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ON FORESIGHT PROCESSES AND PERFORMANCE OF INNOVATION NETWORKS

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Abstract: This dissertation seeks to increase understanding of how innovation systems perform, and therefore to provide stronger foundation on the evaluation and development of technology policy instruments. The five essays contained in it examine the rationales for government intervention in the commercialisation of new technologies, and within that context the role of instruments facilitating emergent and embedded foresight processes is elaborated on. This higher-level analysis is complemented with the quantitative modelling of factors affecting inventive performance within an industrial research organization, especially considering the effects of intra- and inter-organizational collaboration networks.

Overall, the analyses are based on an open system perspective, and the research addresses how the absorptive capacity of different participants is affected by the organizational and cross-organizational arrangements. The approach is normative in the sense that it aims to provide policy and managerial recommendations for improving the system performance, even in conditions of bounded rationality.

At the policy level, the dissertation argues that innovation policy instruments should mitigate anticipatory myopia that is a potential hindrance to the overall performance of innovation system. Hence, there is a key role for instruments that support foresight in the innovation system, and accordingly emergent and embedded foresight processes should be taken into account in instrument design. Control systems, mechanisms for focusing the research and technology development effort, as well as means to identify required complementary actions can be inbuilt to the policy instruments when innovation performance is addressed as a multi-layered issue.

At the micro level, the results call for the re-examination of the concept of organizational boundaries in the innovation process, as within-firm arrangements can enable some market-like characteristics to industrial research. Parts of the organization can behave as “boundary operations”, bridging between the organization’s core and its environment. Policy instruments should leverage, not dismiss, this behaviour as appropriate for enhancing system-wide innovation performance.

Keywords: innovation system, collaboration network, inventive productivity, anticipatory myopia, technology foresight, innovation policy

Academic dissertation

Systems Analysis Laboratory
Helsinki University of Technology

On foresight processes and performance of innovation networks

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Official opponent:	Professor Luke Georghiou, PREST, University of Manchester

Publications

The dissertation consists of the present summary article and the following papers:

(1) J.-P. Salmenkaita and A. Salo: "Rationales for Government Intervention in the Commercialization of New Technologies," *Technology Analysis & Strategic Management*, Vol. 14, No. 2, June 2002, pp. 183-200.

(2) J.-P. Salmenkaita and A. Salo: "Emergent Foresight Processes: Industrial Activities in Wireless Communications," *Technological Forecasting and Social Change*, 2004 (to appear).

(3) A. Salo and J.-P. Salmenkaita: "Embedded Foresight in RTD Programmes," *International Journal of Technology, Policy and Management*, Vol. 2, No. 2, 2002, pp. 167-193.

(4) J.-P. Salmenkaita: "Organizational Learning in Industrial Research: Inventive Productivity vs. Emergence of Technological Programs," *International Studies of Management & Organization*, Vol. 33, No. 4, Winter 2003, pp. 8-33.

(5) J.-P. Salmenkaita: "Intangible Capital in Industrial Research: Effects of Network Position on Individual Inventive Productivity," In: R. Bettis (ed.): *Strategy in Transition*, Blackwell Publishing, 2004 (to appear).

Contributions of the author

Papers (1) and (2) were initiated by Salmenkaita, who was the primary author of the papers. Salo was the initiator and primary author of paper (3), and he also managed the technology programme evaluation project in which the empirical material was collected. Salmenkaita conducted the majority of qualitative material collection and analysis, and was the co-author in writing the paper. Papers (4) and (5) are the sole work of the author.

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Fleet, UK, October 2004

Jukka-Pekka Salmenkaita

1 Introduction

Innovation is important for society at many levels. The competitiveness of firms, especially at high technology industries, is dependent on their ability to maintain leading positions in product performance, production costs, and the attractiveness of their products to their customers (e.g. Freeman and Soete, 1997). Innovation – carrying out new combinations in the economy (Schumpeter, 1934) – is required to perform in these aspects either better or sooner than the competitors do (Kline and Rosenberg, 1986; Brown and Eisenhardt, 1995).

The competitiveness of economic systems, national, regional, or multinational, is affected by how individual firms are able to innovate, which in turn is dependent on the interactions the firm has with the other organizations involved in the various stages of research and technology development (e.g. Porter, 1990). Successful innovation provides not only economic benefits, but also results in the development of technology that can directly or indirectly enhance the quality of life (e.g. OECD, 1997a).

These things considered, it is not surprising that "enhancing innovation" has received considerable policy attention and practical development proposals (e.g. Caracostas and Muldur, 1998; OECD, 1998). Evaluating the merits of these proposals is, however, challenging. First, the innovation process typically involves many different kinds of organizations, and the beneficial effects to one participant might have undesirable effects to the others. Second, the innovation process is typically competitive, and if the development proposals lessen the level of competition in some areas the overall result can be negative. Third, the system contains feedback loops, e.g. increased profits from successful new products may enable a higher level of research spending, which can magnify the effects of even small changes in starting positions.

The essays of this thesis seek to increase understanding of how innovation systems perform, and therefore to provide a stronger foundation on the evaluation and development of initiatives that seek to improve the innovation system. Although the essays focus on different aspects and levels of the innovation system, they share several premises.

