Department of Mathematics and Systems Analysis

Dynamic modelling for the analysis and support of systemic innovations and competition strategies

Sampsa Ruutu

Aalto University

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Dynamic modelling for the analysis and support of systemic innovations and competition strategies

Sampsa Ruutu

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Abstract

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Abstract

The research question of the Dissertation is to look for new possibilities of dynamic modelling related to systemic innovations and competition strategies. The dynamic modelling approaches considered include qualitative and graphical models (causal loop diagrams and stock and flow diagrams) as well as quantitative simulation models (system dynamics and agent based modelling). Simulation modelling is used to show the emergent behaviour due to the interrelationships between parts of a socio-technical system. Dynamic modelling is used as an analysis tool in combination with other tools from the fields of innovation studies and foresight. Methods are developed for evaluating the impacts of innovations with system dynamics modelling. In **Article 1**, system dynamics modelling is applied to show different impacts of an innovation and the interrelationships between different dimensions of impacts. In **Article 2**, a participatory process is created for supporting the development and adoption of systemic innovations. In the process developed, system dynamics modelling is combined with foresights tools. Dynamic modelling is also used as a tool for theoretical analysis. The effects of different sources of complexity are studied. Interdependencies between parts of an innovation are examined in **Article 3**. As indicated by the results, the best way of organising innovative activities depends on the decomposability of the innovation. Increasing returns mechanisms are examined in **Article 4**. Policies to overcome the undesired effects of increasing returns mechanisms related to digital platforms are also designed and tested. In **Article 5**, the effects of time delays on the competition between two firms are studied. As a result of the Dissertation, new case-specific results as well as theoretic insights are obtained. Based on these observations, it is concluded that there are rich opportunities for dynamic modelling combined with other tools in the domains of innovation studies and competition strategies.

Keywords system dynamics, agent based modelling, systemic innovation, competition strategy

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Tekijä
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Väitöskirjan nimi
Dynaaminen mallinnus systeemisten innovaatioiden ja kilpailustrategioiden analysoinnissa ja tukemisessa

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Tiivistelmä
Väitöskirjan tutkimuskysymyksenä on etsiä uusia hyödyntämismahdollisuuksia dynaamiselle mallinnukselle systeemisiin innovaatioihin ja kilpailustrategioihin liittyen. Käytetty dynaaminen mallinnus pitää sisällään kvalitatiiviset ja graafiset mallit (kausaali- ja varasto-virtaus-diagrammit) sekä kvantitatiiviset simulointimallit (systeemidynamiikka ja agenttipohjainen mallintaminen). Simulaatioiden avulla näytetään, millaista käyttäytymistä sosioteknisen järjestelmän osien väliset vuorovaikutussuhteet saavat aikaan. Dynaamista mallinnusta sovelletaan yhdessä muiden innovaatiotutkimuksen ja ennakoinnin menetelmien kanssa. Menetelmiä kehitetään myös systeemidynaamisen mallinnuksen hyödyntämiseksi innovaatioiden vaikutusten arvioinnissa. **Artikkelissa 1** systeemidynaamista mallinnusta käytetään innovaatioiden erityyppisten vaikutusten tunnistamiseen sekä eri vaikutusulottuvuuksien välisten riippuvuuksien kuvaamiseen. **Artikkelissa 2** kehitetään vuorovaikutteinen prosessi tukemaan systeemisten innovaatioiden kehitystä ja leviämistä. Kehitetyssä prosessissa systeemidynaaminen mallinnus yhdistetään ennakoinnin työkalujen kanssa. Dynaamista mallinnusta käytetään myös teoreettisen analyysin työkaluna. Tarkastelun kohteena on eri tekijöiden synnyttämä monimutkaisuus. Innovaation osien välistä vuorovaikutusta tutkitaan **Artikkelissa 3**. Tulokset osoittavat, että paras tapa organisoida innovaation kehittäminen riippuu siitä, miten innovaatio voidaan jakaa eri osiin. Mittakaavaetuja tutkitaan **Artikkelissa 4**. Artikkelissa suunnitellaan ja testataan myös toimenpiteitä, joilla voidaan estää mittakaavaetujen ei-toivottuja vaikutuksia digitaalisiin alustoihin liittyen. **Artikkelissa 5** tutkitaan aikaviiveiden vaikutuksia kahden yrityksen väliseen kilpailutilanteeseen. Väitöskirjan tuloksena saadaan sekä uusia tapauskohtaisia tuloksia että teoreettisia löydöksiä. Näiden havaintojen perusteella lopputuloksena todetaan, että dynaaminen mallinnus yhdistettynä muiden työkalujen kanssa tarjoaa monipuolisia hyödyntämismahdollisuuksia innovaatiotutkimuksessa ja kilpailustrategioiden tarkastelussa.

