends prioritized projects									
Lavender	0	0	1	0	0	0	0	0	0
Lime	0	0	0	0	0	0	0	2	0
Blue	0	0	0	0	0	0	0	1	0
Tan	0	0	0	0	0	0	0	0	0
Project committee									
Milestone decisions*									
D2: Enter *stage S2*	23	11	12	24	12	18	15	17	9
D3: Enter *stage S3*	14	4	5	13	9	3	8	5	4
D4: Enter *stage S4*	16	3	3	9	7	11	7	7	7
D5: Enter *stage S5*	15	9	6	6	8	5	6	6	6
D6: Enter *stage S6*	12	6	1	5	2	2	2	6	5

Note: Total annual values are reported.

*) includes decisions reconfirmed by portfolio board, and for year 1, includes all entries from the year before

Appendix 8 Portfolio dynamics

Year	1	2	3	4	5	6	7	8	9
Projects by business unit									
Lavender	16	19	21	33	33	36	36	37	36
Lime	27	27	25	27	32	32	34	33	30
Blue	12	15	12	11	19	17	19	18	17
Tan	1	3	2	4	11	8	7	6	2
Total	56	64	60	75	95	93	96	94	85
Prioritized projects by business unit									
Lavender	3	7	4	5	7	10	11	11	15
Lime	5	8	8	9	10	11	11	12	10
Blue	3	6	4	4	9	8	6	4	4
Tan	0	0	0	0	0	1	1	1	0
Total	11	21	16	18	26	30	29	28	29
Project by development stage									
Stage S2	16	17	14	26	26	27	24	21	22
Stage S3	8	8	10	12	17	15	12	13	11
Stage S4	11	14	9	10	13	11	17	17	17
Stage S5	10	12	15	16	22	22	23	22	18
Stage S6	12	16	16	15	16	18	21	19	17
Priority status by project stage									
Stage S2	1	4	2	2	2	2	2	2	4
Stage S3	0	0	1	1	2	2	2	3	3
Stage S4	2	4	2	3	3	4	4	5	3
Stage S5	4	6	5	7	13	14	11	11	9
Stage S6	4	7	7	6	5	7	9	8	10
Priority by project stage in *Lavender*									
Stage S2	0	2	1	1	2	2	1	1	4
Stage S3	0	0	1	1	1	1	2	2	1
Stage S4	1	2	1	2	2	4	4	4	3
Stage S5	2	2	0	1	2	2	3	4	5
Stage S6	0	1	1	1	0	1	1	1	2
Priority by project stage in *Lime*									
Stage S2	1	1	1	1	0	0	1	1	0
Stage S3	0	0	1	1	1	1	2	2	1
Stage S4	0	1	1	1	1	0	0	0	0
Stage S5	1	1	2	3	5	6	5	5	3
Stage S6	3	5	4	4	3	4	5	5	5

Note: Average (median) annual values are reported.

Appendix 9 Portfolio age

Year	1	2	3	4	5	6	7	8	9
Age of project by business unit									
Lavender	0	0	13	15	22	27	29	35	30
Lime	0	0	19	23	26	35	40	46	46
Blue	0	0	20	26	25	31	29	31	31
Tan	0	0	20	17	10	20	24	19	20
Age of prioritized projects									
Lavender	0	0	18	17	22	35	42	47	36
Lime	0	0	21	30	36	44	50	54	59
Blue	0	0	21	31	33	39	52	61	70
Tan	0	0	0	0	0	13	21	29	0
Age of projects by stage									
Stage S2	0	0	7	8	10	15	13	16	11
Stage S3	0	0	16	18	18	26	27	28	28
Stage S4	0	0	21	25	23	24	26	30	30
Stage S5	0	0	19	25	31	39	44	47	51
Stage S6	0	0	22	28	35	46	52	60	64
Age of prioritized projects by stage									
Stage S2	0	0	12	16	17	22	19	26	12
Stage S3	0	0	12	25	31	41	40	38	30
Stage S4	0	0	22	28	34	38	39	45	39
Stage S5	0	0	20	28	30	36	46	49	53
Stage S6	0	0	22	28	41	52	59	66	68
Age of prioritized projects in *Lavender*									
Stage S2	0	0	13	13	17	26	32	39	12
Stage S3	0	0	12	25	33	43	43	37	26
Stage S4	0	0	23	27	31	38	40	47	40
Stage S5	0	0	17	7	15	26	41	42	45
Stage S6	0	0	23	8	0	54	62	70	62
Age of prioritized projects in *Lime*									
Stage S2	0	0	13	21	0	0	5	12	5
Stage S3	0	0	0	0	29	39	45	38	33
Stage S4	0	0	22	30	29	0	0	0	13
Stage S5	0	0	24	34	36	41	52	55	59
Stage S6	0	0	20	30	0	52	57	64	71

Note: Project age is measured as the number of committee meetings during project lifetime. Portfolio ages are annual averages.