The innovation process can start with technological invention. The creation of the invention itself, however, is not sufficient for reaping economic rewards. Rather, the invention can initiate complementary innovation activities, which, if successful, result in new products and associated economic consequences. Hence, innovative activities are aligned with only a subset of all the inventive activities.

The innovation process crosses organizational boundaries. The information and know-how requirements for successful inventive and innovative activities are so broad that cross-organizational collaboration, either formal or informal, is the norm rather than the exception. In addition, innovative activities can necessitate access to complementary assets, agreement on technological standards, or other forms of collaboration among organizations (e.g. Teece, 1986; Tassey, 2000; Powell *et al.*, 1996).

The system in which innovations happen is inherently multi-layered. *National innovation system* is a high-level abstraction for all the factors that affect organizations in research and technology development (RTD) work and commercialization of the results. Specific *policy instruments* can target to mitigate some imperfections of the innovation system. The research and technology development work, as well as complementary commercialization activities, are performed by *network of organizations* consisting of both firms and non-profit organizations like universities and government research institutes. Finally, it is *individuals* that create the inventions and champion the innovation efforts.

It is due to these complex characteristics of innovation systems that although support for "more innovation" is a broadly accepted goal in modern capitalist economies, the analysis of the bottlenecks divides expert opinions (e.g. Nelson, 1996; Andersson, 1998). Actions that presumably enhance the system in some aspects can also have negative effects in other aspects. The quantitative modelling of the whole system is not feasible, so the trade-offs cannot be directly measured. Accordingly, the practices for evaluating policy instruments are evolving to focus appropriately (e.g. OECD, 1997b; Georghiou and Roessner, 2000; Salo *et al.*, 2004a). At the same time, practitioners and policy-makers in both public and private sector are constantly experimenting with novel approaches. The essays of this thesis seek to close part of this gap between the attempts to improve the system and our understanding of how innovative performance is created and maintained.

The overarching research questions to which this thesis contributes are as follows:

(a) What is the role of new policy instruments in enhancing innovation performance?
(b) How the multi-layered nature of innovation systems should be taken into account in the analyses of innovation performance?
(c) How should organizational boundaries be taken into account in the analyses of innovation performance?

These questions outline themes for research that no single set of essays can comprehensively cover. Moreover, the experiments by policy-makers and practitioners in RTD organizations cause the empirical system under study to be a constantly evolving target. However, specific essays can address some aspects of these questions that are new to the field of innovation studies. The consequent contributions can either be in describing new empirical phenomena so that they can be later scrutinized with regard to the overarching research questions, or in examining a well-known phenomenon in more detail to provide more depth to the research questions.

This thesis consists of contributions of both of the above kinds. The essays that address the levels of national innovation system and policy instruments describe rationales for intervention and associated new policy instruments. The work is empirically grounded and descriptive, yet seeks to build a normative framework on how to apply the instruments. At this stage the research does not attempt to validate the effectiveness of the instruments.

The essays at the levels of organizations and individuals involved in RTD examine inventive productivity, a subject often addressed in innovation studies (e.g. Henderson and Cockburn, 1994; 1996). The work is empirical and data-driven in the sense that the studies operationalized new measures of inventive performance, and the analyses sought either to confirm prior theory-based hypotheses or to identify new factors affecting inventive productivity.

The individual essays approach the overarching research questions from different angles. The research topics vary across the multiple layers of innovation system with different emphases on the research questions, as summarized in Table 1.

2 Theoretical framework

The essays of this thesis analyze innovation systems at different levels. Accordingly, theoretical frames that provide structure to the analyses and help to interpret the findings vary. This section summarizes the theoretical perspectives adapted in the essays, and highlights common themes that cross the levels of analysis.

Paper (1) contains a literature review and synthesis of the rationales for government intervention in commercialization of new technologies. The rationales are linked to the conceptualizations of innovation process, which have evolved from unidirectional 'science-push' models towards more complex models that account for interactions between science, technology and markets (Kline and Rosenberg, 1986). The first two rationales, market and systemic failure, take the institutional structure of the R&D system as a given and attribute the production of non-optimal outputs to the problems of appropriability (Arrow, 1970) and coordination (Andersson, 1998), respectively. The third rationale, structural rigidities, examines the structure of the innovation system as a potential target for interventions that initiate changes that are institutionalized as new practices (Metcalfe, 1995; see also North, 1990). The paper also proposes that these rationales also cumulatively cause anticipatory myopia, a condition in which individuals and organizations underinvest in the generation and assimilation of information that contributes to their ability to act with foresight.

Papers (2) and (3) examine policy instruments that can alleviate anticipatory myopia by supporting foresight in the innovation system. The shared premise for these papers is that although much of the foresight literature has been concerned with the shaping of science and technology priorities, foresight can also be defined in a less instrumental sense as "a purposefully organized process bringing together expectations of diverse actors about a technology, to formulate strategic views about the future that take into account broad social and economic developments" (Webster, 2002). Both papers build upon this process-centric perspective by examining approaches in which foresight generation is not organized as a stand-alone activity, but rather is either emergent in the cross-organizational collaboration activities or embedded in research and technology development (RTD) programs. The motivation to study foresight processes is shared with the literature examining "explicit" foresight exercises (e.g. DGXII, 1998). The papers, however, are not theory-driven but rather field studies of new instruments of foresight, including some elements of grounded-theory building. In paper (3) the viable system model from Beer's (1985) organizational cybernetics was used as the framework of the analysis. The model is based on five managerial functions – policy, intelligence, coordination, control and operations – which seek to ensure that the organization is capable of evolving so as to achieve its objectives. The model addresses organizations from open system perspective, and thereby ties the work to the considerable body of related organizational studies (for overview, see Scott, 1998).