Avainsanat systeemidynamiikka, agenttipohjainen mallintaminen, systeeminen innovaatio, kilpailustrategia

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Espoo, 22 November 2018
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Contents

Acknowledgements......1
List of articles 4
Author's contribution 5
1. Introduction...... 7
2. Theoretical and methodological background 8
2.1 Dynamic modelling used in the Dissertation...... 8
2.2 On innovation and competition...... 8
3. Research contribution 10
3.1 Use of dynamic modelling for the analysis and support innovation processes...... 11
3.2 Use of dynamic modelling for the analysis of competition strategies......12
3.3 Contributions by article 12
3.4 Summary of results 14
4. Discussion and conclusions......15
4.1 Managerial and policy implications......15
4.2 Limitations and avenues for future research......16
References......18

List of articles

This doctoral dissertation consists of a summary and the following articles:

Article 1: Hyytinen, Kirsi; Ruutu, Sampsa; Nieminen, Mika; Gallouj, Faïz; Toivonen, Marja. 2014. A System Dynamic and Multi-Criteria Evaluation of Innovations in Environmental Services. Economics and Policy of Energy and the Environment, 3/2014, 29–52.
DOI:10.3280/EFE2014-003003.

Article 2: Auvinen, Heidi; Ruutu, Sampsa; Tuominen, Anu; Ahlqvist, Toni; Oksanen, Juha. 2015. Process Supporting Strategic Decision-Making in Systemic Transitions. Technological Forecasting and Social Change, 94, 97–114.
DOI:10.1016/j.techfore.2014.07.011.

Article 3: Ruutu, Sampsa; Windrum, Paul; Hyytinen, Kirsi; Toivonen, Marja; Tuovila, Hannamaija. 2018. Demand Heterogeneity, Decomposability and the Coordination of Service Innovation in Multi-Unit Organizations. European Review of Service Economics and Management, n° 5, 2018–1, 15–44.
DOI:10.15122/isbn.978-2-406-08064-0.p.0015.

Article 4: Ruutu, Sampsa; Casey, Thomas; Kotovirta, Ville. 2017. Development and Competition of Digital Service Platforms: A System Dynamics Approach. Technological Forecasting and Social Change, 117, 119–130.
DOI:10.1016/j.techfore.2016.12.011.

Article 5: Luoma, Jukka; Ruutu, Sampsa; King, Adelaide; Tikkanen, Henrikki. 2017. Time Delays, Competitive Interdependence, and Firm Performance. Strategic Management Journal, 38(3), 506–525.
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Author's contribution

Article 1: A System Dynamic and Multi-Criteria Evaluation of Innovations in Environmental Services

Ruutu and Hyytinen were jointly responsible for the methodological development. Ruutu was responsible for developing the system dynamics model and contributed to the writing of the article related to the role of system dynamics in the developed methodology. Hyytinen was responsible for the theoretical analysis, collected the empirical data and analysed the data using the multi-criteria framework. Toivonen, Gallouj, and Nieminen contributed to the development of the theoretical analysis and provided comments.

Article 2: Process Supporting Strategic Decision-Making in Systemic Transitions

Ruutu was responsible for the methodological development from a system dynamics perspective. Ruutu was responsible for the framing and development of the system dynamics model. All authors contributed to the idea, methodological development, case analysis, and writing of the article.

Article 3: Demand heterogeneity, decomposability and the coordination of service innovation in multi-unit organizations

Ruutu was the main author and in charge of the model development, analysis, and writing of the article. Windrum contributed to the idea and writing of the article. Hyytinen, Toivonen, and Tuovila were in charge of collecting the empirical case study data.