Appendix 10 Frequencies of project ages by business unit and project phase

Age	>80	>70	>60	>50	>40	>30	>20	>10	>0
All projects by business unit									
Lavender	3	3	3	7	6	14	11	24	20
Lime	10	4	3	5	4	9	9	12	10
Blue	3	1	1	5	4	3	10	11	9
Tan	0	0	1	0	0	3	4	7	3
Total	16	8	8	17	14	29	34	54	42
Prioritized projects by business unit									
Lavender	0	0	1	1	3	4	4	9	7
Lime	2	3	2	1	0	3	3	1	1
Blue	2	0	1	0	2	2	2	2	4
Tan	0	0	0	0	0	0	0	0	2
Total	4	3	4	2	5	9	9	12	14
All projects by stage									
Stage S2	0	0	0	1	2	6	24	43	71
Stage S3	0	0	0	0	2	6	14	18	22
Stage S4	0	0	0	0	5	9	11	18	19
Stage S5	1	1	3	6	2	7	12	15	15
Stage S6	4	4	2	2	2	5	5	8	9
Prioritized projects by stage									
Stage S2	0	0	0	0	1	2	4	13	21
Stage S3	0	0	0	0	1	3	6	3	3
Stage S4	0	0	0	0	2	3	5	6	7
Stage S5	1	1	1	2	2	6	8	7	5
Stage S6	2	2	1	1	0	2	3	4	3

Note: Project age is measured as units of time from the number of committee meetings during project lifetime.

Appendix 11 Sales, performance, and investment in personnel and in R&D

Year	1	2	3	4	5	6	7	8	9
Firm performance indexes*									
Sales index	100	103	115	141	152	157	151	154	166
Earnings index	100	104	110	145	141	145	143	152	195
Personnel index	100	102	105	111	118	123	125	123	118
R&D investment indexes*									
R&D cost index	100	110	120	143	152	166	162	161	173
Project number index	100	106	106	134	153	144	144	136	134
Prioritized projects index	100	171	159	171	200	253	247	253	271
R&D cost per project	100	104	113	107	99	115	113	118	129
R&D cost per prioritized project	100	64	75	83	76	66	66	64	64

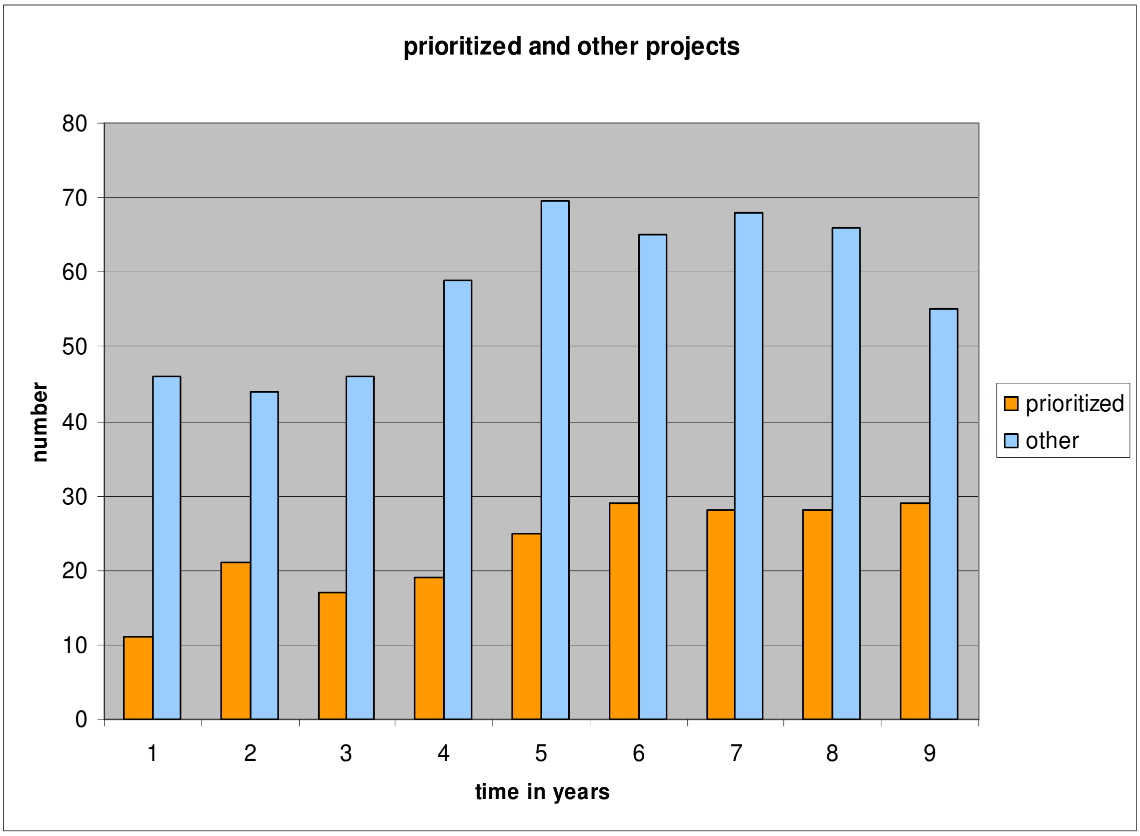
* Year 1 = 100

Appendix 12 Necessary conditions for co-selection by business unit

Lavender *	*Lime* *	*Blue* *	*Tan* *
S2 + S3 + pre-priority * S4 + pre-priority * S5	S2 + S3 + S4 + S5	S3 + S4 + pre-priority * S6	S3

(+) Denotes Boolean addition, corresponds to the logical connective "or"
(*) Denotes Boolean multiplication, corresponds to the logical connective "and"
(S2) Denotes stage S2
(S3) Denotes stage S3
(S4) Denotes stage S4
(S5) Denotes stage S5
(S6) Denotes stage S6
(Pre-priority) Denotes "already prioritized project"