Paper (4) examines innovation performance in the context of industrial research that has a central role in the theories of industry dynamics and the growth of enterprises (Schumpeter, 1942; Penrose, 1959). Prior empirical studies have verified that scale, scope, and spillovers are important determinants of research productivity (Henderson and Cockburn, 1994; 1996), as well as identified organizational factors that contribute to innovative performance (e.g. Teece, 1982; Tushman and Anderson, 1986). Overall, the prior empirical findings support notions of semi-permanent firm-specific differences in the firms' ability to perform research (Wernerfelt, 1984; Teece *et al.*, 1997). The exact sources of these differences, however, are still a subject of continuing research.

Two streams of arguments aim to explain persistent differences in a firm's ability to perform research. First, "absorptive capacity" entails a firm's ability to recognize the value of new information, assimilate it and apply it to commercial ends (Cohen and Levinthal, 1990). The concept is based on an open-system view of organizations. The knowledge a firm possesses is only a small subset of the knowledge in the environment. The knowledge within a firm, however, provides a basis for further learning. Internal R&D is both a source of inventions and mechanism to support assimilation of external knowledge. These two faces of R&D complement each other. Inventive activities are most productive in areas in which a firm's knowledge base is strong, and the knowledge base is strengthened via learning in areas of active R&D. This duality creates path-dependencies into R&D activities, as both learning and inventive activities are supported by the prior knowledge base.

The second stream of arguments emphasizes factors within a firm as sources of persisting differences in research capability. At the level of research programs, individual researchers learn the special skills of their co-workers, and develop "search routines" and "heuristics" that make them especially productive in their efforts (Henderson and Cockburn, 1994). The research programs contribute to the product development and marketing activities of the firm (Kline and Rosenberg, 1986). The contributions consist not only of tangible technological artifacts, but they also involve joint problem-solving activities, consultation on emerging technological issues, and the setting of mutual research priorities. Due to these intangible aspects, research groups can be characterized as deeply embedded within the firms and this embeddedness is manifest in the structure of communication and collaboration networks within a firm. These networks and associated collaboration coalitions serve a critical role in how the firm makes sense of its environment and matches potential solutions to emerging problems (Cyert and March, 1963). Henderson and Clark (1990) found out that the use of established communication channels is routine to the extent that it can lead into obsolete patterns of problem-solving that do not correspond to new challenges set by the environment. Thus, both theoretical considerations and empirical findings suggest that, although the internal collaboration and communication structure is important to the firm's capability to process information, the development of that structure is dependent on history. This structure is only partially designed by explicit choices by management due to bounded rationality.

Paper (5) focuses on one major antecedent of successful innovation - inventive activity - and the related form of intangible capital - technological know-how. The development of technological know-how is investigated within the context of the industrial research laboratory, a form of organizing inventive activities that dates back to the early 20th century (Mowery, 1990). A stream of research inspired by Schumpeter (1934, 1942) has studied the factors that affect inventive productivity in industrial research. Specifically, Schumpeter surmised that "technological progress is increasingly becoming the business of trained specialists who turn out what is required and make it work in predictable ways" and, as a result, "innovation itself is being reduced to routine" (1942: p.132). The stylized context for this routinization of innovation was "the perfectly bureaucratized giant industrial unit" (p.134), although in his earlier work he emphasized that inventions are economically irrelevant unless put into practice (1934: p. 88), and presumed that the new combinations (i.e. innovations) do not generally arise from old firms but from new ones beside them (p. 66). Thereby, the investigation of the regularities of inventive activities within the context of industrial research is an important intermediary stage for understanding which, if any, aspects of the innovation process can be routinized. The paper (5) contributes to this research agenda by examining the role of collaboration networks as a form of intangible capital in inventive activities. A competence-based approach is used to develop measures for technological know-how internal to the organization (Henderson and Cockburn, 1994; 1996). The innovation network approach provides the rationale to extend the analysis beyond the focal organization (Powell *et al.,* 1996). Finally, the social capital approach is used to integrate the external and internal perspectives (Burt, 2000).

Although the individual papers build upon different streams of prior research, they also share key themes. First, from organizational theory perspective they examine the organizational arrangements from open system perspective (Scott, 1998). At the highest level of analysis, the open system perspective is integrally embedded in the concept of national innovation systems. The open system view, however, is also useful in analyzing the conditions that active innovation policy sets for the intervening agency, as exemplified in the discussion of policy capture in paper (1). At the level of innovation policy instruments, like the means used to support embedded and emergent foresight as discussed in papers (2) and (3), the open system perspective is implicit as the focus of analysis is specifically on the activities necessitating cross-organizational collaboration. At the within-firm level of analysis of innovative performance the merits of open system view are more uncertain. Indeed, papers (4) and (5) explicitly sought to clarify the relative weights of firm-internal and cross-organization factors on inventive performance.

