Systems Engineering Applied to Evaluate Social Systems

Analyzing systemic challenges to the Norwegian welfare state

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Thesis for the degree of philosophiae doctor (PhD)

at the University of Bergen

2017

Date of defence: December 1, 2017

Year: 2017

Title: Systems Engineering Applied to Evaluate Social Systems: Analyzing systemic challenges to the Norwegian welfare state

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Print: AiT Bjerch AS / University of Bergen

Scientific Environment

This PhD project was completed at the University of Bergen (UiB), Faculty of Social Sciences, in the Department of Comparative Politics with the Challenges to Advances Democracies (CHAD) research group, as well as in cooperation with the Department of Mechanical and Industrial Engineering at the Norwegian University of Science and Technology (NTNU).

Preface/Acknowledgements

The PhD is a rite of passage – the trial at the gates of professional academia. Writing a PhD dissertation is never an easy task, and while an overwhelmingly positive experience, the journey was not infrequently fraught with peril. Because this PhD project spanned both systems engineering and the social sciences, it presented with unique challenges requiring openminded mentorship in order to navigate the rocky waters of interdisciplinary research. The PhD journey is one that is impossible to take alone, and there are many people to thank for their expertise, coaching and moral support. I believe very strongly in the inter-generational contract in academia, meaning that you must mentor, just as you have been mentored. I have been privileged to have been mentored by some incredible people, and I have quite the mentoring job ahead of me to fulfil my obligation.

It has been an honor to have Stein Kuhnle as my PhD supervisor. I am very grateful for your willingness to take me on as a PhD student. I have learned a lot from you in a very short time. Enjoy your retirement! Cecilia Haskins, my co-supervisor and so much more. You changed my life six years ago when you introduced me to systems engineering. You took me under your wing at INCOSE, where I found my tribe. I am spoiled to have you as a mentor and friend. Thank you for everything!

Birgit Kopainsky, thank you for all your advice over our countless good times these past few years. To say I am grateful for your support is a gross understatement. Thank you to my wonderful co-authors (both PhD papers and extra-curriculars): Sabin Roman, Sarah Hafner, Benedicte Wilson and Alberto Sols. Thank you to Camilo Olaya for your mentorship and for leading me down the ethics path. Thank you to Klaus Pedersen and to everyone at the Welfare State Research Center at the University of Southern Denmark. Thank you to all the incredible people that I've met at NordWel and SNoW. Half of the articles in this dissertation were workshopped at NordWel and SNoW events. Not only

did these valuable networks serve to improve my PhD papers, but they fostered lasting friendships.

To those at the Department of Comparative Politics at the University of Bergen: Give me your tired, your poor, your huddled masses yearning to breathe free, the wretched refuse of your teeming shore. There should be a plaque with this somewhere on the outside of Christies gate 15. A very heartfelt thank you to Gunnar Grendstad and Kristin Strømsnes for giving me a home at Sampol!

Thank you to my mom who puts journal copy editors to shame! A very special thanks goes to my husband Stein, who (besides being forced to move to Bergen) was also forced to read all my papers, and then again after every revision, achieving the title of "most well-read of the Palmer literature." Congratulations: achievement unlocked! Thank you for giving me the confidence to press the submit button…and refusing to do it for me. And most importantly thank you to my son, Hans Markus, who I am afraid was forced to speak the Bergen dialect due to his residence in Bergen during this PhD (I hope this hasn't scarred you for life.) You contributed absolutely nothing to the development of this PhD dissertation Hans Markus…except making it so much more fun!

Systems Engineering Applied to Evaluate Social Systems

Analyzing systemic challenges to the Norwegian welfare state

by

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Dissertation for the degree philosophiae doctor (PhD)
at the University of Bergen

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Bergen, 22nd of September 2017

Abstract

The Norwegian welfare state is one of the most generous in the world providing social security through universal healthcare, education and childcare. Elderly Norwegians also face a relatively secure retirement with a solid pension system (even for those never employed), and the unemployed have access to resources for financial support and to facilitate their path back into paid employment. Given the generous nature of the Norwegian welfare state, there are concerns about its longevity. There is pressure from a variety of sources that puts stress on many social benefit categories in Norway. Social and economic sustainability are inextricably linked, such that social unsustainability can lead to economic unsustainability and vice versa. Demographic pressures affect both the economic and social sustainability of the Norwegian welfare state, as they threaten both. Although immigration and aging are both demographic challenges that receive a lot of attention in both public discourse and academia, of equal importance are the ways in which gender can affect the stability of the Norwegian welfare state. The social and economic sustainability of the Norwegian welfare state in light of current and future demographic challenges is the central focus of this PhD project.

Welfare state research employs many methods both qualitative and quantitative, but there is a clear need for more and varied methods to analyze its diverse topics. This problem was highlighted by Esping-Andersen in a 2009 report to the Norwegian Research Council evaluating its program for welfare state research, called the VAM (Velferd, arbeidsliv og migrasjon) program. In this report, he explained that descriptive studies are represented disproportionately, and there are few examples of studies that employ state-of-the-art methods. He also goes on to explain that too often social scientists lack the methodological skill to handle complex data. He argues that, among other improvements, increasing the sophistication of the methodology will have a positive influence on the quality of applied research.

Given the current methodological situation of welfare state research, this PhD project accepts the challenge posed by Esping-Andersen and uses innovative methods to evaluate Norwegian social policy using dynamic modeling and systems engineering. Systems engineering encourages an evaluation of the Norwegian welfare state as a system, and this discipline includes an array of tools and methods. However, to conduct the analysis in sufficient depth, the project focuses on two welfare state sub-systems: the pension system and the absenteeism system, and analyzes gender and related demographic challenges to each. This PhD project utilizes a type of dynamic modeling called system dynamics modeling. As a result, this PhD project achieves new insight into well-researched topics in social policy; the most important of which is the identification of specific structural mechanisms in welfare state systems, where policy can be directed to affect real change in system behavior.

List of Articles

1) Palmer, E. (2017). Beyond Proximity: Consequentialist Ethics and System Dynamics. *Nordic Journal of Applied Ethics*. 1: 89-105. DOI: 10.5324/eip.v11i1.1978

2) Palmer, E. (2017). Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System. *Social Sciences.* 6(1): 22. DOI: 10.3390/socsci6010022

3) Palmer, E. (2017). The heavy cost of care: Systemic challenges in Norwegian work absenteeism. In review, *Policy and Politics*.

4) Palmer, E. and Wilson, B. (2017). Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems. *Journal of Science and Engineering Ethics*, In press. DOI: 10.1007/s11948-017-9923-1

The order of the articles listed above reflects the chronological order in which they were first developed in the PhD project, with the first article developed in February 2015 and the last in December 2016.

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Glossary

Table 1: Terms and Definitions

Term	Definition
Emergent behavior	… is behavior of a system that cannot be fully explained by the behavior of any individual system parts. (INCOSE, 2015)
Flow	The rate of increase or decrease in stocks (Sterman, 2000)
Stock	Stocks are accumulations. They characterize the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. (Sterman, 2000)
System	a combination of interacting elements organized to achieve one or more stated purposes. (INCOSE, 2015)
System boundary	system elements under design control of the project team and/or enterprise and expected interactions with systems external to that control boundary. (INCOSE, 2015)
System element	a member of a set of elements that constitutes a system. (INCOSE, 2015)
Systems engineering	an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE, 2015)
Variable	Synonymous with system element, however in system dynamics modeling this is also known as a converter.

Acronyms

Table 2: Table of Acronyms

Acronym	Meaning
ABM	Agent-based modeling
CLD	Causal loop diagram
Espanet Europe	European Network for Social Policy Analysis
EU	European Union
INCOSE	International Council on Systems Engineering
NordWel	Nordic Centre of Excellence: The Nordic Welfare State – Historical Foundations and Future Challenges
ODE	Ordinary differential equations
PAYG	Pay as you go
SEM	Structural equation modeling
SFD	Stock and flow diagram
SNoW	Sino-Nordic Welfare Research Network
SPADE	Stakeholders, Problem Formulation, Analysis, Decision-Making and Evaluation
SSB	Statistics Norway
TFR	Total fertility rate
VAM	Velferd, arbeidsliv og migrasjon (welfare, work environment and migration)

Part I: PhD Project Summary

1.0 Introduction

In 2014, the University of Bergen allocated research funding for a systemic evaluation of the demographic challenges to the sustainability of the Norwegian welfare state. This PhD project was formed to address this research topic, and the scope was only broadly defined, meaning that the direction and boundaries of the research was largely defined by the PhD Fellow in cooperation with the supervisors. Although the scope was broadly defined, certain parameters needed to be met; specifically, the use of system dynamics modeling. As this PhD project was part exploratory, the type of sustainability, demographic challenges and welfare state systems investigated were defined in the course of the project. In the end, gender and the challenges it poses to the social and economic sustainability of the pension and absenteeism (or sickness absence) systems were the focus of this PhD project. This introduction provides a background to the research problem, the research questions and the layout of the PhD dissertation.

1.1 The PhD Project: Gender and the Systemic Challenges to the Norwegian Welfare State

The Norwegian welfare state is one of the most generous in the world providing social security through universal healthcare, education and childcare. Elderly Norwegians also face a relatively secure retirement with a solid pension system (even for those never employed), and the unemployed have resources for financial support and to facilitate their path back into paid employment. The Norwegian welfare state has much in common with its Nordic neighbors and fits into the Nordic Model of welfare, which illustrates the similarities in the social and economic systems in the Nordic group. The Nordic group is comprised of Norway, Sweden, Finland, Denmark and Iceland, and although there is

debate about its composition, the central tenets of the Nordic model are presented in Figure 1.[1]

The Nordic Model	A comprehensive welfare state with an emphasis on transfers to households and publicly provided social services financed by taxes, which are high notably for wage income and consumption.
	A lot of public and/or private spending on investment in human capital, including child care and education as well as research and development (R&D)
	A set of labor market institutions that include strong labor unions and employer associations, significant elements of wage coordination, relatively generous unemployment benefits and a prominent role for active labor market policies

Figure 1: The main attributes of the Nordic Model, adapted from Andersen et al. (2007).

Given the generous nature of the Norwegian welfare state, there are concerns about its longevity (Andersen et al., 2007). There is pressure from a variety of sources that puts stress on many social benefit categories in Norway. Economic pressure from a recent downturn in the oil industry (since 2014) and the reliance of the Norwegian annual budget on oil-related income to the state are two examples of noted challenges to the funding of the welfare state (Koranyi, 2014). Economic sustainability of the Norwegian welfare state is also called into question because of the aging population and the stress this puts on pension funding and care services for the elderly (Holmøy & Stensnes, 2008). However, economic concerns are not the only stress upon the welfare state. Social

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[1] Selected studies on the Nordic Model of Welfare can be found in: Erikson (1987); Esping-Andersen (1990); Kuhnle (1983); Kildal & Kuhnle (2005); Kautto et al. (2001).

sustainability is also of concern as immigration in Norway is rising in several migration categories (SSB, 2016a), and there are concerns that this will not only stress the funding of Norway's social benefits, but also the social equity of the welfare state (SSB, 2014a; SSB, 2014b).