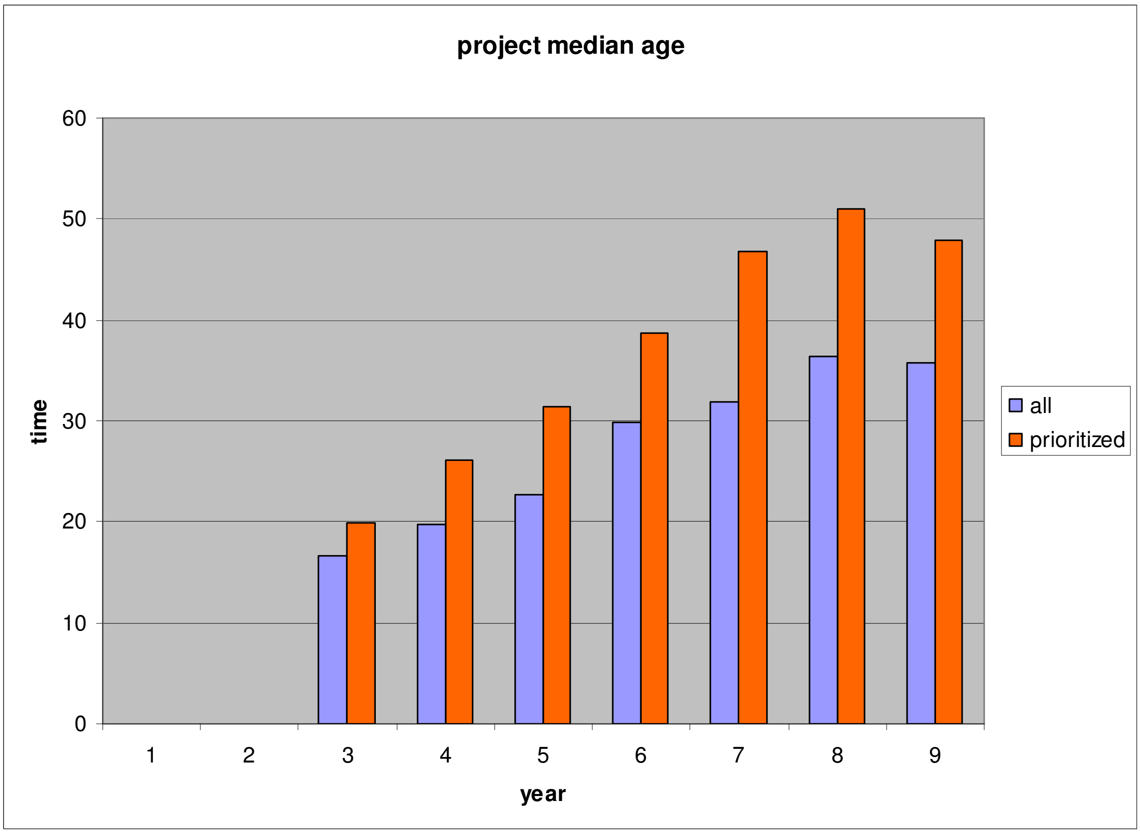
Appendix 13 Projects and prioritized projects



Horizontal axis: time in years

Vertical axis: number of projects

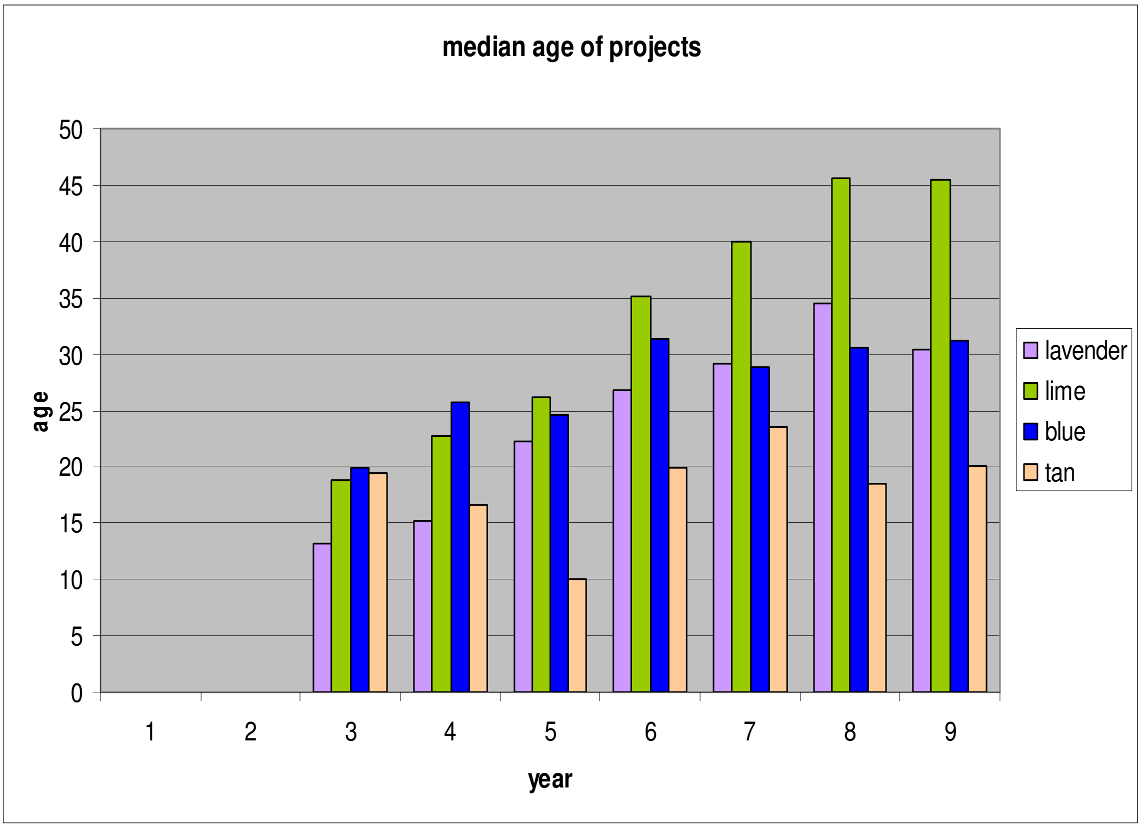
Appendix 14 Median age of projects and prioritized projects