Second, the research on factors affecting inventive and innovative performance can also be seen as research on factors affecting absorptive capacity (Cohen and Levinthal, 1990; Zahra and George, 2002). If absorptive capacity of organizations is considered dynamically over longer periods of time, then mitigating anticipatory myopia and providing effective means of acquiring absorptive capacity can be considered strongly co-aligned rationales for active innovation policy. In this sense papers (2) and (3) are studies of new instruments for enhancing the absorptive capability of the innovation system. At the within-firm and individual levels of analysis absorptive capacity is based on the conceptualizations of knowledge stocks. Especially paper (5) operationalized measures and verified the effects of accumulation of knowledge stocks on inventive performance, thereby contributing to the theory testing of absorptive capacity arguments.

Third, although the overall research agenda is normative and targeting at policy and managerial recommendations, the limitations that are due to bounded rationality (Cyert and March, 1963) are inbuilt to the analysis. Specifically, in paper (1) a framework of the role of evaluation in policy development is presented to limit interventions in situations in which the benefits are not transparent. The interlinked evaluations control and guide the policy development in ways that are beyond the practical information access and the processing capabilities of individual decision-makers. At the instrument level, the viable system model in paper (3) distributed the various managerial functions into smaller tasks that are practically feasible for individual decision-makers. The tasks, when considered together, control and guide the technology program beyond the individual capabilities. In the firm-level analysis, paper (4) developed an evolutionary framework that positioned industrial research as "boundary operations" within the more complex organizational learning system. Given this positioning, individuals can have roles like "venture champion" or "research program manager" that contribute to the organizational learning, yet there is no requirement for centralized control system that would exceed the limits of bounded rationality.

3 Research methodology

Especially when the phenomena under study are complex and not well understood, triangulation based on applying multiple research methods can be used to approach the research question (Singleton and Straits, 1999). Triangulation can reduce the errors and biases of any individual method, and also help in interpreting the results in the research setting. Accordingly, the essays of this thesis vary in their methodological approach. Paper (1) is primarily a literature review, with a new synthesis of the addressed topic and some related empirically-grounded theory-building. Papers

(2) and (3) are field studies that describe new phenomena for the field of foresight studies. Papers (4) and (5) address a research topic covered by a significant amount of prior research, and a hypothetico-deductive method is adopted. Participant observation was used to some degree in all the papers of this thesis, as well as semi-structured and informal interviews.

Overall, case studies are very suitable for describing new phenomena, but are subject to interpretation biases by the researcher. Moreover, predictions made based on case studies can be subject to contingency factors not present or transparent in the case descriptions. Consequently, the research methodology adopted in papers (2) and (3) should be considered as a starting point for further studies that verify and validate the findings using complementary methodologies. Multiple-case studies could be used in the next stage, later on followed by hypothetico-deductive approach (Eisenhardt, 1989).

However, as discussed in paper (1), there are arguments that promote experimentation in the innovation policy. That is, an effective innovation policy could necessitate constant design of new policy instruments by policy-makers and practitioners (see also Metcalfe and Georghiou, 1998; Smits and Kuhlmann, 2002). To the degree that policy practices will develop to this direction, there will be opportunities for numerous further studies following a methodology similar to papers (2) and (3), as the policy experimentation proceeds into new directions.

4 Results

In this section the findings of the individual papers are first reviewed, and then the results are synthesized and their relevance with regard to overarching research questions is discussed.

In paper (1) we presented that selected innovation policy instruments, or even institutional structures related to agency operations, may continue to be supported due to high information asymmetries with regard to innovation processes. This mode of sustained government intervention was referred to as “policy capture”. To succeed in its innovation-facilitating operations (especially presuming an agency is not in the “policy capture” mode), the agency requires internal expertise and access to a wide variety of information. It is paradoxical that while autonomy of agency operations is likely to contribute to the development of expertise, it may decrease the government’s ability to detect “policy capture” mode activities. Also, embeddedness in the innovation system supports information acquisition, but increases the risk of collusion in “policy capture” mode activities. The systematic application of different kinds of policy evaluation – *ex ante*, constructive, and *ex post* – can mitigate these perplexing dilemmas.

Active government participation in the allocation of resources for R&D should not be viewed narrowly as a task of establishing priorities for projects or technological fields. Rather, there is a need for participatory activities that allow the government to recognize different rationales for its intervention and to take systemic considerations into account. For this purpose, the instruments of technology foresight can raise the general awareness of new opportunities, and also reduce counterproductive inertia by suggesting suitable means to apply the other policy instruments.

In paper (2) we conducted a case study of Wireless World Research Forum (WWRF). The findings suggested that successful future-oriented activities can be organized by relying on a bottom-up approach where the participating RTD organizations and other stakeholders are engaged in a relatively unstructured but iterative, competitive, and action-oriented emergent foresight process.

Such a process may offer considerable benefits in that the discussions remain closely related to the RTD agendas of the participating organizations. Thereafter the results can be translated straight into action within the collaborative networks that are shaped and strengthened through the emergent foresight process.