Social sustainability is generally defined as the ability of a system (in this case the Norwegian welfare state system) to meet a desired level of well-being indefinitely (UN General Assembly, 2015). Economic sustainability is (in this project) defined as the balancing of the state budget. Social and economic sustainability are inextricably linked, and very often social unsustainability can lead to economic unsustainability and vice versa. Demographic pressures concern both the economic and social sustainability of the Norwegian welfare state, and it is for this reason that the social and economic sustainability of the Norwegian welfare state was identified by the university as a topic for PhD research.

Social benefits and the pressure arising from demographic challenges are popular topics with the general public and the media, as well as academia. Political ideology shapes the public debate about how, for example, policy is formed concerning immigration and benefit entitlement (Fox et al., 2017). Although immigration was mentioned above as an example of how demographic pressure can challenge welfare state sustainability, immigration is far from the only demographic challenge to welfare states. Many countries are now facing an aging population and declining fertility rates (below replacement rate) (OECD, 2016), threatening the funding of social benefits due to a shrinking working age population (Lutz et al., 2006). Of likely equal importance is gender with regard to how it can affect the social and economic sustainability of the Norwegian welfare state, and it is gender that was chosen as the focus of this PhD project.

Researching gender issues in welfare state policy is well-established in the literature, but as will be explained in this dissertation, gender issues in several parts of the welfare state systemically affect the sustainability of the system itself.

1.2 Background and Research Questions

Welfare state research uses many methods both qualitative and quantitative, but there is a clear need for more and varied methods to analyze its diverse topics. This problem was highlighted by Esping-Andersen in a 2009 report to the Norwegian Research Council evaluating its program for welfare state research, called the VAM (Velferd, arbeidsliv og migrasjon) program (Esping-Andersen, 2009). Esping-Andersen states: "the proportion of the studies that can be considered applying state-of-the-art methodology is rather small – less than half of all (and here the economists are overrepresented). There is still a preponderance of descriptive rather than analytical studies" (Esping-Andersen, 2009, p.2). He also goes on to explain that too often social scientists lack the methodological skill to handle complex data. He argues that, among other improvements, increasing the sophistication of the methodology will have a positive influence on the quality of applied research.

Given the current methodological situation of welfare state research, this PhD project accepts this challenge posed by Esping-Andersen and uses methods from systems engineering and applies them to a new domain: the evaluation of welfare state policy. In this project, systems engineering is used to investigate the Norwegian welfare state as a system, and this discipline includes an array of tools and methods that are relevant in the evaluation of social systems. Evaluating social systems with systems engineering tools and methods has, to date, few examples (Gilbert & Troitzsch, 2005; Logtens, 2011). This project utilizes a systems engineering tool: a type of dynamic modeling called system dynamics modeling. By using systems engineering tools in the domain of welfare state research, this PhD project achieves new insight into previously well-researched topics in welfare state policy. The most important of these insights is the identification of specific structural mechanisms in welfare state systems, where policy can be directed to affect real change in system behavior.

An explanation of the methods used in this project is presented in section 3.0: Methods. However, an understanding of basic methodological terms is necessary at the outset of this dissertation. Figure 2 provides an overview of these terms and the relationship between them.
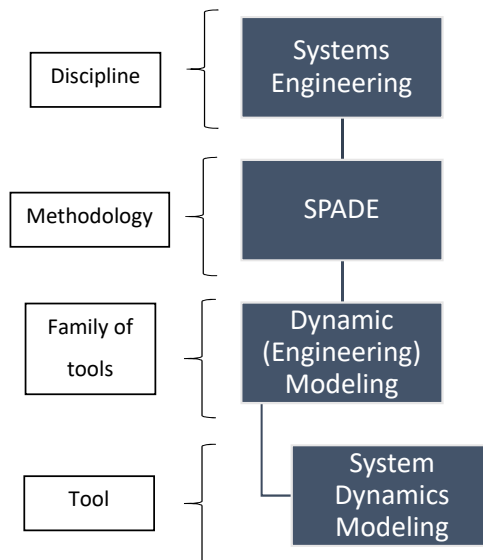
Figure 2: The methodological terms in the project and the relationship to each other.

This PhD project is not the first study using systems engineering methods in social systems – see selected studies on system engineering approaches to the evaluation of social systems: Warfield (1976; 2006); Banathy (1996). However, systems engineering methods have made few inroads in the social sciences, a shortfall this project seeks to address.

The PhD project has two central research questions:

i) How does gender pose systemic challenges to the Norwegian welfare state?

ii) How and to what benefit can systems engineering methods be used in the analysis of systemic challenges in social systems?

Layout of the PhD Dissertation

To address these questions, four research articles have been developed since the start of this PhD project in August 2014. These are listed on the section *List of Articles*, and they have either been published at the time of the PhD dissertation publication or are in review at various international academic journals. This dissertation is composed of two parts and an appendix; Part I is a summary of the PhD project and Part II is the output of the PhD project: the academic articles. Part I is composed of three main sections and a conclusion; the first section provides a theoretical foundation for the PhD project (section 2.0 Theoretical Foundation); the second section explains the methods (section 3.0 Methods); and the third section discusses the results of the PhD project (section 4.0 Results).

Section 2.0: *Theoretical Foundation and Ethical Considerations* provides a brief overview of the theories used as a foundation for this PhD project and discusses how this project contributed to the discussion of specific ethical issues. The intersection of social investment theory and gender theory is discussed in the second article (*Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System*). Gender theory was an important part of the third article (*The heavy cost of care: Systemic challenges in Norwegian work absenteeism*) concerning the Norwegian labor force and female absenteeism rates. Gender theory also formed the core of the fourth article in this dissertation (*Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems*). This article discusses gender theory implications for a new domain: dynamic engineering modeling, and contributes to the development of the concept of feminist engineering ethics. The ethical considerations when using system dynamics modeling has been an early and important focus in this project explored in the first academic article: *Beyond Proximity: Consequentialist Ethics and System Dynamics*.

Section 2.3 discusses this article and the ethical issues that are often overlooked when performing system dynamics modeling.

Section 3.0: *Methods* gives a brief overview of what systems engineering is; specifically: the background of systems engineering and information about the discipline and its central concepts. This project uses the SPADE methodological framework, which is explained in section 3.1.2. The systems engineering tool used in this PhD project is a type of dynamic modeling called system dynamics modeling. Section 3.2 gives an overview of this type of modeling and the modeling process. Although there is great potential for using system engineering methods in the evaluation of social systems, there are also limitations, as discussed in Section 3.3.

Section 4.0: *Results* provides a summary of the core output of the PhD project. This section gives a brief introduction to the history of the Norwegian welfare state and where it is today, before it explores several parts of the Norwegian welfare state as systems, specifically pension and absenteeism (sections 4.1 and 4.2). The criteria for why these welfare state systems were selected in this study are also outlined. Gender is the demographic challenge investigated in this PhD project, but this was decided when scoping the project. Section 4.3 explains the demographic challenges to the Norwegian welfare state, the degree to which they represent a challenge to the sustainability of the Norwegian welfare state and why gender was the decided focus of the evaluation in this project. The outcome of the evaluation of the two welfare systems that form part of this PhD project: pension and absenteeism, is summarized in reference to the academic articles this PhD project produced (sections 4.4 and 4.5). This includes the system models and the unique insight that they give to the welfare state systems concerning their sustainability. The limitations of each model are also given as each system is presented.

The final section of Part I is 5.0: *Contribution and Conclusion*, which discusses how this dissertation (both Part I and Part II) addresses the research questions presented in this

introduction and the unique contribution of using systems engineering tools to evaluate social systems. This section also explores possibilities for future research.

Part II of this PhD dissertation provides copies of all the academic articles that were produced as part of this project. Because social scientists have had a limited exposure to dynamic modeling, the application of dynamic modeling, which is woven throughout this dissertation, is presented in such a way that even those without a background in dynamic modeling can understand how it was used. This is purposely done because 1) the results can be understood by a larger audience and 2) it serves as an introduction for other social scientists who want to explore the method. Detailed documentation and validation testing of the system models in this PhD project are presented in the Appendix A.

1.3 The Academic Articles

The output of this PhD project is four academic articles. This section provides a summary of each with an overview of which research question they are addressing (Table 3).

1)   Palmer, E. (2017). Beyond Proximity: Consequentialist Ethics and System Dynamics. *Nordic Journal of Applied Ethics*. 1: 89-105. DOI: 10.5324/eip.v11i1.1978

Consequentialism is a moral philosophy that maintains that the moral worth of an action is determined by the consequence it has to the welfare of a society. Consequences of model design are a part of the model lifecycle that is often neglected. This discussion investigates this issue using system dynamics modeling. As a system dynamics model is a product of the modeler's decision-making in design, the modeler should consider the life cycle consequences of using the model. In this light, the consequences of the policy developed from system dynamics models are what determines the moral value of a model (ethical/unethical) in a consequentialist perspective. This concept is explored by discussing model uncertainty in an engineering perspective. In this perspective, the

ethical considerations shift from the behavior of the modeler (away from validation) to the model itself and the model's inherent uncertainty. Given that the ethical considerations are taken away from the modeler and placed on what the model does, the ethical boundaries are extended beyond the proximity of the model. This discussion renews the ethics conversation in system dynamics by considering this shift in philosophical perspective and investigates the application of consequentialist moral philosophy to the modeling process and in communication with decision-makers. A model of social assistance in Norway in light of immigration pressure illustrates possibilities for addressing these ethical concerns. This paper argues for an ethical framework, or at the very least, an ethical conversation within the field of system dynamics.

2)   Palmer, E. (2017). Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System. Social Sciences. 6(1): 22. DOI: 10.3390/socsci6010022

Norway is a world leader in gender equality according to sustainable development performance indicators. This study goes beyond these indicators to investigate systemic economic disadvantages for women, focusing specifically on the Norwegian pension system. System dynamics modeling is used to understand how gender disparity is built into social systems. A significant contributor to the gender inequality in pensions is the difference in lifetime working hours due to childbearing/rearing. There are childcare policies in place to equalize lifetime working hours between the genders; however, these policies require women to conform to the pension system structure and outsource their childcare. The system dynamics modeling illustrates how social investment strategy requires women to conform to a masculine pension system if they want equivalent financial security when they reach retirement.

3)   Palmer, E. (2017). The heavy cost of care: Systemic challenges in Norwegian work absenteeism. In review, *Policy and Politics*.

Work absenteeism is very high in Norway, costing the state 120 billion NOK annually (includes: sickness benefits, disability benefits, vocational rehabilitation allowance, work assessment allowance and rehabilitation allowance). If the level of absenteeism continues to rise, it threatens the economic sustainability of the Norwegian welfare state. Social sustainability is also challenged with women having a much higher absenteeism rate than men. To understand this phenomenon systemically, system dynamics modeling is used to investigate operationally how women attain a high rate of work absenteeism. The model focuses on care work because this is the profession category where women are most represented. Two important drivers were found to affect female absenteeism in care work: (1) low involvement in decision-making in the workplace stemming from women having a high rate of part-time work and (2) understaffing in care work environments. The analysis of the feedback in the system indicates that competing theories of female absenteeism illustrate different sides of the same story.