Horizontal axis: time in years

Vertical axis: age of projects, units in time

Appendix 15 Median age of projects by business unit



Horizontal axis: time in years

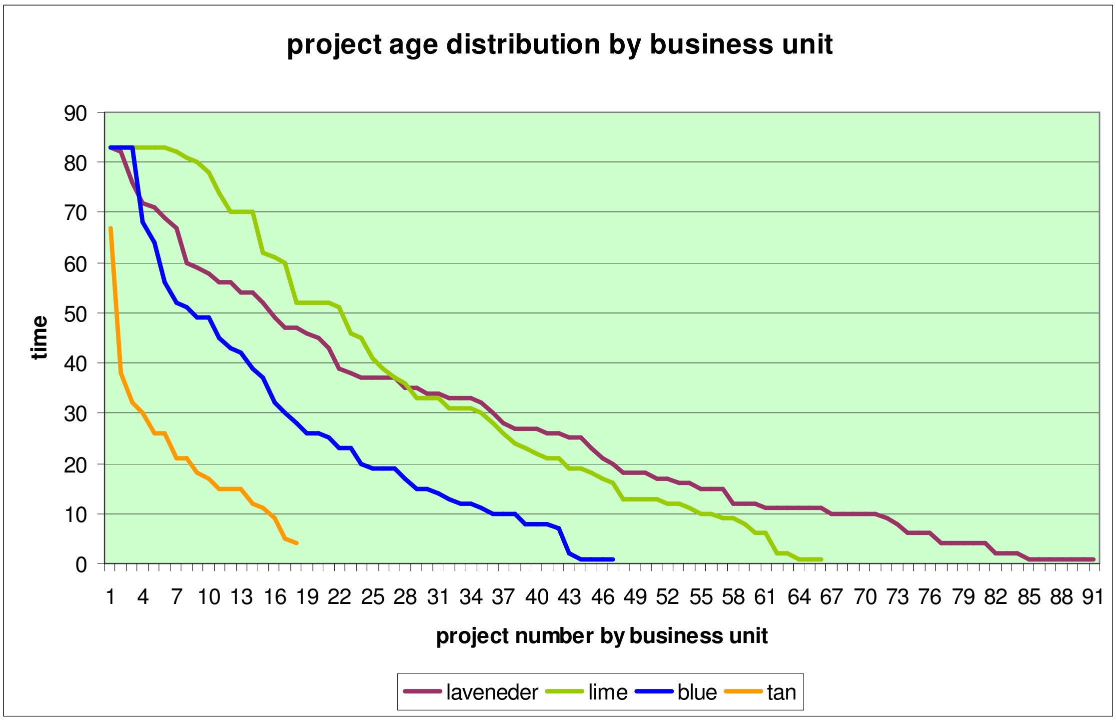
Vertical axis: age of projects, units in time