Furthermore, we presented an empirically grounded conceptualization of different modes of foresight activity. The role ascribed to proactive innovation policies is that of (i) recognizing the characteristics (preconditions, functions, limitations) of each mode (explicit, embedded, emergent), and (ii) catalyzing different kinds of foresight activity, to overcome the limitations of any single approach. Toward this end, it may be beneficial to establish varying temporal links between different modes of foresight activity. Here, the very dynamism of innovation suggests that any standardized foresight processes (e.g., studies with a highly similar structure) will encounter difficulties in reflecting changes in innovation networks, systemic technologies, and the society at large (see also Salo *et al.*, 2004b).

Even if no proactive measures are taken to mitigate anticipatory myopia, innovation policy is still responsible for the development of (implicit or explicit) priorities for public RTD expenditure. The development of these priorities is no guarantee for effective performance, unless systemic considerations for the implementation of RTD activities following these priorities are taken into account as well. The analysis of the WWRF case suggests that it may be beneficial to complement explicit foresight exercises through action-oriented work where continual iteration and rivalry is purposely encouraged in the shaping and sharing of RTD agendas. Apart from ensuring the actionability of resulting outputs, such emergent processes can solve some issues of consortia formation that are difficult to deal within the context of the more traditional explicit foresight exercises.

The analysis in paper (3) demonstrates that the evolution of Finnish technology programs has given rise to organizational structures and knowledge sharing practices, which seek to ensure that insights on technological opportunities are fed into the shaping and implementation of program priorities. These practices have not emerged as an attempt to conduct foresight activities as such. Rather, the motivation has been in creating capability for strategic flexibility, which is crucial for RTD programs in rapidly changing fields such as electronics and communications. One implication of the analysis is that large-scale national foresight exercises – which are unlikely to be repeated more than every three or four years – may benefit from complementary foresight processes that are embedded into the RTD programs. The objectives for these foresight processes would include (i) the translation of results from national exercises into actions within the RTD programs, (ii) the continuous questioning of relevance and validity of earlier foresight conclusions and, more generally, (iii) the proactive provision of recommendations for enhancing the innovation system and its knowledge sharing processes.

Since the effective implementation of embedded foresight necessitates empowering the RTD programs accordingly, there is a need for closer integration of technology foresight, technology assessment and program evaluation activities. On one hand, this is because the dynamics of technological change calls for continuous foresight processes that benefit from the ability to commission further assessment studies as required. On the other hand, these processes support other activities, such as *ex post* program evaluations where the RTD efforts are contrasted with the objectives defined through earlier foresight processes. Overall, then, it seems that developing RTD programs into integrated instruments of technology policy will entail a host of new managerial and coordination challenges.

Paper (4) set out to investigate organizational learning in industrial research, starting with the determinants of inventive productivity. The results of the quantitative empirical analysis confirmed hypotheses made in prior literature with regard to slack, but also challenged well-established views of the role of external networks. Based on the quantitative analysis, some tentative characterizations were made. Specifically, internal discretion to allocate funds for exploratory research efforts was positively associated with inventive productivity, and a positive association also applied to the accumulated stock of technological-knowledge capital. These results confirm empirically hypotheses that were made based on prior theoretical literature. Hence, the exploration-exploitation dilemma of organizational learning can be framed as balancing the creation of new knowledge stocks (technological programs) while utilizing the existing ones.

In addition, the effects of collaboration across organizational boundaries were analyzed. Contrary to prior literature, internal ties rather than external innovation networks were associated with inventive productivity. This result challenges the generalizability of results from prior external innovation network literature. Hence, the exploration-exploitation dilemma can also be framed as balancing externally oriented sources of variation with internally oriented selection mechanisms. These issues were synthesized as an evolutionary variation-selection-retention framework with explicit attention on organizational boundaries. The routines that allocate exploratory freedom have a dual role in firm-internal knowledge creation and in setting the scope for the boundary operations of a firm. The framework combines two previously separate streams of prior literature in a way that addresses more comprehensively the results of the empirical analysis.

Paper (5) found out that organizations aiming to routinize inventive activities benefit from mechanisms that support the formation of collaboration clusters. Collaboration clusters are needed to realize the complementarities of technological know-how possessed by the individuals. Also, collaboration clusters are avenues by which new individuals are introduced to the tacit and firm-specific elements of the technology. In addition, the more systemic the underlying technological knowledge, the relatively more beneficial these mechanisms can be hypothesized to be.

The knowledge required to identify beneficial collaboration opportunities may involve a significant tacit element. Consequently, internal brokerage, i.e. individuals who by their collaboration network connect otherwise unconnected clusters within the organization, is valuable for the organization. Internal brokerage provides immediate benefits when previously unrecognized opportunities between the complementary bodies of technological know-how are realized via new combinations. In addition, internal brokerage contributes to the renewal of the organization’s internal collaborative structure. Thus, mechanisms that support internal brokerage are beneficial to both inventive productivity and the organization’s internal adaptation aimed at better realizing inventive opportunities.

From the perspective of the social network analysis, both a membership in a collaboration network closure and a brokerage position are plausible candidates for intangible capital for an individual. The analysis, however, provides support only for brokerage as a form of intangible capital, whereas closures are instrumental in promoting individual level technological know-how in various combinations. Although important for the overall inventive productivity, the benefits of closures seem to be fully captured in the individual level knowledge capital measures. That is, without closures the inventive productivity would be diminished, but in the long term the closures as such do not enhance inventive productivity beyond the effects of accumulating individual level knowledge capital stocks.