4)   Palmer, E. and Wilson, B. (2017). Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems. *Journal of Science and Engineering Ethics*, In press. DOI: 10.1007/s11948-017-9923-1

Dynamic engineering models have yet to be evaluated in the context of feminist engineering ethics. Decision-making concerning representing gender in dynamic modeling design is a gender and ethical issue that is important to address regardless of the system in which the dynamic modeling is applied. There are many dynamic modeling tools that operationally include the female population, however, there is an important distinction between females and women; it is the difference between biological sex and the social construct of gender, which is fluid and changes over time and geography. The ethical oversight in failing to represent or misrepresenting gender in model design when it is relevant to the model purpose can have implications for model validity and policy model development. This paper highlights this gender issue in the context of feminist engineering ethics using a dynamic population model. Women are often represented in this type of model only in their biological capacity, while lacking their gender identity.

This illustrative example also highlights how language, including the naming of variables and communication with decision-makers, plays a role in this gender issue.

Summary of PhD Project

Table 3 provides an overview of the PhD project. The research questions are given again as a reference.

Research Questions:

1. How does gender pose systemic challenges to the Norwegian welfare state?
2. How and to what benefit can systems engineering methods be used in the analysis of systemic challenges in social systems?

Table 3: Summary of the PhD project

Article	Working Period	Topic	Research Question	Main finding
1	Year 1 Spring 2015	Ethics	2	Outlines ethical questions that must be addressed in dynamic modeling projects.
2	Year 2 Fall 2015-Spring 2016	Pension	1, 2	Finds that women in Norway must conform to a masculine pension system structure to gain the same financial security as men at retirement.
3	Year 2/3 Spring 2016-Fall 2016	Absenteeism	1, 2	Illustrates how competing theories of high female absenteeism are complementary when brought together using dynamic modeling.
4	Year 3 Fall 2016	Gender issues in dynamic modeling methods	2	Shows how dynamic modeling often misrepresents or does not represent gender in models that should, and illustrates how to correct this.

2.0 Theoretical Foundation and Ethical Considerations

This purpose of this PhD project was not to build theory; however, this project is rooted in several theoretical concepts. As the point of departure for this project was the challenges of gender to the sustainability of the Norwegian welfare state using systems engineering methods, social investment, gender and systems theory are threaded throughout the academic articles of this PhD project. Systems theory will be introduced in section 3.0 Methods; in this section, social investment theory and gender theory are discussed in relation to how they were used in the academic articles.

This project rests upon a foundation of and contributes to concepts in moral philosophy. Two of the academic articles are related to ethics (articles 1 and 4). Article 4: *Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems*, brings together gender theory and dynamic engineering models to contribute to the development of the concept of feminist engineering ethics (section 2.2). Article 1: *Beyond Proximity: Consequentialist Ethics and System Dynamics*, applies consequentialism to a new domain: system dynamics modeling (section 2.3).

2.1 Social Investment and Gender Theory

Two central theoretical concepts in this PhD project are social investment and gender. These are first briefly introduced, followed by how these concepts were used in the academic articles. Only articles 2 and 3 are discussed in this section, as articles 1 and 4 are also related to ethics and discussed separately in sections 2.3 and 2.2 respectively.

2.1.1 Social Investment
An important concept in the Norwegian welfare state is social investment. This concept, illustrated in Figure 3, means that an investment in the juvenile population will result in a more productive working age population that contributes more to the national economy

and requires fewer social benefits (Esping-Andersen, 2002). Because of the focus on children in social investment, universal, high quality childcare and education are important components of implementing social investment. These social policies form part of a state's social investment strategy - the purpose of which is for states to earn a financial (as well as social) return on their investment. Social investment strategy leads to, for example, a productive labor force, and the labor force (i.e. tax-payers) is the foundation of the Norwegian pension system (Pay-As-You-Go (PAYG)). This is one way in which social investment strategy follows the population through their lifespan (Figure 3), which is referred to as the inter-generational contract (Kvist, 2016).
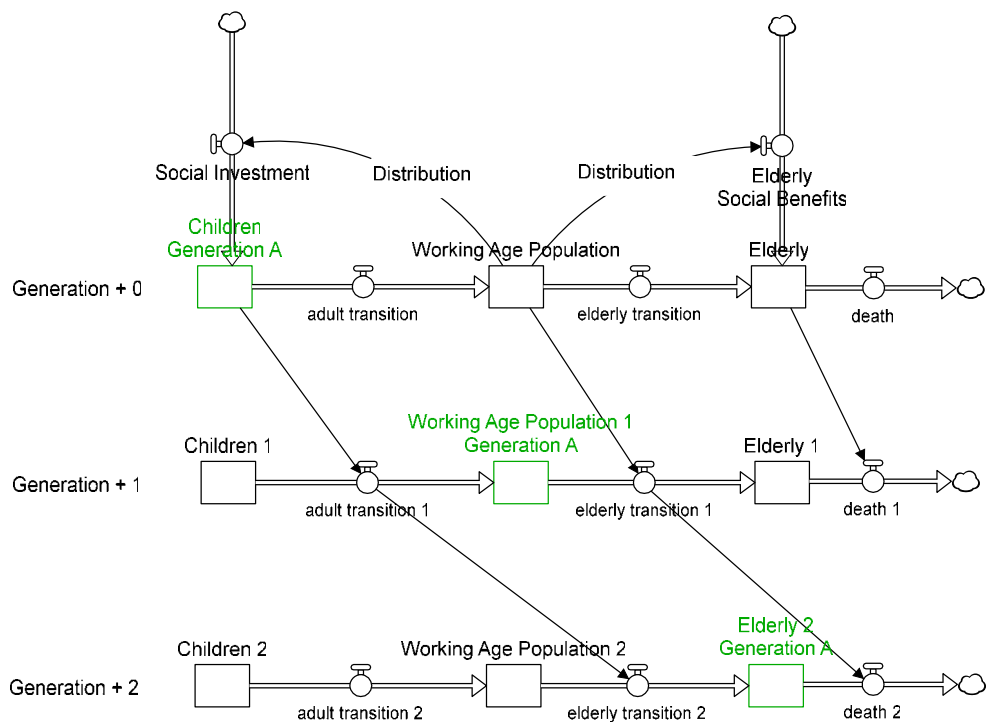
Figure 3: The inter-generational contract adapted from Kvist (2016). This also shows elements of social investment strategy, where the working age population invests in children and supports the elderly population.

2.1.2 Gender Theory

Gender theory encompasses many theoretical concepts, but at its core, a central pillar is the difference between sex and gender. Sex is biologically determined as either male or female, while gender is the social construct of man and woman. It is important to note however that gender is not binary (man or woman) and is considered a spectrum between masculine and feminine (gender fluidity), which is not static (e.g. trans-gender individuals) (Wade & Ferree 2015). Gender is much more than just biology, as it is a socially constructed attribute that is fluid and changes over time and geography. The concept of gender is highly complex and influenced by a variety of factors such as race, ethnicity, nationality, class and many other dimensions of social life (Fausto-Sterling, 2000) as well as being an aspect of individual identity (Jeanes, et al. 2012). As gender is an aspect of social-structural processes and thus also embedded in institutions (Jeanes et al., 2012), this underlying gendered logic is continuously re-constructed by affirmative everyday practices, which is not obvious at first glance; this is the process named "doing gender" (West & Zimmerman, 1987). Gender is part of the fabric of most societies and institutions, marginalizing half the world's population to varying degrees. Gender determines who goes hungry, lives in poverty, has access to resources, has the right to vote, marry, etc. in many countries (Celis et al., 2013). On the state level, many governments, such as Norway, focus their attention on national gender issues. Examples of this are often connected to social investment, such as social policies for work/family balance found in the Nordic countries (Heikkila et al., 2002).

While social investment strategy systemically addresses many social and economic issues in Norway, when one problem is solved, very often another emerges. The results of article 2: *Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System*, are thoroughly explained in the results section: 4.4: Pension and Gender. However, it is introduced here to illustrate how this project highlighted the interaction of social investment and gender theory.

Article 2: Social Investment and Gender Theory

There is a social dilemma associated with having children in Norway and most modern societies because of the large economic burden for the parents; yet children are valuable and necessary for the society (Palme, 2009). It is not a rational economic choice (in terms of pension) for women to provide their own childcare versus having it provided by the state. This does not mean that most women who use state provided childcare resources would rather stay home with their children (though some most likely would). Many do however choose to stay home either full-time or part-time and are not rewarded (in terms of their pension) for their contribution to the social investment.

The "new gender contract," advocated by Gøsta Esping-Andersen is the concept that welfare states should support a child-centered social investment strategy, where female labor force participation is necessary for the sustainability of the political economy (Esping-Andersen, 2002). Norway's social welfare policy has focused on making this a reality, and women are needed in the labor force to do so, making gender equality both an economic issue and a social issue (Rice, 2010). Increasing female labor force participation leads to what Esping-Andersen calls "female life course masculinization," and men should hopefully adopt (and must in order for the new gender contract to work) a more "feminine life course" (higher rate of care duties at home). However, a more feminine life course for men is not easily achieved, and has as yet not been achieved to the level where childbearing/rearing does not affect female position percent (level of part-time work). Although feminists are skeptical that the focus on children in social investment strategy will have a positive outcome for women (Jenson, 2009), this problem with the new gender contract and social investment strategy should rather instigate a call for the revival of the concept of husbandry (Nelson, 2016). Husbandry is a richer gender identity for men, where they identify beyond "the economic man." Husbandry is not "a male mother;" and women need not become an "honorary man" or adhere to female life course masculinization. The argument in the revival of husbandry is that caring is a

human trait, where men are leading less full lives without having it as part of their gender identity.

In addition to the analysis of the Norwegian pension system, gender theory was also a foundation for the third article in this PhD project: *The heavy cost of care: Systemic challenges in Norwegian work absenteeism*. The results of this article are thoroughly explained in the results section: 4.5: Absenteeism and Gender. It is introduced in the following section, however, to further illustrate how this project used gender theory.

Article 3: Gender Theory

Women have a much higher rate of absenteeism than men, and there are many theories attempting to explain this phenomenon (Ose et al., 2014). The largest diagnosis categories are muscle/skeletal complaints and mental illness. Aside from pregnancy-related reasons, these two illness categories also represent the largest reported gender difference (NAV, 2014). One theory for the gender difference is the "double burden theory," which states that because women work full-time jobs and do the majority of care work at home, they can become fatigued/burned out and are more likely to take sick leave (Kostøl, 2010). Another theory for the gender difference in absenteeism rates is that men and women are susceptible to different illnesses, i.e. women generally have higher rates of anxiety and depression (Eaton et al., 2007) and skeletal and muscle complaints (Gjesdal et al., 2011). Yet another theory explains that the gender disparity in absenteeism rates is related to gender differences in profession categories (Campos-Serna et al., 2013). The profession category with a high percentage of female employees is care work, and care work is physically and psychologically intensive work.

Despite government policy that encourages women to enter male-dominated fields, the gender distribution in Norway strictly follows traditional gender roles when it comes to employment. Women make up the vast majority of what are called "care workers." Care workers (for the purposes of this study) include: nurses, teachers, and elder and child care workers. Care work is shown to be not only much more physically demanding than male-

dominated professions, but it also creates a unique psychological strain on the employee. In addition to the emotional toll, the psychological strain in care work derives mostly from understaffing/over-work and low employee involvement in decision-making (Mitchie & Williams, 2003; Elstad & Vabø, 2008; Magnusson Hanson et al., 2008).