Article 4: Development and Competition of Digital Service Platforms: A System Dynamics Approach

Ruutu was the main author and responsible for the model development, analysis, and writing of the article. All authors contributed to the idea of the article.

Article 5: Time Delays, Competitive Interdependence, and Firm Performance

Ruutu was mainly responsible for the development of the simulation model. Ruutu and Luoma did the model analysis jointly. Luoma was mainly responsible for the theory building and writing of the article. King and Tikkanen provided comments.

1. Introduction

Dynamic modelling approaches can be used to help to understand how dynamic phenomena unfold over time. The research question of this Dissertation is to look for possibilities of dynamic modelling related to systemic innovation and competition strategies. Dynamic modelling is used in two ways: 1) as a tool that is used in combination with other tools, and 2) as a tool for theoretical analysis.

Dynamic modelling approaches applied in this Dissertation include qualitative and graphical models (causal loop diagrams and stock and flow diagrams) as well as quantitative simulation models (system dynamics and agent based modelling). Simulation modelling is used to show the emergent behaviour due to the interrelationships between parts of a socio-technical system. In system dynamics (Forrester, 1961, Sterman, 2000), the analysis starts from the feedback and stock-flow structure of the system. In agent based modelling (Axelrod, 1997, Epstein, 2006), the analysis starts from the properties and decision-making rules of the agents.

First, dynamic modelling is applied to the study of innovation processes. The "process" of innovation means that the focus is on understanding how innovations develop and are adopted over time. Innovations are not inventions that emerge suddenly but are rather the "results of a continuous and complex interaction between many actors" (Toivonen and Tuominen, 2009).

Regarding the development of innovations, a key aspect is the need to take into account the nature of the interdependencies between the parts of an innovation. Regarding the adoption of innovations, key questions relate to the understanding of the wider innovation system and business ecosystems in which the innovations are developed. However, because the development and adoption of innovations do not proceed as a linear process (Kline and Rosenberg, 1986, Walrave and Raven, 2016), a third important aspect is to understand the feedback loops between the development and adoption of innovations.

A second theme in the Dissertation is the analysis of competition strategies. Here, the competition between firms is seen as a dynamic process: It changes over time and depends on each firms' previous actions and on the outcomes of those actions (Chen and Miller, 2012).

2. Theoretical and methodological background

2.1 Dynamic modelling used in the Dissertation

The dynamic modelling approaches used in the Dissertation are system dynamics and agent based modelling. The focus is in understanding how change in complex systems occurs. Both system dynamics and agent based modelling have previously been applied for studying innovation systems (Uriona and Grobbelaar, 2018, Ahrweiler, 2017).

Innovations can be seen as the result of search processes for new technologies and organisational routines. The outcomes of these search processes depend not only on the effectiveness of the actors developing the innovation but also on the simultaneous actions of competing actors. In order to model the decision-making of actors, a boundedly rational perspective is adopted in the Dissertation (Morecroft, 1985, Chang and Harrington, 2006).

The multi-level perspective of Geels (2004) is a framework that is used to understand change processes in innovation systems. It is useful as it provides a set of concepts to structure and interpret empirical phenomena, but its key limitation is that it does not specify exactly the causal mechanisms involved in change processes within an innovation system. This is why researchers have increasingly started to complement it with system dynamics modelling (Walrave and Raven, 2016, De Gooyert et al., 2016, Ulli-Beer et al., 2017, Papachristos, 2018) and with simulation modelling in general (Holtz et al., 2015).

2.2 On innovation and competition

The complex systems view (Watts and Gilbert, 2014) is used for understanding innovation and the competition between firms. In this Dissertation, the focus is in three sources of complexity in particular: 1) *interdependencies* between parts of an innovation, 2) *increasing returns* mechanisms (positive feedback loops) related to the development of firms' offerings and their adoption in markets, 3) the effects of *time delays* on decision-making.

Interdependencies between parts of an innovation cause difficulties in finding the best combination of interacting technical and non-technical design elements (Gallouj and Weinstein, 1997). The development of an innovation may also depend on the development of complementary innovations (Teece, 1986). For example, an innovation in the context of health care can entail multiple changes in a health care organisation, such as the development of e-health services, integration of outpatient care with dental care, and segmenting patients based on their health needs.