4.1 Role of new policy instruments in enhancing innovation performance

Paper (1) argued that innovation policy instruments should mitigate anticipatory myopia that is a potential hindrance to the overall performance of innovation system. Hence, there is role for instruments that support foresight in the innovation system. However, traditional foresight exercises have at times faced challenges in transferring their findings to actions with the RTD participants. In paper (2) the role of industry-driven collaborative exercises as means to leverage emergent foresight was elaborated, and in paper (3) RTD programmes were presented as means to support embedded foresight. These instruments complement traditional foresight exercises, and recommendations on how to employ them synergistically were provided in paper (2). However, yet other instruments could be created to serve similar purposes. Further work on foresight instruments can continue by elaborating the causes of anticipatory myopia in more detail, and examining the effects of new instruments vis-à-vis these criteria.

The findings from the individual level analysis in paper (5) suggest a priority order of conditions for effective inventive work in which accumulated technological knowledge capital, ability to form tight working groups, and ties to market requirements form the first priority group. External ties contribute only in the second priority group. Therefore although mitigating anticipatory myopia calls for more interaction across organizational boundaries, the role of new instruments is in fine-tuning a system that is working well in its basic function. If the cross-organizational, somewhat loose, collaboration activities start to replace the internal working groups there is a risk that the overall innovation performance will actually diminish.

The exceptions to the above logic could be found in situations of technological discontinuity. The individual-level study did not address the novelty dimension of the created inventions, and further work in that area should examine if the cross-organizational arrangements are especially suitable for facilitating inventions for technological areas new to the firm. It is also possible that the new policy instruments mitigating anticipatory myopia can be more effective in general when applied to industries and technological areas undergoing rapid or disruptive changes.

In paper (1) anticipatory myopia was conceptualised as the accumulated result of market failure, systemic failure, and structural rigidities. To a certain degree, these underlying analytical perspectives have been informed by organizational behaviour studies and organizational learning literature. However, there remains an opportunity for a more comprehensive literature review and synthesis of the contributing factors of anticipatory myopia. Moreover, eventually the instruments targeting to mitigate anticipatory myopia have to influence firm-internal decision-making (e.g. Cyert and March, 1963; Bower, 1970; Burgelman, 1983). There is a need for similar decision-making analysis in this new "open innovation" setting in which the organizational boundaries are often crossed during the innovation process (cf. Chesbrough, 2003).

4.2 Multi-layered systems and innovation performance

Paper (1) developed a framework for using a variety of evaluation approaches to take into account the challenges of proactive innovation policy in the multi-layered environment. Specifically, by distinguishing between the goal, instrument, and the impact of intervention on the first dimension, and the timing of evaluation in relation to the intervention on the second dimension, then *ex ante*, constructive, and *ex post* evaluations can guide policy development even in conditions of ambiguous goals and imperfect information. Consequently, self-reflective evaluation practices can be seen as tools for managing innovation system at the policy level (see also Kuhlmann, 2003).

Papers (2-3) elaborate on specific policy instruments. Yet, even a specific instrument can be so complex in its embeddedness to the innovation system that a multi-layer approach is warranted. For example, paper (3) applied a five-layer organization cybernetics model on distinguishing the managerial functions within a technology program. The approach can be taken as a first step towards understanding the differences between mechanisms that direct the innovation efforts from the mechanisms that affect the performance of specific projects. Although innovative output is aggregate of outputs of specific projects, the impact of the outputs is dependent on how the efforts are directed or focused in the larger RTD context. Consequently, the analysis of long-term innovation performance has to consider both factors affecting the output productivity per se, as well as the higher-level routines used in selecting suitable areas of activity. Instruments that leverage embedded or emergent foresight processes can accordingly provide benefits beyond immediate increases in innovative output.

In paper (4) the findings of inventive performance were set into multilevel evolutionary framework in order to take into account the complementary requirements of innovative performance. In general, realizing the innovation potential of technical inventions will necessitate actions beyond the scope of the RTD project itself. For analyzing innovation performance, the indicators of inventive output are not adequate without understanding the systems capability to pursue the opportunities that are created.

In synthesis, explicitly addressing the innovation performance as a multilayer issue can enable control systems, mechanisms for focusing the RTD effort, as well as identify required complementary actions beyond strict RTD. However, the selection of most relevant dimensions to the analysis is complicated by abundant alternatives: level of analysis (from innovation system to individuals), organizational focus (core, boundary, external), time dimension, evolutionary framework (variation, selection, retention), organizational cybernetics (policy, intelligence, coordination, control, operations), and so on. Clearly it is not feasible to operationalize measures along all of these dimensions when analyzing, for example, a new policy instrument. Therefore, pre-analyses should be conducted in which the included, and excluded, dimensions are specified.

Invariably there is friction of various kinds in the innovation system, which reduces the overall performance, as well as constrains intervention attempts, including foresight exercises. The research designs of papers (2) and (3) were not targeted to systematically identify the sources of friction. In further work analyses of the sources of friction should be conducted, for example, in connection to constructive policy evaluations. Rich empirical data will be required, and the foresight architecture framework presented in paper (3) can be used to select complementary foresight exercises under study. Analyses can examine not only public-private joint efforts, but also fully industry-driven efforts, for example, in the standardization of emerging technologies.