This point of departure, steeped in the theoretical concept of gender, was the foundation for the development of model development in article 3: *The heavy cost of care: Systemic challenges in Norwegian work absenteeism*; the results of which are presented in section 4.5. Gender theory was used not only as a theoretical foundation for articles 1 and 3, but it was also used to explore issues in moral philosophy. The next section explains how article 4: *Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems*, used gender theory to contribute to the development of a relatively new ethical concept: feminist engineering ethics.

2.2 Gender Theory and Dynamic Engineering Models

The purpose of writing the fourth article as part of this PhD project was to show not only how to represent gender theory using dynamic modeling, but also to show how it can easily go wrong. This was the last article produced in the PhD project, and it represents a reflection of the experience that I gained throughout the PhD project on the difficulties of representing gender theory mathematically.

Dynamic engineering models, such as agent-based models, dynamic structural equation models (SEM) and system dynamic models, are engineered artifacts that have not, as yet, been evaluated under the lens of feminist engineering ethics. Feminist engineering ethics, as a term (Riley, 2013), is rather new, and as many dynamic modeling tools are used for analyzing an ever-increasing array of complex problems, the need for evaluating the treatment of gender in these models becomes even more relevant. Dynamic engineering modeling is often used to understand population dynamics operationally; for example, to understand how different age groups increase and decrease over time SSB. (2010a). This

is of specific interest for those evaluating the challenges associated with the increasing elderly population in Norway. A very common use of dynamic engineering models of population dynamics is to investigate a decreasing total fertility rate (TFR). The female population is an important part of this type of modeling. A basic model of a population aging chain is shown in Figure 4.

Figure 4: Basic Population Aging Chain

Starting with the population aging chain shown in Figure 4, Figure 5 is developed to understand a decreasing TFR. The model structure shown in Figure 5 illustrates an endogenous TFR. This means that the model structure is not using data to calculate the TFR, but includes model structure to calculate the TFR. This model structure is built using the Easterlin Hypothesis which states that as disposable income increases, the TFR increases (Easterlin, 1987). This is balanced by a feedback loop that decreases the amount of disposable income once more children are born. The problem with the model structures shown in Figures 4 and 5 is that neither one represents gender. There are many feedback mechanisms in population dynamics, which differ on the national and global

level, and the Easterlin Hypothesis is commonly tested in population economics and population dynamics research in national studies (e.g. Macunovich, 2011; Waldorf & Byun, 2005; Jeon & Shields, 2005), which is the reason it was used as the modeling example in this study.
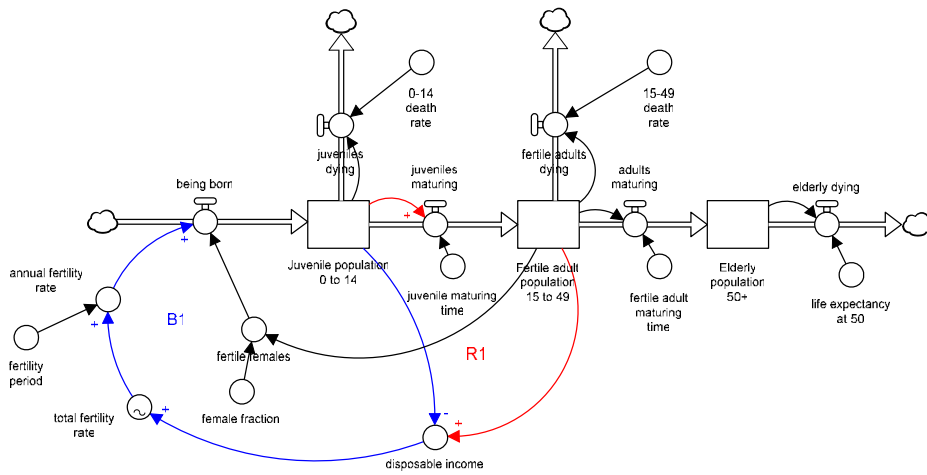

Figure 5: Population aging chain with an endogenous TFR based on the Easterlin Hypothesis, which creates two feedback loops in the system that interact to both increase and then stabilize the TFR.

The difference between sex (biologically-determined) and gender (socially-constructed) is important to represent accurately in models that are built to develop policy. Figure 4 and 5 represent biological female humans and not women. There is nothing in these model structures that represents the gender identity of women or men, which is vitally important for policy development and implementation. Building a policy on the model presented in Figure 5, would mean that all that would have to be done to increase the TFR would be to increase state-supported childcare resources, allowing more women to enter the labor force and hence increasing disposable income. Building such a policy on a model that misunderstands the difference between such a basic social concept as sex and gender happens however (Iannelli et al., 2005) because dynamic modelers are often not social scientists, and social scientists are often not dynamic modelers.
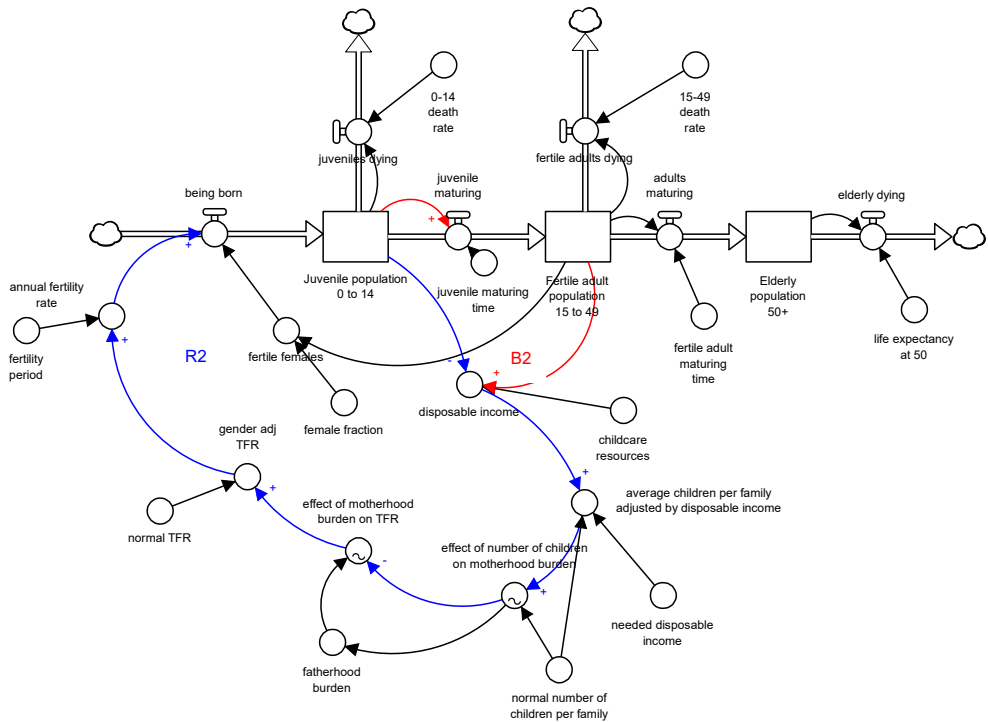
Figure 6: Population aging chain with an endogenous TFR that includes gender.

The model presented in Figure 6 however shows how population dynamics could be represented in dynamic models with gender included in the model structure. In this model structure, disposable income matters, but so does the burden of motherhood. As childcare resources increase, disposable income increases, which increases the number of children per family. These children increase the motherhood and fatherhood burden, which decreases the TFR to create the gender-adjusted TFR. This is a hypothetical example loosely based on Norwegian population dynamics, and is meant as an illustration to both social scientists and system engineers how to better represent gender in dynamic engineering models. Building a policy based on a model where gender is included has a much higher chance of implementation success with fewer unintended consequences.

By including gender in the original model design, the policy of childcare resources would need to be designed in a way that the mother/fatherhood burden does not increase because, in this example, this will lead to a decreasing TFR and total population. This assumes however that, when considering feminist engineering ethics, the model problem (low TFR) and desired dynamics (increasing TFR) still allows for further model development; i.e. feminist engineering ethics may indicate that the gender consequences are too great to warrant further model policy development. Feminist engineering ethical concerns in modeling can be identified in many stages of the modeling process. The modeling example highlights several, though it focuses on the modeler's decision-making in design; whether this is the design of the desirable dynamics of the system or the design of the model and policy system structure. As the literature on feminist engineering ethics continues to grow, the concept will evolve as well. It is with hope that dynamic modelers will heed the concerns of feminist engineering ethics as it becomes better known in the engineering and scientific community.

The modeling example given here is not meant to be comprehensive, showing all possibilities of how you can model gender in population models. Many variables influence men and women to have children, and this example includes only a couple of these variables to highlight one gender issue (the difference between sex and gender) in dynamic engineering models of populations for the purpose of exploring the concept of feminist engineering ethics. Feminist engineering ethical concerns were not the only ethical issues that this PhD project explored. Consequentialism and the ethical responsibility of unintended consequences in system dynamics modeling were explored in the first academic article: *Beyond Proximity: Consequentialist Ethics and System Dynamics*, which is presented in the following section.

2.3 Consequentialism and System Dynamics Modeling

It can be difficult for dynamic modeling (of all types) to be accepted in its use in addressing research questions in a variety of disciplines because it is often rejected by academics as not being scientific and because it does not build theory (Olaya, 2014). As will be explained in 3.0 Methods, there are academics who consider system dynamics a field of study; and as a field, system dynamics positions itself as a science. There are many however (especially in engineering fields) who use many types of dynamic models, and system dynamics modeling is considered just another dynamic modeling tool (Estefan, 2007). Although the practice of system dynamics is not contingent on whether it is considered a scientific field, a method or a tool, the degree to which system dynamics modeling is accepted is contingent on how system dynamic modeling is viewed. If system dynamics modeling, as with other types of dynamic modeling, is best described as an engineering tool, then the ethical considerations shift away from the behavior of the scientist and towards the tool itself as an "ethically-charged engineering artifact." Exploring this issue was a vital part of the foundation for this PhD project, which resulted in the first academic article of the project: *Beyond Proximity: Consequentialist Ethics and System Dynamics*. Although this article focuses on system dynamics modeling, the ethical concerns raised are of equal relevance for other forms of dynamic engineering modeling in the social sciences.

Consequentialist Ethics

If system dynamics modeling is considered an engineering endeavor, then the ethical implications are different in scope. Of particular concern are the consequences for society of using system dynamics modeling, and it is for this reason that system dynamics modeling is examined with the moral philosophy of consequentialism. There are other moral philosophies against which to consider system dynamics modeling, and for an overview, please see Pruyt & Kwakkel (2007). Consequentialism was chosen for this

study because of the lack of discussion of the ethical responsibility of unintended consequences in the literature and the system dynamics community.

Consequentialism is simply explained with the following statement: the best decision in any given situation is the one that provides the greatest benefit overall, as judged from an objective standpoint (Scheffler, 1988). The net benefit of a decision is the result of positive and negative consequences of making the decision. Dynamic modeling requires many decisions; these decisions concern model assumptions, model boundaries and overall model design. The moral value of these decisions is based on the net benefit it has for those affected by the decision. Policy decisions that influence dynamic modeling is meant to increase desirable dynamics of the system. However, there can be negative consequences as a result of implementing policies depending on the chosen model design. All the consequences of a modeling decision cannot be known before a policy decision is made, and a completely objective standpoint in which to judge the normative value of the consequences of these decisions is rarely possible.