Appendix 16 Median age of prioritized projects by business unit

Horizontal axis: time in years

Vertical axis: age of projects, units in time

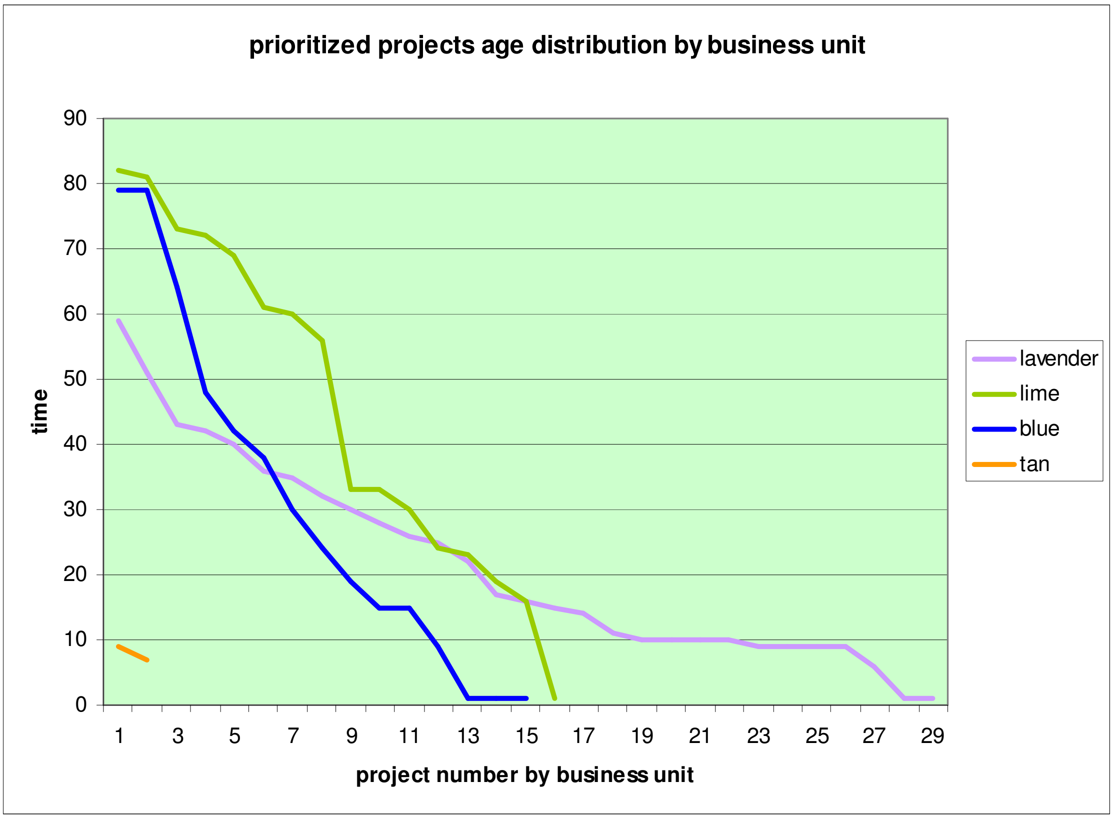
Appendix 17 Project age distribution by business unit



Horizontal axis: number of projects

Vertical axis: duration, units in time

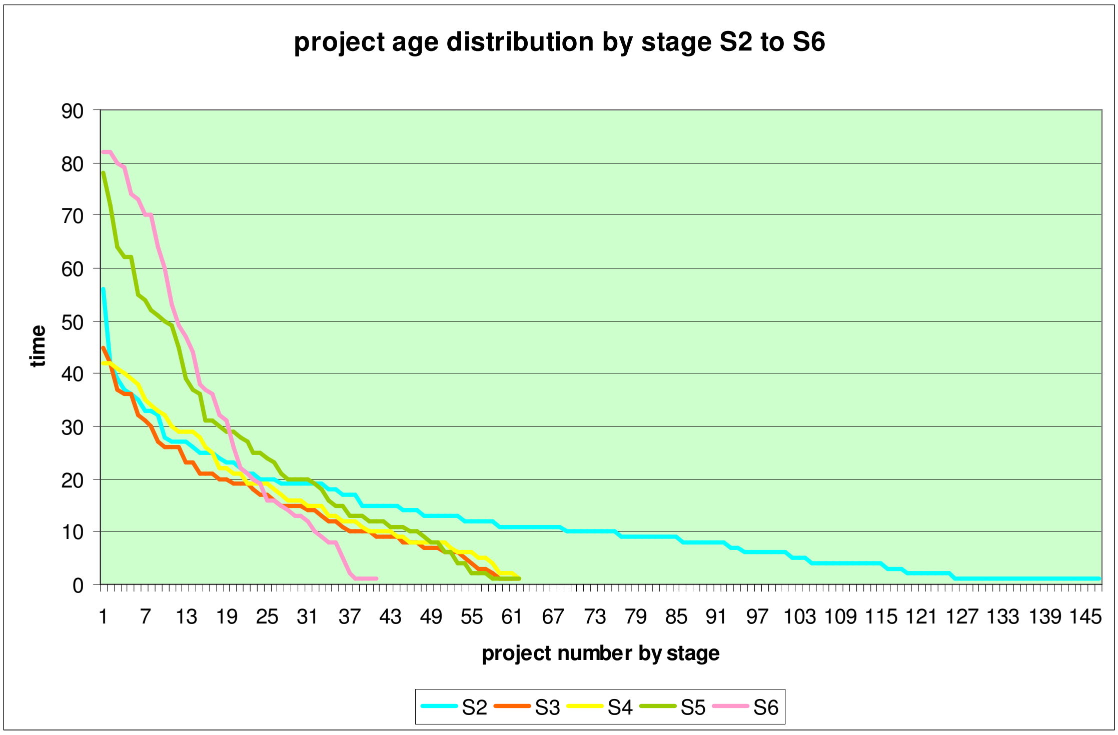
Appendix 18 Prioritized project age distribution by business unit