The NK model (Kaufman, 1993) is a widely used model in the field of organisational strategy and innovation (Ganko and Hoetker, 2009, Frenken, 2006). In the NK model, a system is seen as an ensemble of *N* design elements and *K* interrelationships between these elements. The objective is to find the values (typically 0 or 1) of each design element that result in the highest "fitness". Many interrelationships between design elements (high values *of K*) result in high complexity, and a local search performed by an organisation can become trapped into a suboptimal local peak rather than finding the optimum set of design elements (Kollman et al., 2000, Nickerson and Zenger, 2004). In addition, the pattern of the interactions, i.e. whether the system can be decomposed into modules, can influence the performance of search strategies (Rivkin and Siggelkow, 2003, Ethiraj and Levinthal, 2004).

Increasing returns mechanisms reflect positive feedback – the more something grows, the more it will grow in the future. There are several increasing returns mechanisms related to demand-supply coevolutions of innovations (Safarzyńska and van den Bergh, 2010). Increasing returns mechanisms create path dependence and can cause lock-ins, which means that it is difficult to steer an existing socio-technical system into a new direction (Geels, 2004, Geels and Schot, 2007). Researchers have identified several key processes and feedback loops between these processes that need to be activated for innovations to be developed and adopted (Hekkert et al., 2007, Suurs, 2009, Walrave and Raven, 2016).

In digital service platforms, important increasing returns mechanisms can result from network effects in multi-sided markets (Casey and Töyli, 2012). For example, consider new mobility services based on a digital platform. Here, the challenge can be in developing new digital services and simultaneously trying to obtain a critical mass of end users and service providers to the new platform. These increasing returns mechanisms can also have significant effects on the competition between an incumbent firm, which has an established installed base of products, and a new market entrant equipped with a better technology (Zhu and Iansiti, 2012).

The consequence of *time delays* can be that learning is difficult when decision makers are not able to assess and take into account the length of the delay in taking action and observing the outcomes (Rahmandad et al., 2009). This has implications on the development of innovations, their market adoption, and the competition between firms. Because of delays, strategies that could yield long-term benefits can be undervalued (Repenning and Sterman, 2002, Rahmandad, 2008). Delays can also result in oscillation and instability because people have a tendency towards "misperceptions of feedback" (Sterman, 1989, Sterman et al., 2007).

3. Research contribution

The overview of the Dissertation is presented in Figure 1. The research question of the Dissertation is to look for possibilities of dynamic modelling. Modelling is related to two themes: systemic innovation (**Articles 1–4)** and competition strategies (**Articles 4–5)**. **Article 4** serves as a bridge between these two themes. In this article, a situation is considered in which two competing firms develop innovations simultaneously. Dynamic modelling is used in two ways: as a tool that is used in combination with other tools for case-specific analysis (**Articles 1–2),** and as a tool for generic theoretical analysis (**Articles 3–5)**. Based on the individual articles, new case-specific results as well as new general theoretical insights are obtained.