However, there is an important distinction between "unwanted" versus "unintended" consequences (Koehn, 2010). Unwanted consequences are foreseen consequences, and the decision-maker chooses to avoid them (morally good) or not (morally bad). Unintended consequences are unforeseen consequences that neither the modeler nor the policy decision-maker can control. In the case of system dynamics modeling, unintended consequences are the result of uncertainty in the model, which will always be present because of the assumed causality (see section 3.3). Ethically, this means that the modeler must be transparent in the modeling assumptions especially if model design is meant to influence policy decision-makers. However, because as argued above, modeling is an engineering endeavor, the moral responsibility lies not with the modeler but is placed onto the model itself.

In engineering, the relationship between engineering models and moral philosophy is represented to some extent in the literature, which explains that the engineered artifact itself is where the ethical issues lie (e.g. Herkert, 2000; Jenkins, 2015; Katz, 2011). Those using dynamic modeling must go beyond their own ethical behavior and consider the model an "ethically-charged artifact" because of the potential harm this may have for society, which is why consequentialism is relevant in this discussion. Even though a modeler may be acting as ethically as humanly possible (unbiased and completely transparent in an objective environment), once the model leaves their hands and is used by policy decision-makers, the model is a tool that can produce harm. Placing the focus away from the modeler and onto the model requires the modeler to expand their ethical awareness beyond the modeling process. In engineering, this is termed the "product life cycle," and in this case, the model is the product of the modeler.

This is shown in Figure 7, where in each step of the model's life cycle, there are ethical implications of the model. Given that the ethical considerations are taken away from the model itself and placed onto what the model does, the "ethical boundaries" are extended beyond the proximity of the model, which is very well expressed by Bowen (2009):

> *It may be proposed that the articulation of an aspirational engineering ethic can be facilitated by extending the I-You vocabulary beyond proximity, to include a relationship with people who may be distant in place and/or distant in time. Thus, the task of the engineer may be viewed as the development of technical knowledge and technical activities, the world of I-It, in response to an I-You concern for those benefiting from the technical advance. The people affected by the activities may be located far from the place where the engineering work is conceived and planned. In some cases, they may be far from the place where the engineering artefacts are constructed or even far from the place where the completed, engineered artefacts are located (p.140).*

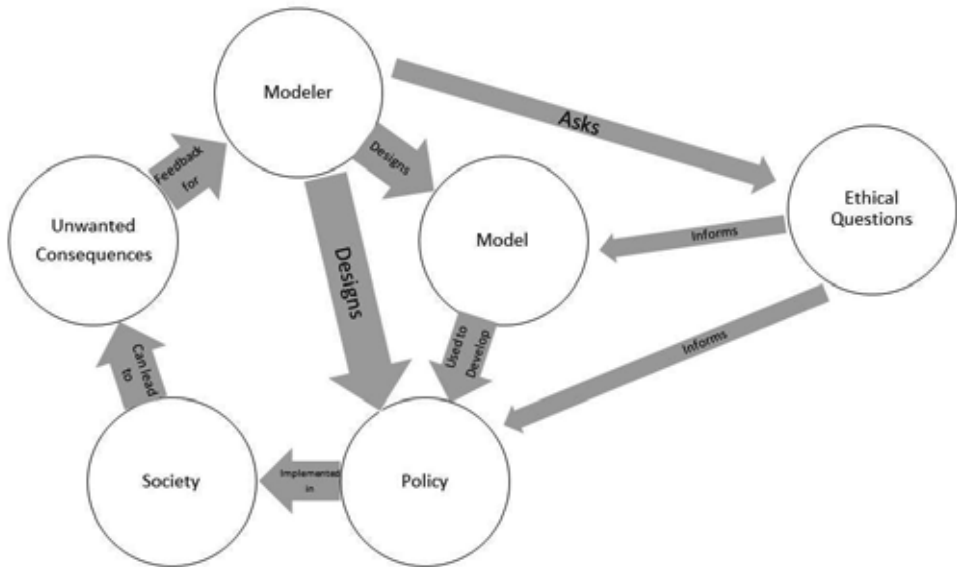*Figure 7: The life cycle of the model and where to ask the ethical questions (Palmer, 2017a)*

The philosophy behind and the ethical implications of applying system dynamics modeling to social systems was an important foundation for starting this PhD project, which is why these issues were explored in the first article. The following section provides an overview of the methods used in this PhD project and their limitations.

3.0 Methods

Many disciplines employ a systems approach, many of which evolved as an offshoot of general systems theory. General systems theory is "*a name which has come into use to describe a level of theoretical model-building which lies somewhere between the highly generalized constructions of pure mathematics and the specific theories of the specialized disciplines.*" (Boulding, 1956; as quoted in Klir, 1969: p. *vii*). This PhD project is rooted in this theory as it brings together research from many fields of social science through the use of mathematical modeling. At the core of this theory is the concept of a system. A system is a cognitive schema for capturing the interconnected nature of the world around us (Martin, 2007). Systems thinking is the discipline of seeing wholes as well as parts (Senge & Sterman, 1992), viewing the causes and effects as endogenously linked; this is in opposition to a centralized mindset that views cause and effect with an event-based world view (Resnick, 1996). The system structure determines the behavior of a system in a systems approach, and if you understand society as a system, you will have a different perspective on the society's emergent behavior. Systems engineering is embedded in this way of thinking.

This PhD project is carried out using a systems approach, and employs a systems engineering methodology to investigate social systems in the Norwegian welfare state. A systems approach applied to the social sciences is sparsely represented in the literature. Where a systems approach is seen in the social sciences is when the concept of communication is in focus (Luhmann, 1993; Stichweh, 2000; Görke & Scholl, 2006). This project is not the first, however, to use systems engineering to evaluate social systems, but builds upon the work of Warfield (1976; 2006) and Banathy (1996), who were pioneers in the application of a systems approach to the evaluation and design of social systems.

As illustrated in Figure 2, this project uses systems engineering methodology, specifically the SPADE methodological framework (Haskins 2008a). Dynamic (engineering) modeling is the family of tools that this project uses, from which system dynamic modeling was the specific tool chosen for the analysis (as mentioned in the introduction, this was a project requirement). A background to system dynamics modeling, an introduction of the basic concepts and an outline of the basics of the technical modeling is given in section 3.2. As with the ethical considerations highlighted in the previous section, there are methodological limitations in using dynamic modeling, and these are discussed in section 3.3.

3.1 Systems engineering

3.1.1 Background

Systems engineering is multi-disciplinary, in that it spans all fields of engineering, and its methods are applied in many scientific disciplines. There are core concepts in systems engineering that are also found in other disciplines. Table 1 lists several important concepts and their meaning as defined in systems engineering.

One engineering use of systems engineering is a means to optimize product development by following standard processes in the evaluation and building of systems. Although several systems engineering professional organizations exists, the International Council on Systems Engineering (INCOSE) is the professional organization that also acts as the certification body in systems engineering. It is important to note that INCOSE and the systems engineering community is motivated to promote the application of systems engineering in the social sciences (Haskins, 2008b; Beihoff et al., 2014).

In the sciences, systems engineering tools and methods help to identify and analyze research problems. These tools and methods are both qualitative and quantitative. Qualitative systems engineering tools, such as "soft systems methodology" developed by Checkland (1981; 2000), were developed as a response to the reductionism that natural

sciences impose on the study of systems. Another example is the Causal Loop Diagram (CLD), which is shown in Figure 8.
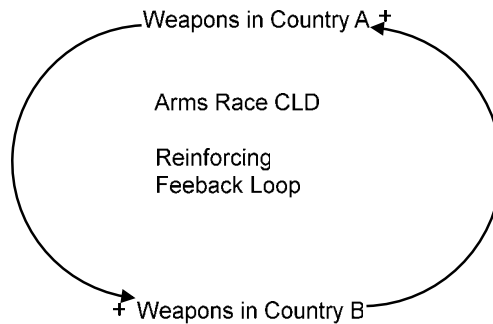

Figure 8: Example of a CLD: As Country B increases their number of weapons, Country A increases their number of weapons.

Using qualitative in addition to quantitative systems engineering tools is especially helpful when evaluating social systems to offset the criticism it receives from social scientists. This criticism is most often related to (though not limited to) mathematical models of social systems being too reductionist and not an accurate representation of society (Weidlich, 2006). It is for this reason that this PhD project uses CLDs in addition to quantitative tools, specifically system dynamics modeling.

Dynamic modeling is a type of mathematical model that evaluates behavior that changes over time. An example of dynamic modeling that has been used in the social sciences is structural equation modeling (SEM) (Schumacker & Lomax, 1996). This dynamic modeling tool has made the greatest inroads into the social sciences. To a much more limited extent, agent-based modeling (ABM) (Epstein, 2006) and system dynamics modeling (Sterman, 2001) have also been used to address research problems in the social sciences. System dynamics modeling is similar to structural equation modeling, which helps its acceptance in the social sciences since structural equation modeling sets a precedent in the field for dynamic modeling. The main difference between structural

equation modeling and system dynamics modeling is that system dynamics modeling evaluates feedback within the system (Hovmand, 2003). Understanding the systemic feedback is of particular interest in this PhD project, and it is for this reason that system dynamics modeling was chosen as the systems engineering tool to address the research questions.

System dynamics modeling is a tool (see Figure 2), however, system dynamics outside of systems engineering is considered a field of its own. System dynamics modeling has long been used to evaluate social phenomena. However, as a field of its own, system dynamics modeling techniques are vulnerable to a lack of innovation because of its isolation from researchers with different tools and different perspectives. By expanding the capacity of systems engineering and utilizing system dynamics modeling to evaluate and design social systems, there is a greater potential for system dynamics modeling techniques to evolve, which raises its capability to address social problems.

This PhD project is an example of how systems engineering through the use of system dynamics modeling can expand its reach into issues within the social sciences. While system dynamics modeling is not unknown as a tool in systems engineering (e.g. Madni et al., 2015; Ng & Lam, 2011), system dynamics modeling has not been fully utilized for its strength in evaluating social systems in systems engineering. Evaluating demographic challenges to the sustainability of the Norwegian welfare state using system dynamics modeling serves as an example of how other researchers can systematically and systemically investigate emergent social behavior using systems engineering.

3.1.2 SPADE Methodological Framework

SPADE is a systems engineering methodological framework developed by Haskins (2008a). Although this project required the use of a specific tool (system dynamics modeling) in order to address the research questions, SPADE was selected as the systems engineering methodology to set the research direction for the overall project.

SPADE is an acronym, which stands for: **S**takeholders, **P**roblem Formulation, **A**nalysis, **D**ecision-Making and **E**valuation. SPADE is a non-sequential methodological framework, where each part of the framework can be used at any point in the research process, each individually or several simultaneously, and iteratively. This section outlines how each part of the SPADE framework was used in this project.

Stakeholders: The stakeholder part of the SPADE methodological framework requires the identifications of stakeholders or elements in the system (i.e. variables in the system dynamics modeling). This project used a modeling backwards approach (Wheat, 2015) in the identification of system stakeholders. The system structure in the model is built by researching, with both a literature review and with subject matter experts, each relevant variable within the system boundary starting with the problematic behavior and working backwards. For example, what is influencing the problematic behavior? What is influencing the variable that is the answer to this question? This process continues until a first iteration model is complete, which is then tested and brought before subject matter experts. Using the feedback from these experts, further model iterations are required.

Problem Formulation: In the problem formulation part of the SPADE methodological framework, this project again used a modeling backwards approach. This approach requires beginning the modeling process with a dynamic problematic behavior (i.e. the reference mode, see section 3.2). The modeling then seeks to explain how the problematic behavior is emergent from the system structure.