Horizontal axis: number of projects

Vertical axis: duration, units in time

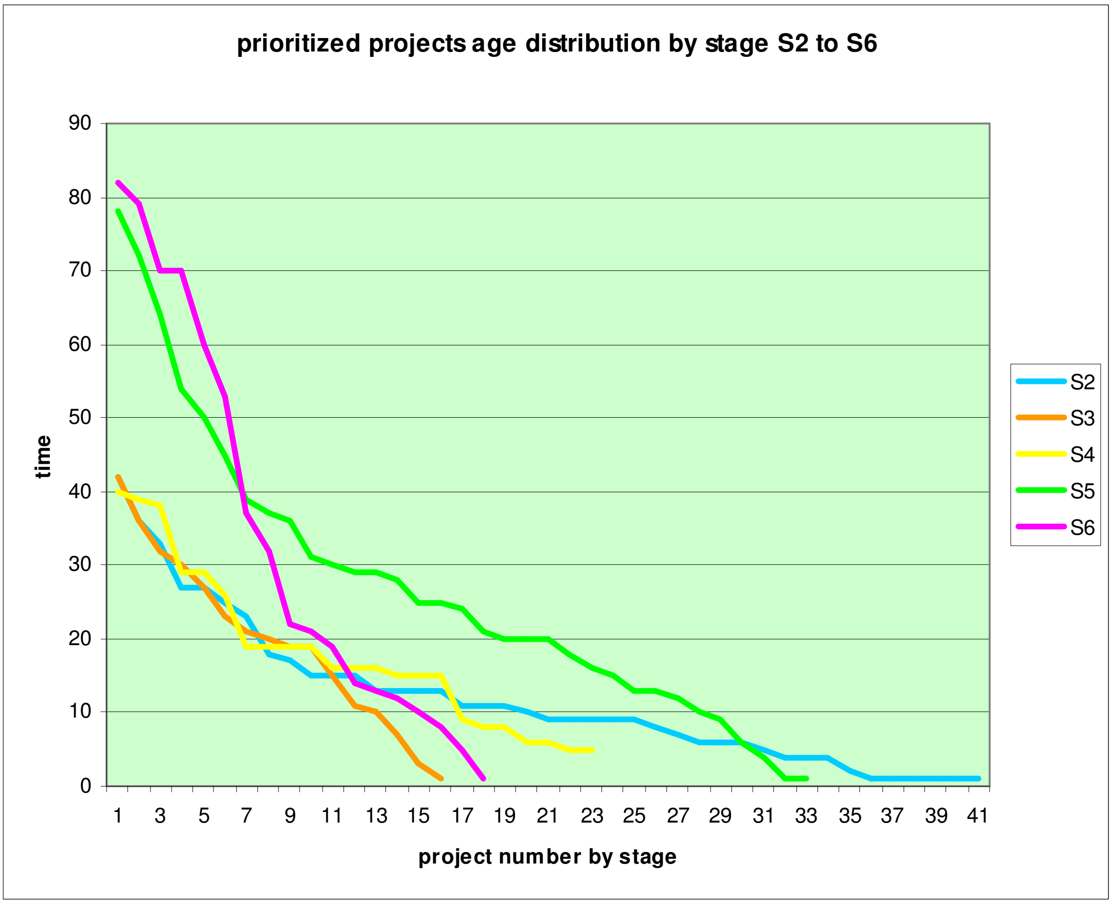
Appendix 19 Project age distribution by development stage