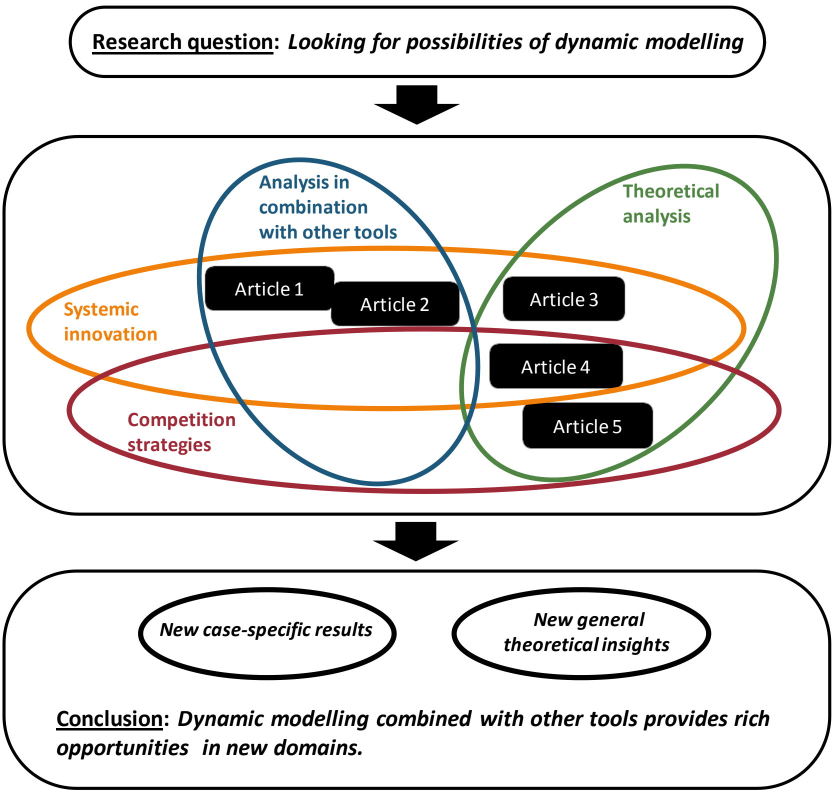

Figure 1: Overview of the Dissertation

3.1 Use of dynamic modelling for the analysis and support innovation processes

The first theme of the Dissertation is the use of dynamic modelling for analysing and supporting innovation processes. **Articles 1–4** are related to this theme, and the contributions of these articles are summarised in Table 1.

Table 1: Summary of article contributions (Theme 1)

	Topic	**Objectives**	**Method**	**Results**
1	Impact assessment of the multiple impacts of an innovation	To develop a method for assessing the impacts of an innovation. To show how different assessment criteria are interrelated.	Qualitative system dynamics	Development of a method that includes multi-criteria impact assessment and system dynamics. Demonstration of the method in the context of environmental monitoring.
2	Strategic decision-making to support innovations	To develop a process for the use of system dynamics modelling for supporting innovations.	System dynamics simulation	Development of a process in which system dynamics is used together with other foresight tools. Demonstration of the process in the context of transport.
3	Organisation of innovation in multi-unit organisations	To study the effects of decomposability of an innovation and differences in demand between organisational units.	Agent based simulation	Comparison of alternative forms of centralised and decentralised strategies. Illustration of the modelling results using a case study of a health care organisation.
4	Development and market adoption of a digital platform	To study the effects of multiple increasing returns mechanisms and time delays.	System dynamics simulation	Identification of factors leading to a failure in platform development. Design and testing of two policies.

3.2 Use of dynamic modelling for the analysis of competition strategies

The second theme of the Dissertation is the use of dynamic modelling for analysing competition strategies. **Articles 4–5** are related to this theme and the contributions of these articles are summarised in Table 2.

Table 2: Summary of article contributions (Theme 2)

	Topic	Objectives	Method	Results
4	Competition between two digital platforms	To study the effects of multiple increasing returns mechanisms and time delays.	System dynamics simulation	Identification of factors leading to a winner-take-all situation in a market. Design and testing of two policies.
5	Competition between two firms	To study the effects of time delays and competitive interdependence on firm activity and performance.	Stochastic system dynamics simulation	Time delays hinder learning from past actions, but time delays at the level of industry may increase industry profits.

3.3 Contributions by article

Article 1 is related to innovations. In the article, a method is developed for assessing multiple impacts of a systemic innovation. In the method, system dynamics modelling is combined with a multi-criteria impact assessment[1] framework. In the framework, the impacts of an innovation in five different dimensions (industrial and technological, market and financial, relational, responsibility, and reputational) are assessed (Djellal and Gallouj, 2013).

The use of the framework helps in identifying relevant factors of a systemic innovation. System dynamics modelling is used to show how the various dimensions of impacts are interrelated. The developed method is illustrated using an empirical case study of an environmental data platform[2]. In the case example, system dynamics modelling is used to show multiple positive feedback loops that involve developer actor networks, opening of public data reserves, and

1 Here, multi-criteria impact assessment refers to a framework from innovation studies that shows the impacts of an innovation along multiple dimensions. However, unlike in multi-criteria decision analysis methods developed in the field of operational research, the focus is not in comparing alternatives or weighting the values of different attributes.