Analysis: The goal of the analysis is to identify how and what structural mechanisms in the system structure allow the problematic behavior (identified in problem formulation) to emerge. The identification of feedback mechanisms in the pension and absenteeism system structures, presented in section 4.4 and 4.5, is the outcome of the analysis activities of the SPADE framework.

Decision-Making: Decision-making refers to possibilities for solving the problem. Researchers using system dynamic models often have a goal of developing policy to

address the problematic behavior identified in the system. As will be explained in sections 3.2 and 3.3, this was not a goal of this project. Decision-making is best left in the hands of policy decision-makers. This project identifies what structural mechanisms a policy should affect to lead to desirable system behavior within a system.

Evaluation: Evaluation is a continual process of model improvement. As is mentioned throughout this dissertation, building models requires many iterations to refine the model structure. Each iteration of the model structure is based on published literature and feedback from subject matter experts. Making assumptions however (as is discussed in section 3.3) is part of the modeling process as it is rarely possible to have published data available to support every variable and equation. Where assumptions are made, experts in the specific subject matter are consulted to raise the validity of the model. This process took many forms throughout the modeling process, for example:

- feedback from my main supervisor, Stein Kuhnle, a Norwegian welfare state expert;
- presentations at conferences and workshops (European Network for Social Policy Analysis (Espanet Europe), the Sino-Nordic Welfare Research Network (SNoW) and the Nordic Centre of Excellence: The Nordic Welfare State – Historical Foundations and Future Challenges (NordWel)); and
- working as a visiting scholar at the Welfare State Research Center at the University of Southern Denmark.

This PhD project can best be described as "living" in the SPADE framework. The problem formulation was initially defined, and then re-defined at many points in the process. Stakeholders and system elements were added and deleted constantly throughout the project. Analysis on early model iterations revealed that research questions were off-course, and in one case, this required deleting an entire model section (see section 4.5). Decision-making related to possible policy alternatives suggested by the models was fine-tuned as the analysis became more in-depth. Throughout the entire research process, evaluating was at the core of the methods. Updating, changing and improving the model

is a process that is never complete. Models are never finished, they are only improvements on the models that came before them.

3.2 System Dynamics

System dynamics modeling is the systems engineering tool that is used in this PhD project. This section gives a background to the technique and how it is used. This section also provides a brief history of system dynamics and an outline of system dynamics concepts.

3.2.1 Background

System dynamics is a relatively new discipline that saw its formation in the mid-20th century and began to spread with the publication of *Industrial Dynamics* by Jay Forrester (1961). System dynamics is used when analyzing a domain as a system to understand the feedback within the system in order to develop solutions to inherent problems versus symptoms. The methodology was developed originally at MIT (Meadows, 2008). The researchers were engaged by the Club of Rome to create the World model, which has been a cornerstone of sustainability and climate change analysis (Meadows et al., 1972; Randers, 2012).

System dynamics is an iterative, interdisciplinary process, which views problems holistically. Essentially, using system dynamics involves identifying elements, subsystems, and the context, boundaries and properties of the system under investigation. System dynamics is both systematic and systemic in that there are systematic processes to be followed, and it is rooted in systemic thinking in order to recognize and solve complex problems by seeing the whole instead of only the parts.

3.2.2 The Concept of Feedback in System Dynamics

A fundamental concept in system dynamics is feedback which originates in cybernetics. In the evaluation of the relationships between elements in a system, there are often

feedback loops operating in a system (Lane, 1999). A feedback loop is the interconnection of variables in a system that circles back into itself. This is a closed loop system. Open loop systems do not have a feedback loop, and often the policy goal in these systems is to close the loop, especially in environmental management systems. Open loop systems have exogenous variables that influence the system structure from outside the system and thereby influence the system behavior. Closed loop systems have endogenous variables, where the behavior is influenced by forces within the system. An example of this is climate change variables. When modeling societal collapse in history (e.g. the classic Mayans), climate change (drought) influenced societal collapse. Climate change is exogenous in this example because the population did not cause the drought. However, when modeling human-induced climate change in contemporary societies, climate change is endogenous because human activity influences climate change and climate change, in turn, affects human societies (Roman & Palmer, 2017).

A causal loop diagram (CLD) shows the relationships between elements in a system (the feedback loop), which can be either positive or negative. A positive relationship means the elements develop in the same direction (when one increases, so does the other), and a negative relationship means the elements develop in opposite directions (when one increases, the other decreases). A balancing feedback loop means that the relationships between the elements keep the accumulated elements (stocks) at equilibrium. In addition to the balancing feedback loop, there is also a reinforcing feedback loop, where the behavior of the stock does not find an equilibrium and continues to increase or decrease over time.

3.2.3 System Dynamics Modeling

There are both qualitative and quantitative modeling techniques in system dynamics. The qualitative system dynamics modeling usually takes the form of CLDs. CLDs are a simplified form of the system structure and are usually used in conjunction with quantitative modeling. The main modeling technique is stock and flow modeling represented in stock and flow diagrams (SFD) – see Figure 9. Stock and flow models are

a set of linked ordinary differential equations (ODE), often called "system dynamics models." System dynamics models consist of stocks, flows and variables in an SFD. Stocks are an accumulation of flows over time, and flows represent addition and subtraction to the stock over time. Variables in stock and flow models are elements that affect the inflows and outflows. The variables are linked to other variables and flows through instantaneous causal links. The accumulated causal behavior in the stock is affected by the flows, which are in turn affected by the variables (see Figure 9). Table 5 provides a definition of system dynamics terms with associated notations.
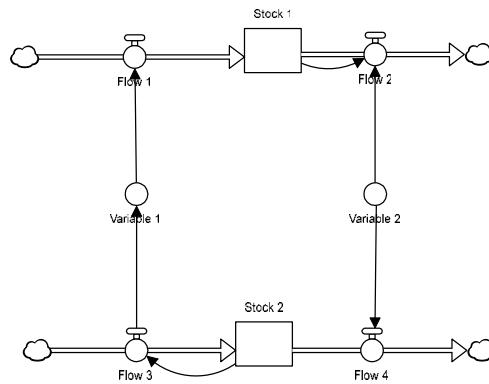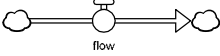

Figure 9: Example of a system dynamics model as a stock and flow diagram (SFD)

Table 4: Definition of System Dynamics Terms with Notations

Term	Definition
Flow flow	The rate of increase or decrease in stocks (Sterman, 2000). The clouds represent sources and sinks. An "inflow" refers to a flow going into a stock (addition to stock level), and an "outflow" refers to a flow leaving a stock (subtraction to stock level).
Stock Stock	Stocks are accumulations. They characterize the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. (Sterman, 2000).
Variable variable	A system element that can be a constant, contain data or an equation. In system dynamics modeling, this is also known as a converter.

System dynamics modeling is aided by the use of software. Popular programs include Powersim, Vensim and Stella Architect. Stella Architect 1.0 was used in this PhD project. The structure of a system yields the behavior over time (accumulated in stocks), and the goal is to identify all the elements and relationships in a system and reproduce the observable reference mode behavior (actual system behavior) – see Figure 10. In system dynamics models, there are endogenous and exogenous elements. Endogenous elements are incorporated in the model structure in relation to other structural elements. Exogenous elements are variables that contain data that are directly imported into the model structure. One of the major goals of system dynamics is to understand the structure of the system (Figure 9) that results in the observable behavior (Figure 10).
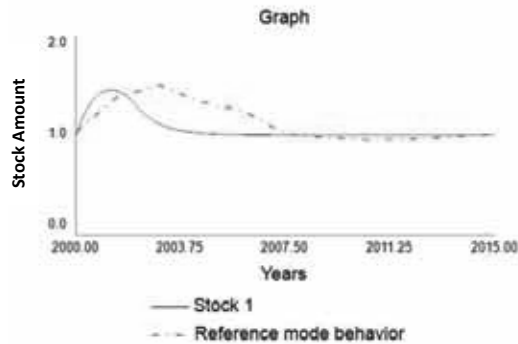
Figure 10: System Behavior: Simulated (Stock 1) vs. Actual (Reference mode behavior)

Originally, system dynamics modeling was applied in industrial engineering, but over time its application broadened to include a wide variety of research areas, such as supply chain management (Angerhofer & Angelides, 2000), business and economics (Sterman, 2001), environmental issues (Ford, 1999) and increasingly (as in this research) social policy (Gilbert & Troitzsch, 2005). System dynamics is especially useful for exploring the underlying structure of a complex, dynamic problem with the objective to eliminate undesirable dynamics and to strengthen the desirable dynamics. In addition to this, system dynamics modeling is interdisciplinary, with experts on specific model sectors giving input into how the system operates (Barlas, 2007). Because of this, system dynamics modeling can be very helpful in the analysis of problems arising in a multi-disciplinary environment. The use of system dynamics modeling and dynamic modeling in general, has many limitations, and the following section discusses several of the most important limitations.

3.3 Methodological Limitations

Dynamics modeling is not without its limitations. All forms of mathematical modeling are simplifications of reality. While models are still useful in their simple and abstract representation of actual system structure, this does limit their usefulness. Although there are validation tests that evaluate the robustness of the model, as in the sensitivity analyses shown in Appendix A.4, uncertainty is never fully removed, as discussed in section 2.3. Any type of dynamic modeling can be taken as a very deterministic method, especially when uncertainty is not made transparent. Modelers need to be careful about assuming or influencing others to believe that the assumed causality represented in the model structure are actual causal relationships. Dynamics models are engineering tools, where system model design can be represented in nearly limitless ways. Just because one system design shows a certain outcome, this does not mean that a different model design of the same system will replicate that outcome.

This is of specific concern in studies that use dynamic modeling in social systems because of the limited application of dynamic modeling in social policy analysis. As is discussed in section 3.1.2, models evolve over time, and the novelty of all the models presented in the studies in this PhD project is that they are first iteration models, meaning there are no previously published models on which the models in this project could have been built. Because of this, there are issues regarding not only robustness, but also of model scope. As models evolve over time, with many modelers of different backgrounds developing them, the robustness of the model is strengthened and the scope is widened, making the model outcome much more supportable.

In addition to this, and related to robustness, is that one of the strengths of dynamic modeling is also one of its weaknesses. Dynamic modeling is largely secondary analysis, but when there are literature gaps about system structure, dynamic modeling has techniques to cope with this shortcoming. Graphical functions in system dynamics

modeling, e.g. as shown in Figure 22 and 24 in Appendix A.4, are able to approximate relationships between variables when there is a dearth of literature or other sources. Dynamic models are engineering models that do not attempt to make causal claims, and therefore justification gaps are supported by model validation. Although graphical functions are a useful technique, they must be used with caution and tested, such that limitations are made transparent. In this project, this was done with sensitivity analyses for many different variables using non-linear graphical functions. It should always be recognized that further model development is needed to strengthen the understanding of the systems where dynamic modeling is used.