4.3 Organizational boundaries and innovation performance

Papers (4-5) operationalized detailed measures of cross-organizational collaboration in the analyses of inventive performance. These measures had significant effect on inventive productivity. However, the effects were not in full alignment with prior literature (e.g. Liebeskind *et al.*, 1996). Specifically, arrangements that enabled within-firm collaboration across internal organizational boundaries had strong positive association with inventive productivity, whereas the role of external ties was more difficult to ascertain with regard to inventive productivity.

These results call for re-examination of the concept of organizational boundaries in the innovation process. As discussed in paper (4), within-firm arrangements can enable some market-like characteristics to industrial research. In this sense select parts of the organization can behave as "boundary operations", bridging between the organization's core and its environment. The development of inventions into innovations often requires access to complementary assets and other forms of interaction beyond firm boundaries. Accordingly, the boundary operations can have a central role both in the innovation process as well as in the renewal of the firm. From this perspective it is unfortunate that for many technology policy instruments the target of intervention is the whole firm due to its status as a legal entity. For supporting innovation performance it would be advantageous to target boundary operations, and to assess the effects of interventions in more detailed organizational level. This approach would be aligned with the notion of organizations simultaneously pursuing multiple, even conflicting goals, and solving resource allocation to innovative efforts partly via coalition-building process (Cyert and March, 1963; Burgelman, 1983).

In papers (2) and (3) the data collection and analysis were partly at the level of individual projects conducted by the organizations involved in RTD as a part of technology programs. This approach enables the observation of the multitude of cross-organizational ties that the various units conducting RTD are involved in. However, there was no attempt to systematically analyse the effect of these interactions, nor to make assessment on the most effective organizational set-ups the instruments could target towards[1]. Indeed, the anticipatory myopia argument of paper (1) could be re-phrased to claim that boundary operations should be strengthened in order to achieve better long-term innovative performance. Consequently, the design of effective technology policy instruments would benefit from more refined conceptual basis of boundary operations, as well as from managerial and administrative means to target them.

4.4 Generalization and limitations of the results

In paper (1) the discussion of the role of agencies is rooted to the national innovation system level of analysis. The findings can be applicable to strong regional innovation systems, but caution is due when generalizing to supra-national contexts (e.g. European Union) that consist of at least indirectly competing national systems. This applies also to the embedded foresight discussion in paper (3). The analysis of the benefits of interlinked evaluation forms in paper (1) is more generic, and could be applied not only on innovation systems at various levels, but also on the management of public and private interventions at other policy areas. The framework developed in paper (2) is not inherently tied to national innovation system perspective. However, the emergent foresight conceptualisation may be applicable primarily to relatively oligopolistic industries in systemic technology areas. Further work on the limits of emergent foresight exercises is warranted.

Papers (4) and (5) examine industrial research specifically from the perspective of a large established company that seeks growth by the means of technological inventions and complementary innovations. Although this is the context that accounts for the largest part of overall R&D effort in modern societies, it is by no means the only context in which R&D efforts are conducted. Indeed, innovation policies should try to leverage the special characteristics of the other contexts, for example, venture capital (e.g. Gompers and Lerner, 1999).

Paper 2 outlined the foresight architecture consisting of three foresight modes. The effective implementation of the modes is an important area for further scrutiny. Some modes can be initiated

[1] Network analysis tools were applied on technology program evaluation in subsequent evaluation project, see Arnold *et al.,* 2002.

and executed effectively at the supra-national level, other modes perhaps only at the national or regional level. A tentative characterization can be made that embedded foresight is most suitable for regional or national settings, and emergent foresight for supranational or global context. Systematic work to understand the incentives for participation in foresight exercises should be carried out (see also Salo, 2001).

Ultimately the analysis of the benefits of national innovation policy has to consider factors like individual-level workforce mobility and global re-location alternatives available to multinational enterprises. The papers (1-5) examine how to organize for effective R&D; the more complete cost-benefit calculations have to consider how "stickiness" is build into regional or national innovation systems, and how the stickiness affects multinational firms' decisions (cf. Saxenian, 1994; Zucker *et al.*, 1998).

5 Discussion

Based on the findings and limitations of this dissertation, following avenues for further research are suggested:

- The systemic vs. atomistic nature of technology is potential contingency factor on the effectiveness of technology policy instruments as well as of collaboration practices beneficial for inventive productivity. Comparative studies should uncover these potential differences at all levels of the analysis. This will help to correctly translate the policy and RTD management recommendations from one context to another with different underlying technology dynamics. Caution is due when generalizing recommendations made based on very specific industry conditions, for example, pharmaceuticals or biotechnology industry. In these industries technology and products are unusually atomistic compared to, for example, communications, Internet, or complex SW technologies and products.
- The antecedent of anticipatory myopia should be elaborated in more detail at the different levels of the innovation system. Consequently, policy instruments can be designed to better target the critical bottlenecks. At the higher levels of the analysis, such work would contribute to our understanding of the rationales of proactive innovation policies. At the lower levels of the analysis the work could be integrated to the re-conceptualisations of absorptive capacity as a factor that is actively shaping the RTD organizations.
- The foresight architecture framework consisting of embedded, emergent, and explicit foresight processes should be validated and further elaborated based on empirical experiences. An especially important and challenging task is to verify whether the foresight processes contribute to inventive productivity at the individual and organizational levels of the analysis. If the effects are only qualitative or appear at higher levels, then appropriate control and incentive mechanisms should be inbuilt to the system.
- In general, the rationales and instruments of proactive innovation policy provide numerous opportunities of meta-analyses. Considering the complexity of the phenomenon under study, meta-analyses can be the only viable means to identify and understand many of the contingency factors affecting the innovation performance at the system level. More specifically, meta-analyses can be used to contrast the conditions in which the instruments are applied to the perceived or factual success criteria. Also, the analyses can be used to combine methodological experiences and lessons learned from different policy experiments. A meta-analysis framework can also provide grounds for comparing and contrasting the