2 The environmental data platform was developed by Cleen Ltd. Cleen Ltd. was a Finnish strategic centre for science, technology and innovation operating in the area of energy and the environment. It joined with another centre operating in the area of bioeconomy to form the Clic innovation cluster (https://clicinnovation.fi).

prosumers who are active in data generation. The model also helps in highlighting potential hindering mechanisms that need to be tackled in order for the environmental data platform to grow.

Article 2 is related to innovations. In the article, a process is developed for the use of system dynamics modelling with a foresight approach in order to support systemic innovations. In the process developed, system dynamics modelling is combined with innovation policy road mapping, which is a method for describing how a change from the present situation towards a future vision could occur (Ahlqvist et al., 2012). In addition, the multi-level perspective (Geels, 2004) from the field of innovation studies is used as an underlying framework. The use of this framework helps in identifying an appropriate scope for the analysis as well as identifying how key elements in the system are related. The process developed can be seen as an extension of the standard system dynamic modelling process (Sterman, 2000, Martinez-Moyano and Richardson, 2013).

The use of the process is illustrated by an example related to the vision of emission-free transport in cities by 2050. In the case example, vision paths are generated for public transport, electric vehicles, and biofuels. Different policy instruments to support the vision paths are analysed. The system dynamics model developed is an extension of the model developed by Struben and Sterman (2008), who analysed transition challenges of alternative fuel vehicles. Here, the focus is not only technological substitution, but also wider behavioural changes of transport users. The model developed shows how policies targeted at each of the different vision paths may have unintended side effects on the other vision paths.

Article 3 is related to innovations. In the article, a computational model of organisational search is developed that is based on the NK model (Kaufmann, 1993). The novelty of the model is that differences in the demands of various units in a multi-unit organisation and varying degrees of search problem decomposability are taken into account. Using the model it is possible to distinguish between the number of interactions in the search problem, the degree of problem decomposability, and the demand heterogeneity, which together determine the overall complexity.

The simulation model is used to compare the performance of three alternative strategies consisting of different forms of centralised and decentralised innovation activity. Simulation results indicate that a partition strategy, in which different units search for partial solutions, is beneficial when the innovation problem is decomposable and when there is a large number of organisational units searching. The modelling results are illustrated using a case study of the renewal process in a health care organisation in Finland.

Article 4 is related to both innovations and competition strategies. In the article, a system dynamics simulation model is presented that is used to examine alternative scenarios of the development and competition of digital platforms. A finding of the simulations is that platform users' decision-making delays can increase the likelihood of achieving critical mass of end users and service providers to the platform. Simulations are also used to show how different factors that affect resource accumulation to the platforms influence the development paths.

Two policies are designed and tested using the model. Both of these policies, namely open interfaces and data transferability between platforms, can accelerate platform adoption by users. Both of the policies are also useful for reducing the risk of a winner-take-all situation in the market.

Article 5 is related to competition strategies. In the article, a stochastic system dynamics model of the competition of two firms is developed. The focus of the model is in analysing how firm specific and industry related delays and the interdependence of the firms in the market for the same customers affect the performance of the firms. As indicated by the results, a simple boundedly rational decision heuristic can lead to the same outcome as a rational agent with perfect information (i.e. the Nash equilibrium strategy) when there are no time delays and no competitive interdependence between the firms.

Time delays hinder learning from experience because the firms do not obtain immediate feedback of the performance effects of past actions. In the case of two firms operating in the same market, time delays act as a barrier for learning for both companies. Because of this, competition is less aggressive and industry profits are higher. In addition, time delays amplify differences in competitive activity among the rivalling firms.

3.4 Summary of results

As a result of the Dissertation, new case-specific results as well as new theoretical insights are obtained. In the Dissertation, case-specific models are built in the context of environmental monitoring and urban transport. The new theoretical insights of the Dissertation are related to the effects of three sources of complexity: interrelationships between parts of an innovation, increasing returns, and time delays. To summarise, the results of the Dissertation indicate that combining other tools with dynamic modelling provides new ways to support innovation and to analyse competition strategies.