4.0 Results

This section presents the results of the research and illustrates how systems engineering methods can be applied to the evaluation of demographic challenges to the Norwegian welfare state. Additional background information provides a brief history of the Norwegian welfare state and where it is today, followed by a discussion of how different parts of the Norwegian welfare state can be understood as social systems. The PhD project focuses on two welfare state systems: pension and absenteeism (also known as sickness absence), and the criteria for why these specific systems were chosen for this PhD project are given in section 4.2. To understand how dynamic modeling is used in the evaluation of the pension and absenteeism systems, the development of the basic model structures is explained first. These basic model structures include the Norwegian population demography model sector and the Norwegian state general accounting model sector. The pension and absenteeism system models are built upon these basic model structures. Of all the demographic challenges that the Norwegian welfare state faces, only one is evaluated in this PhD project: gender. Although briefly explained in section 1.1, the specific criteria for choosing this demographic challenge is further explained in section 4.3. Sections 4.4 and 4.5 provide the analysis of the pension and absenteeism system in light of the challenges posed by gender to each system.

4.1 Background: The Norwegian Welfare State

As early as the 1930s, there are literature references to the homogenous nature of the Nordic countries (Classen, 1937). The notion of a Nordic Model (alternatively labeled the "Social Democratic Model" or the "Scandinavian Model") however has only been in use for the last 30 years, when the term was developed in the 1980s by Esping-Andersen (1990) and Erikson (1987). The Nordic Model is also considered something of a benchmark for economic and social performance. However, critics often question the

sustainability of such a regime (Andersen et al., 2007). This PhD project is meant to respond to some of these questions of sustainability.

A Brief History of the Norwegian Welfare State

As is common in other European countries, the development of the Norwegian welfare state can trace its roots to social and economic transformations in history (Pedersen & Kuhnle, 2017). Before the late 19th century, there was a growing discontent with the system of poor relief that was in place in Norway (Bjørnson, 2001). Under this system, only orphans and the mentally ill were entitled to social assistance, but this would also extend to the disabled, elderly and indigent if impoverishment was threatened. Western welfare states began to evolve as they strove to address "the social question" in the last quarter of the 19th century with the development of social assistance programs. With the example of the impact of such programs in Germany, the Nordic states began to follow suit, with Norway following Denmark and Sweden. Although influenced directly and indirectly by Germany in the late 19th century (Kuhnle, 1983), there is a specific Nordic route to welfare state development, with four factors influencing this: the role of religion, patterns of land ownership, the role of social democratic parties in the 1930s and social structure and values fostering gender equality (Kautto, 2010; Pederson & Kuhnle 2017).

Although the Nordics have a unique development towards welfare state development, Norway was more affected by the German example of compulsory insurance with the introduction of compulsory sickness insurance in 1909 (Kuhnle & Sander, 2010). This insurance also included pioneering medical benefits that extended to family members. There is also evidence of French influence: when France adopted national unemployment insurance in 1905, Norway followed in 1906. Denmark had a non-contributory pension scheme in place in the late 19th century, but Sweden was first among the Nordics in its adoption of the universal contributory old age pension in 1913 (Palme, 1990). In Norway, old age pension developed in the inter-war period, which evolved from the Oslo Pension System of 1918 through the influence of the Labor Party (Bjørnson, 2001). The timing of

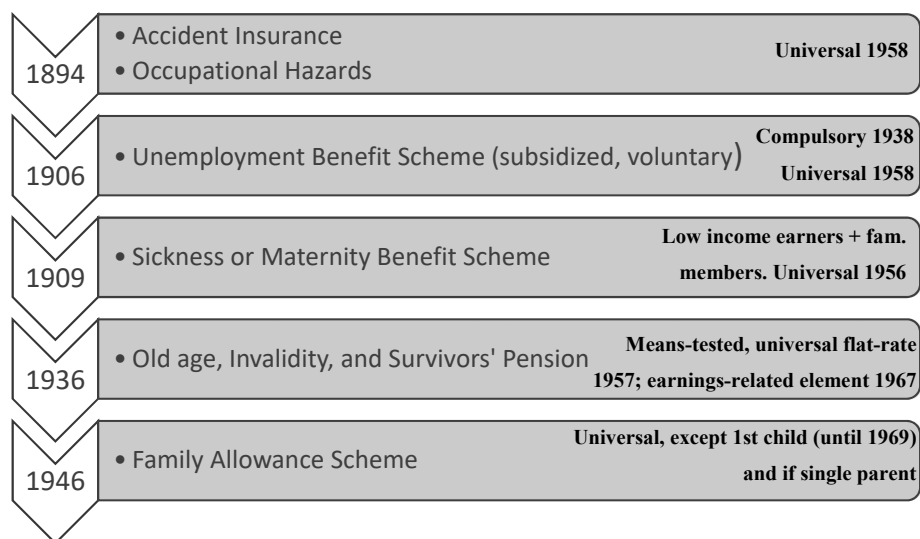the introduction of social benefit programs is outlined in Figure 11 (adapted from Kuhnle & Sander, 2010).

Year	Program	Notes
1894	• Accident Insurance • Occupational Hazards	**Universal 1958**
1906	• Unemployment Benefit Scheme (subsidized, voluntary)	**Compulsory 1938** **Universal 1958**
1909	• Sickness or Maternity Benefit Scheme	**Low income earners + fam. members. Universal 1956**
1936	• Old age, Invalidity, and Survivors' Pension	**Means-tested, universal flat-rate 1957; earnings-related element 1967**
1946	• Family Allowance Scheme	**Universal, except 1st child (until 1969) and if single parent**

Figure 11: Timing of the introduction of social policy; showing the origins of the modern welfare state in Norway

The role of gender is a common thread through Norwegian welfare state development. The social politics until the last few decades dictated that the ideal standard for family structure was the husband as the earner, with the expectation that he will support his wife and children (the male-breadwinner model (Fraser, 1994)). It was also up until the early 20th century that the male earner was expected to support any elderly relatives as well until the old age pension came into effect in the inter-war period (Bjørnson, 2001). The male breadwinner is even further supported in the labor market during this period with wives and children of household earners not having a right to work absenteeism assistance due to sickness because the husband/father was expected to provide for them. Gendered labor division became even more pronounced in the 1920s in Norway both socially and legislatively, leading to child custody being granted to divorced women.

The 1930s is a pivotal time for welfare state development not only in Norway but also for the rest of the Nordic countries (Pederson & Kuhnle, 2017), and it was in this period that many social security provisions were introduced. Among other factors, this period fostered such development because of the growing influence of social democratic political parties in the 1930s (also as government parties) along with the social and economic transformations in the time of the Great Depression up until the aftermath of World War II. Because economic and social transformations are the foundation for welfare state development, the Norwegian welfare state evolved during this period toward the acceptance of universalism. The Norwegian welfare system has developed markedly in the decades following World War II, and it was in this time that it laid its foundation for the modern Norwegian welfare state with the universality of social rights (Kildal & Kuhnle, 2005). This means that social benefits are not limited to those who are in the most need, but to everyone in the population (or in defined categories; e.g. elderly/pension). From the beginning of welfare state development in Norway, "the similar life chances of poor farmers and poor workers contributed to the recognition of similar risks and social rights, and the principle of universalism gained ground and was put into practice in the two decades following WWII" (Pedersen & Kuhnle, 2017; p. 221).

The "passion for equality" (Graubart, 1986) is (alleged to be) an important central attribute of the modern Norwegian welfare state, and the momentum of the socio-metabolism towards social class equality shifted as the political bargaining power of the peasant and working class grew both before, but especially after, World War II (Pedersen & Kuhnle, 2017). In addition to universality and equality, another defining attribute of the modern welfare state is the role of state and local governments. In history, the Nordic populations faced less state oppression because of the recognized legal unit of local government. The positive interaction between the state and local government continues to shape the development of the welfare state.

Given this brief background on the Norwegian welfare state, the next section begins to explain part of the Norwegian welfare state as systems and provides the boundaries of the project and the boundaries of the specific systems under analysis.

4.2 Project Boundaries

This section outlines the project boundaries and why they were chosen. Section 4.2.1 discusses several important demographic challenges to the Norwegian welfare state and gives the criteria for why gender was chosen for further analysis. Section 4.2.2 discusses why pension and absenteeism were the two systems chosen for analysis in this PhD project. In addition, this section also provides information on how system boundaries are set in dynamic modeling.

4.2.1 Demographic challenges

Although there are many demographic groups that present challenges or potential challenges to the Norwegian welfare state, migration is the group that gets the most attention because of the recent refugee crisis in Syria and because of the large number of labor migrants immigrating to Norway, especially from Eastern Europe (SSB, 2016a). At the start of this PhD project, one of the aims was to investigate how migration is affecting the sustainability of the Norwegian welfare state. However, it became quite clear in early iterations of the dynamic modeling for this project that migration is not an economic challenge to the funding of social benefits in Norway. In fact, there is evidence for the opposite: though not investigated with a long-term perspective, immigration currently significantly supports the welfare funding in Norway because of the large amount of income tax labor migrants contribute to the state (SSB, 2014a). There is also evidence that immigrants take out fewer social benefits than native Norwegians for a couple of reasons: (1) most are young (in the working age population) and (2) they are mostly employed upon arrival as the majority of immigrants are labor immigrants (SSB, 2014a). The only migration challenge for the sustainability of the Norwegian welfare state is if

emigration of labor migrants increases or the rate of labor immigration decreases. Neither of these are deemed likely (SSB, 2016a).

Although immigration has increased significantly since the 1970s, it was in the 1970s that labor immigration to Norway became very restrictive (Brochmann, & Hagelund, 2012). Refugee immigration is very low in Norway compared to the other Nordic countries (SSB, 2016b). Since the 1994 European Economic Area (EEA) agreement, labor migration is however governed by European Union (EU) regulations in Norway; and with many Eastern European countries joining the EU as of 2004, labor immigration has increased significantly over the last decade (SSB, 2016a). With high labor immigration and low refugee immigration, the immigration situation is tilted in Norway's favor economically. Because of the early model iterations showing migration strengthening the economic sustainability of the Norwegian welfare state (within the model boundaries), as well as the literature supporting this (SSB, 2014a), migration was not investigated in this project as a demographic challenge to the Norwegian welfare state.

Norway has an aging population, and is often cited as a challenge to the Norwegian welfare state (Andersen et al., 2007). With an increasing elderly population coupled with a lower than replacement level total fertility rate (TFR), about 1.8, a natural choice for investigating demographic challenges to the pension system is aging. However, this topic is heavily represented in the literature, with dynamic modeling already conducted by Statistics Norway (SSB) showing that with the recent reforms to the pension system, the pension system is economically sustainable in the medium-term (SSB, 2010a). Because this is well-established in the literature, investigating aging did not form part of this PhD project.

Moving past migration and aging, gender was the next demographic category that was evaluated for inclusion in this PhD project. Gender issues are pervasive in social systems, and this also holds true for welfare state systems. Structural gender inequality in pension systems is well-documented in the literature (Arza & Kohli, 2007), but had yet to be

investigated with dynamic modeling. This led to the development of the first model sector: the pension system. There are many gender issues in the pension system itself that challenge the social sustainability of the Norwegian welfare state. This study investigated only one: how part-time work influences pension amount between men and women. The model sector and academic article titled *Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System* (academic article 2) explores this issue and is presented in section 4.4. There are several types of pension in the Norwegian pension system, and this study investigates models one: "old age pension" (alderspensjon).