Horizontal axis: number of projects

Vertical axis: duration, units in time

Appendix 20 Prioritized project age distribution by development stage



Horizontal axis: number of projects

Vertical axis: duration, units in time

Appendix 21 Projects by development stage

Horizontal axis: time in years

Vertical axis: number of projects

Appendix 22 Prioritized projects by development stage

Horizontal axis: time in years

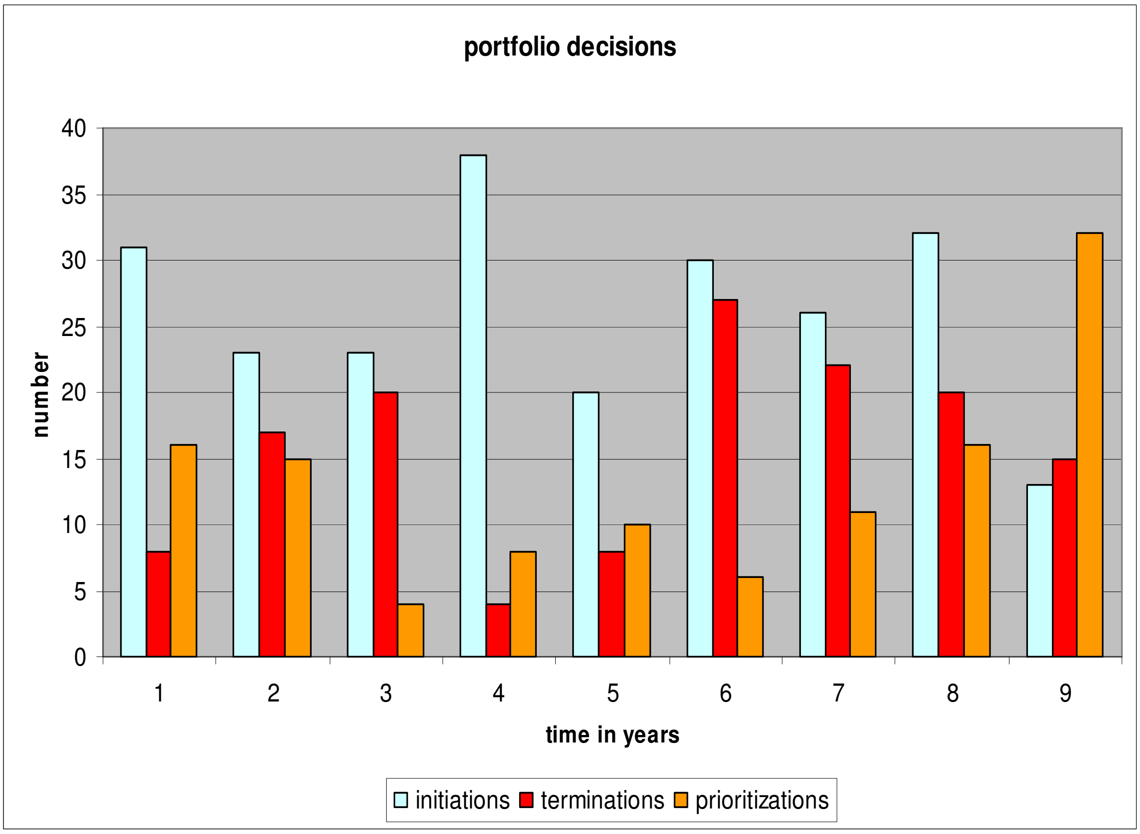
Vertical axis: number of projects

Appendix 23 Average age of all projects by development stage

Horizontal axis: time in years