4. Discussion and conclusions

4.1 Managerial and policy implications

In this Dissertation, dynamic modelling has been used for analysing and supporting innovation as well as competition strategies. The objectives of the dynamic modelling in the articles have been different. As such, the results support the findings of earlier research in which various uses of modelling have been characterised: models that improve understanding; models that provide case-specific policy advice; and models that facilitate stakeholder processes (Halbe et al., 2015, Holtz et al., 2015).

In modelling that aims to improve understanding, the focus is in the development of general insights and new theory (cf. Davis et al., 2007, Harrison et al., 2007). Regarding the development phase of innovations, the findings of **Article 3** are useful in assessing alternative ways of organising innovative activity within an organisation. The findings related to network effects in **Article 4** are relevant regarding both the development and adoption phases of innovations. The findings of **Article 5** are useful for understanding the motivation of firms to engage in innovative activity when there are long time delays between the development of innovations and obtaining positive financial results from them.

Modelling providing case-specific policy advice focuses on the development of practical solutions and comparison of decision alternatives. In **Article 1**, the model building is based on a case study of the development of an environmental data platform in Finland. In **Article 2**, dynamic modelling is used for providing policy advice related to the goal of reducing emissions in urban transport. In **Article 3**, a case study is used for motivating the model building, but the results of the model can be seen as more generic.

One needs to take into account behavioural effects in real life decision processes. Developments in the field of systems science and operational research, such as Group Model Building (Rouwette and Vennix, 2006), Behavioural Operational Research (Hämäläinen et al., 2013) and Facilitated Modelling (Franco and Montibeller, 2010) all emphasise the need to take into account non-technical elements when studying systems and building models.

In order to use dynamic modelling to facilitate stakeholder processes and provide case-specific policy advice, it is useful to combine dynamic modelling with other approaches (Sterman, 2000, p. 80). Methods for using system dynamics modelling with other complementary tools are developed in **Articles 1–2**. In these articles, case studies are also used to demonstrate the combination of these methods. Foresight methods, such as road mapping (**Article 2**), can precede system dynamics building in order to identify a broad array of phenomena that need to be taken into account for supporting systemic innovations. Modelling and simulation can then focus in more detail on the interdependencies between the identified phenomena and policies. Using a combination of methods helps in overcoming path dependence in policy processes due to the limitations of individual methods (Hämäläinen and Lahtinen, 2016).

To support systemic innovations, knowledge from the field of innovation studies is needed. In this Dissertation, two existing frameworks from the field of innovation studies are used in **Articles 1**–**2**. These frameworks are useful regarding two aspects in particular in the modelling process. First, they help in the problem-framing phase to identify a set of key factors. These factors include the multiple impacts of the innovation (**Article 1**) and the innovation system in which the innovative activity is embedded (**Article 2**). Second, these frameworks help in forming initial hypotheses regarding cause-effect chains in the system, which can be then tested using simulation.

To conclude, based on the results of the Dissertation it is clear that there are rich opportunities for dynamic modelling combined with other tools in the domains of innovation studies and competition strategies.

4.2 Limitations and avenues for future research

In Figure 1, the overview of this Dissertation was shown. The figure can also be used to identify opportunities for future research. For example, there is an empty space for future research at the intersection of “competition strategies” and “analysis in combination with other tools”.

The importance of participatory processes has been acknowledged in this Dissertation. However, more actual case examples of applying system dynamics with other tools in participatory processes are still needed. Empirical case examples would be useful to obtain information how to combine different methods in different settings.

A topic for future research is also identification of the types of situations in which it is worthwhile to spend more effort in building a simulation model rather than limiting to a qualitative model. The qualitative system dynamics model developed in **Article 1** could be developed further into a simulation model, which enables a more rigorous analysis of how the system structure creates different kinds of behaviour over time. Even though qualitative system dynamics models are useful as such, quantitative simulation can offer more opportunities.

A final topic for future research is related to the complementarities of different types of knowledge that is produced. On the one hand, insights from case-specific dynamic modelling could be used to obtain general insights (cf. Ulli-Beer et al., 2017). On the other hand, the theoretical insights obtained from the models in **Articles 3–5** could be tested empirically. Based on these models, models that are more detailed could also be constructed to take into account case-specific issues and other sources of complexity than those addressed in this Dissertation.

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