results of quantitative evaluations that operationalize factors contributing to innovation performance in dissimilar ways.

- The papers (1-5) had disparate levels of analysis from policy interventions to individual inventors. Although this approach has its merits, especially for describing initiatives that have received little academic scrutiny earlier, it should be noted that it is the individuals acting in different contexts that possess the knowledge and make the decisions. Future work should examine who participates where, in what kind of roles, and how they can (or, perhaps more importantly, cannot) distribute and utilize the information they have. This would inform the practical design of new policy instruments and cross-firm initiatives like technological standardization groups. Prior studies have examined the various roles of championing in the within-firm context of innovation process (e.g. Day, 1994); similar work should be carried out in the more open, boundary-crossing, innovation context.

The following considerations can be provided for policy development:

- Mitigating anticipatory myopia is an overarching rationale for proactive innovation policies. The implementation of such policies, however, entails agency challenges. These challenges can be countered with well-developed evaluation practices, but also by relying on semi-autonomous instruments, like supporting emergent foresight processes. That is, evaluation practices can be used to control and guide the government interventions, but also non-government driven initiatives warrant due role in the mix of applied instruments.
- "Boundary operations" of established firms can have a critical role in the innovation process. Yet for administrative and legal reasons the support they receive from innovation policy instruments can be less than, for example, the support new start-up companies receive. The design of policy instruments should acknowledge that organizations pursue multiple, even contradictory, goals, and accordingly the instruments should target RTD participants based on their role in the innovation process, not by formal organizational status.
- Conditions that should trigger active use of policy instruments should be more systematically analysed. For example, the foresight framework provides suggestions on how the different foresight processes could be combined to complement each other. The meta-analyses mentioned above could be an excellent source of knowledge for policy development.

Overall, the empirical findings of this dissertation promote a view of managing innovation process by balancing competing factors at multiple levels of the innovation system. Academic understanding can contribute to better management by several means. First, the trade-offs involved in the balancing can be made more visible and transparent by having better conceptualisations of the overall process. That is, as the conceptualisations of the innovation process implicitly and explicitly focus management attention, it is better to focus this scarce resource to where it matters. Second, *ex post* studies can uncover optimal balances for various conditions with hindsight that was not available at the time of decisions. These findings should inform decision-making in the management of future RTD efforts.

The papers of this dissertation are primarily empirics-driven, investigating either policy instruments that have received little earlier academic scrutiny, or analyzing more detailed data sources than what have been available for prior studies. Each of the papers is grounded to the relevant theoretical literature. However, the work as a whole was not an attempt to build theoretical synthesis, nor should such an attempt be made based on just a select few empirical cases. Future work should consolidate findings of a variety of empirical studies on foresight processes, and gradually build a more comprehensive theoretical framework for the findings. Contributing theoretical lenses can include political science, organizational behaviour, strategy, micro-economy, and even individual-level creativity studies. The consolidated view would still approach innovations as "purpose-build" objectives of RTD work, i.e. from a rather technocratic perspective. Innovations are also a result of social construction (e.g. Tuomi 1999; 2003), and this complementary perspective is required to understand techno-economic development in more holistic sense.

This dissertation has also made an argument that proactive innovation policy requires experimentation at various levels, both within firms involved in RTD as well as in the design of new policy instruments. For these purposes, new conceptualisations of the bottlenecks of the innovation process can act as focusing mechanisms for directing the experimentation effort. Moreover, the experiments conducted in one context can provide valuable lessons learned for other contexts, providing the essence of what is under experimentation is properly abstracted. It is within this area where academics, policy-makers, and practitioners can be expected to have the most intense and fruitful interactions.

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Table 1. Research topics of essays and their contribution to main research questions

Paper	**Research topic**	**Contribution to research question**	**Research approach**
(1)	Rationales for proactive innovation policy	Primarily (a), secondarily (b, c)	Conceptual clarification and empirically-grounded theory-building
(2)	New industry-driven innovation policy instruments	Primarily (a), secondarily (b, c)	Case study, participant observation, and qualitative theory-building
(3)	New government-driven innovation policy instruments	Primarily (a), secondarily (b, c)	Case study, participant observation, and qualitative theory-building
(4)	Firm-level inventive and innovative performance	Primarily (c), secondarily (b)	Quantitative theory-testing, participant observation, and qualitative theory-building
(5)	Individual-level inventive productivity	Primarily (c), secondarily (a)	Quantitative theory-testing and participant observation

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