Vertical axis: age of projects, units of time

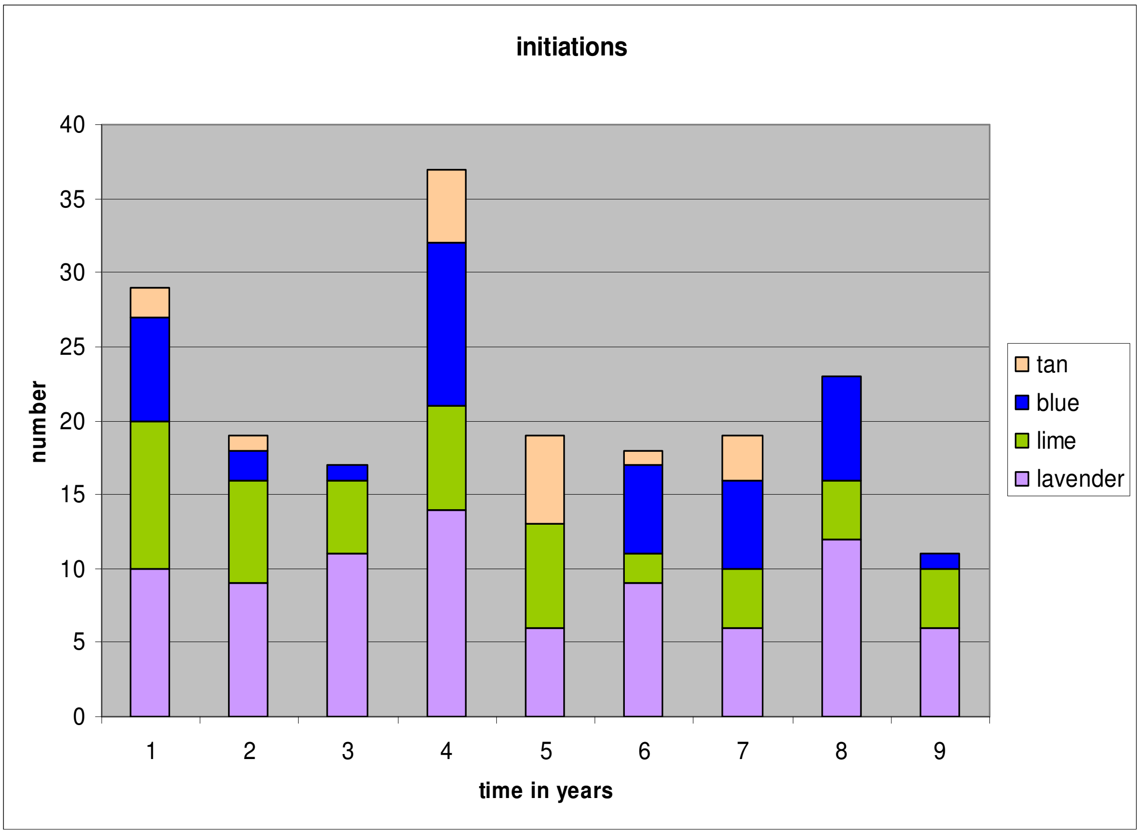
Appendix 24 Portfolio decisions



Horizontal axis: time in years

Vertical axis: number of events

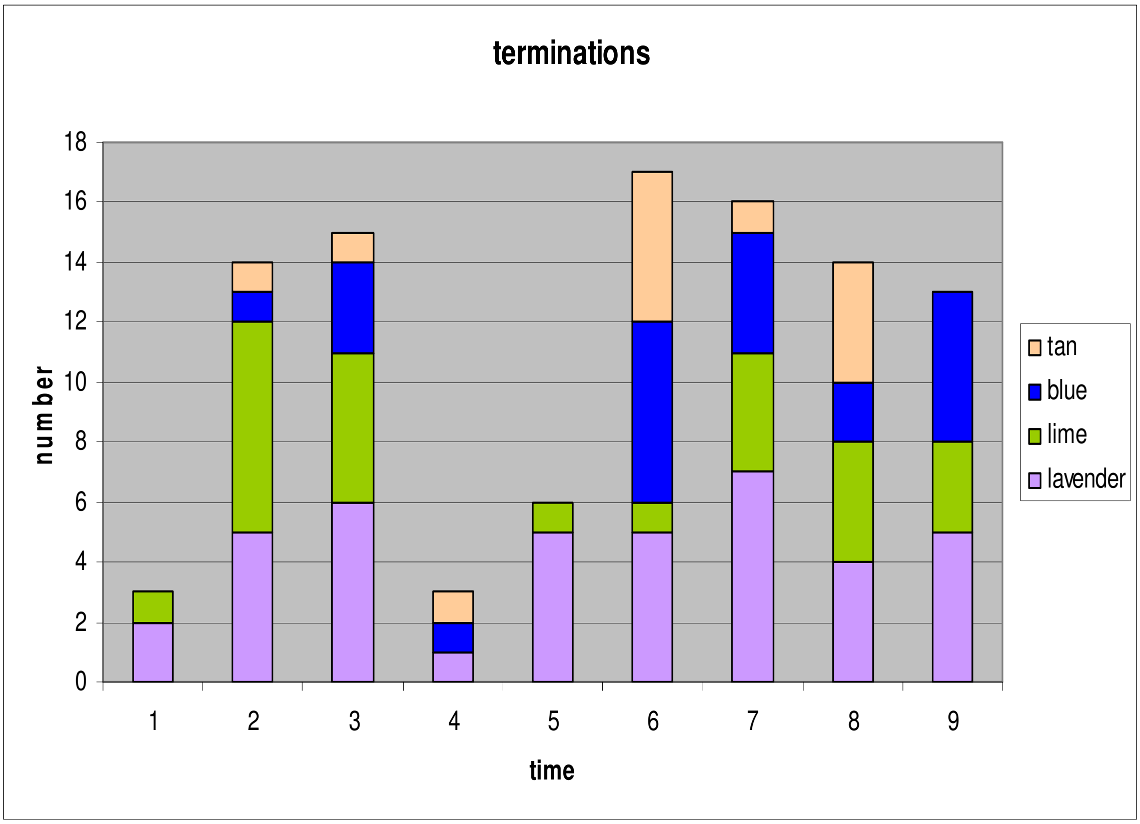
Appendix 25 Decisions to initiate projects by business unit



Horizontal axis: time in years

Vertical axis: number of events

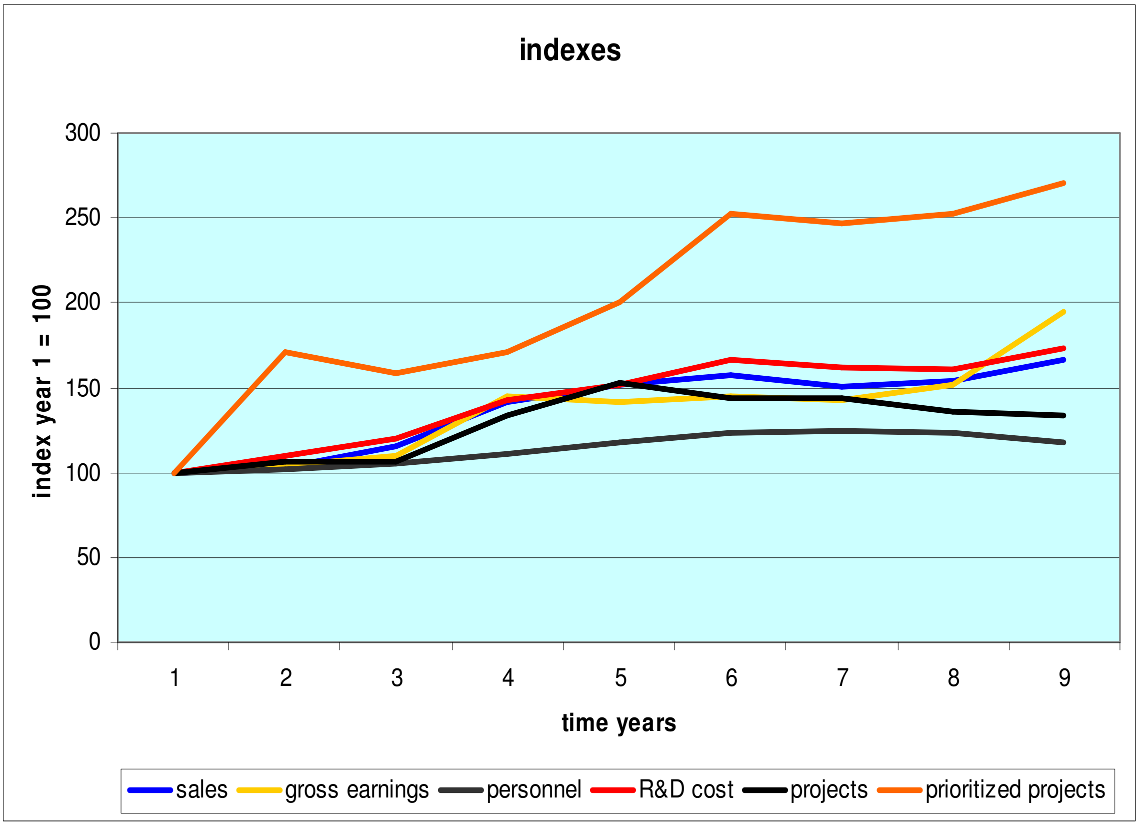
Appendix 26 Decisions to terminate projects by business unit



Horizontal axis: time in years

Vertical axis: number of events

Appendix 27 Firm performance indexes



Horizontal axis: time in years

Vertical axis: index figure