Concerning demographic challenges to the absenteeism system, in the initial development of the absenteeism model sector, immigration was considered in early model iterations. Although non-western immigrants are shown to have a higher rate of absenteeism than other immigrants and native Norwegians (Hansen et al., 2014), this demographic group does not contribute to the majority of the absenteeism costs, and it was for this reason that it was no longer investigated in this study. However, there is a large gender gap in the absenteeism rate, with female absenteeism rates almost double that of the male absenteeism rate. As will be explained in section 4.5, there are many theories for why this is so, and the modeling in this study explored them with varying results. Several elements revolving around part-time work and female-dominated professions as part of system feedback loops were found to have a significant influence on the absenteeism system. The model sector and academic article titled *The heavy cost of care: Systemic challenges in Norwegian work absenteeism* (academic article 3) investigates this connection and is presented in section 4.5.

4.2.2 Pension and Absenteeism

Applying systems engineering methodology to the social sciences requires that different elements of society are analyzed as a system. Pension and absenteeism in this project are described as systems. As described above, systems are made up of many interacting elements. In the pension system, for example, the retired person, their total lifetime income and the number of years they spent in working life are part of the pension system.

The pension system is a much larger system however: if you were to magnify total lifetime income, you would see that many elements directly and indirectly affect this part of the system; for example, whether they work full- or part-time (stillingsprosent), what career path they chose, family life and many others. These are structural elements in the pension system, and the connections between the structural elements very often form feedback loops as described in section 3.2.2. The structural elements and their connections are the social system structure, and the system behavior is what the system structure produces (emergent behavior).
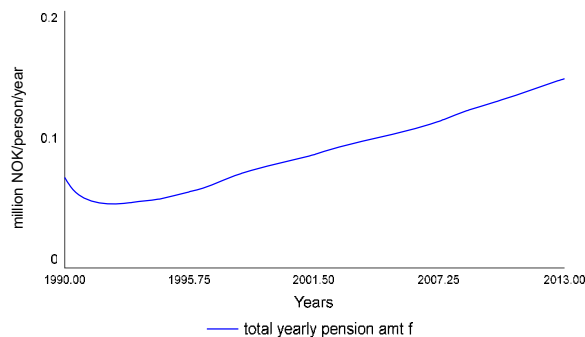

Figure 12: Women's pension amount per person per year from 1990-2013 (graph produced from model simulation)

Social system behavior is how structural elements (affected by all other parts of the social system through feedback) perform over time. An example of this is women's pension amount per person since 1990 (see Figure 12) or absenteeism costs to the state since 1990 (see Figure 13: includes: sickness benefits, disability benefits, vocational rehabilitation allowance, work assessment allowance and rehabilitation allowance). Social system structure is shown in Stock and Flow Diagrams (SFD) or Causal Loop Diagrams (CLD) as discussed in section 3.1.1, and the social system behavior is shown through graphs where the x-axis is always time (e.g. days, months or years).
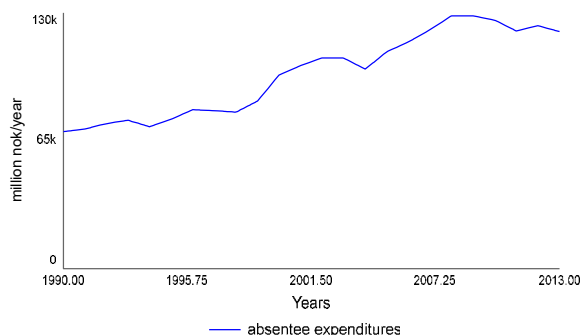
Figure 13: State absenteeism expenditures from 1990-2013: includes: sickness benefits, disability benefits, vocational rehabilitation allowance, work assessment allowance and rehabilitation allowance. Graph produced from data: SSB (2013a).

All parts of the Norwegian welfare state in this study are referred to as systems. Any part of society can be seen as a system, which falls under the domain of systems thinking as discussed in section 3.1. Without boundaries, systems connect and develop into a large system as seen in the World system model (Meadows et al., 1972). This project is much more modest in its system boundaries and is limited to the pension system and the absenteeism system. However, these names are slightly misleading because they only show parts of these systems to address specific research questions. The pension and absenteeism system represent part of a much larger Norwegian welfare state system.

System boundaries are dictated by research questions. If a part of the system is not directly under study, then it should lie outside the system boundary. More is not better when it comes to dynamic modeling. As structural complexity increases, the comprehension of dynamic complexity decreases. In other words, the more system elements and interactions that the system model contains, the more difficult it is to understand how the system structure is leading to the dynamic behavior. What to include inside and outside the system boundaries is a difficult decision to make. You need to include as much system structure as necessary to answer the research questions, but not

too much so that you can understand the system behavior. Placing system boundaries is difficult and includes a host of ethical concerns, some of which are explored in sections 2.2 and 2.3.

Another important challenge related to this is the aggregation of system elements. Within the system boundary, certain elements may be aggregated into one specific variable. This is done to reduce structural complexity when the variable in question does not need to be disaggregated to address the research question. An example of this for the pension system is a variable for "average female salary." This variable aggregates all profession categories. If the research question concerned how the wage gap affects pension in certain industries, then this variable would need to be disaggregated into profession categories to address the research question. In this study, this is not disaggregated because the research question does not require it, and disaggregating would add unnecessary complexity making it much more difficult to understand how relationships in the system structure lead to the emergent behavior.

One of the greatest challenges of applying systems engineering methodology in the social sciences concerns boundaries and aggregation. Using systems engineering methodology, especially dynamic modeling, in the social sciences is rather sparse, though structural equation modeling (SEM) and agent-based modeling (ABM) (Schumacker & Lomax 1996; Epstein 2006) have made some inroads. Presenting system structure with sufficient though necessarily limited boundaries and with aggregated variables to social scientists very often brings rejection of the methodology because it is misunderstood as not being comprehensive enough to give real insight into the research problem. One of the goals of this PhD project is to illustrate the usefulness of systems engineering in the social sciences and the unique insight it can give to research problems. There are limitations to this method as with all methods, which were outlined in section 3.3; though it is important to emphasize that just because a dynamic model of a social system does not perfectly present society, this does not mean that it is wrong. All models (not only system dynamics models) are wrong by this definition as is well-discussed in Sterman (2002).

An analogous example of this issue is that of a map of a university campus. These maps are often cartoonish in their representation of the actual physical geography and are usually intentionally not accurately representing the university on any scale. The goal of the map is for the students and visitors to find their way, and the map is best designed in order for them to do that. Dynamic models of social systems are designed along similar lines. They are not accurate, but this does not discount their usefulness.

With this in mind, let us take a closer look at pension and absenteeism in Norway. The important question here is why and how pension and absenteeism are representative of the Norwegian welfare state. The point of departure for this PhD project was demographic challenges to the social and economic sustainability of the Norwegian welfare state. The selection process for deciding which welfare state systems to investigate started with those that were of the highest cost to the state. The top three highest costs to the state in terms of social benefits are: healthcare, pension and absenteeism (SSB, 2013b). The healthcare system was excluded from this study because of capacity. This is a large and very complex system, and to do it justice, this could be the only system under study in this project. By including only the healthcare system, the health care system would then be representing the entire Norwegian welfare state, and it was left out for this reason. The pension system and the absenteeism system were included in this study because of their high cost to the state and provide a good representation of the Norwegian welfare state.

It is important to note that there are several model structures running in the background of the larger model that investigates pension and absenteeism. The next section discusses these basic model structures.

4.3 Basic Model Structures

Before any welfare systems were modeled, basic demographic and economic modeling was developed. The demographic and economic modeling are considered background

model sectors. This means that they are not investigating a particular issue but act as a necessary foundation for other model sectors. For example, to investigate the Norwegian pension system and its demographic challenges, you need to know how many people are in the retirement age population and how this changes over time.

The first stage of model development was the development of the Norwegian aging chain, which included migration (immigration and emigration) (see Figure 14). As shown in Figure 14, the aging chain is split into four stocks: the juvenile population (0-14), the young adult population (15-49), the late adult population (50-74) and the retirement age population (75 plus). These age categories were chosen because of how data is organized at Statistics Norway (SSB), which is where the initial parameter values were retrieved. Immigrants and emigrants are modeled exogenously and used to calculate the net yearly migration to Norway, which is split into age categories. The total fertility rate (TFR) and death rates for all age categories are also modeled exogenously. All exogenous data was retrieved from SSB, and the model was validated by comparing the simulated model behavior to actual population behavior (also retrieved from SSB). There is more information about the demography modeling in Appendix A.1 and A.3.1.

The next model sector that was developed for this project was the economic sector, which only represents Norwegian general state accounting (see Figure 15). This is not a full Norwegian economic model because the research questions require only state accounting modeling, and as mentioned above, it is important to balance structural complexity with dynamic behavior comprehension. The state accounting sector includes the general fund, representing the annual state income minus annual state expenditures. The other part of the state accounting model sector is the Pension Fund Global, where the annual budget surplus is invested. Data for actual system behavior was retrieved from SSB and the Norwegian State Budget (Statsbudsjettet). There is more information about the economic modeling in Appendix A. It is important to note that the demography modeling shown in Figure 14 is connected to the economic sector modeling. For example, to calculate the labor force population (lower right in Figure 15), the working age population (young and

late adult populations) from the demography sector is connected to the labor force variable where it is multiplied by the labor force participation rate.
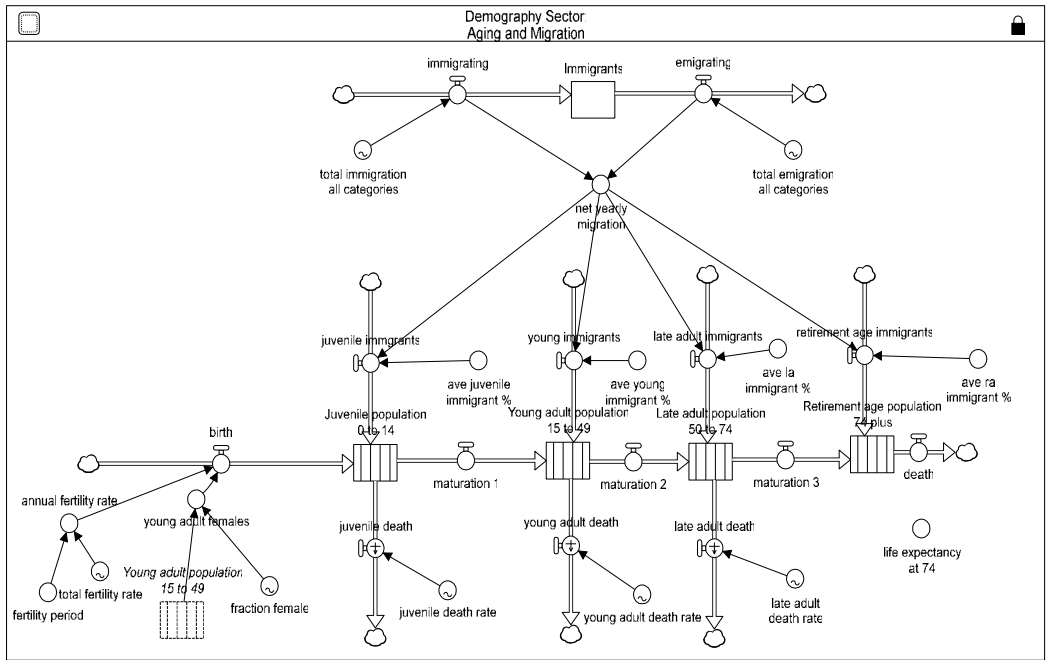

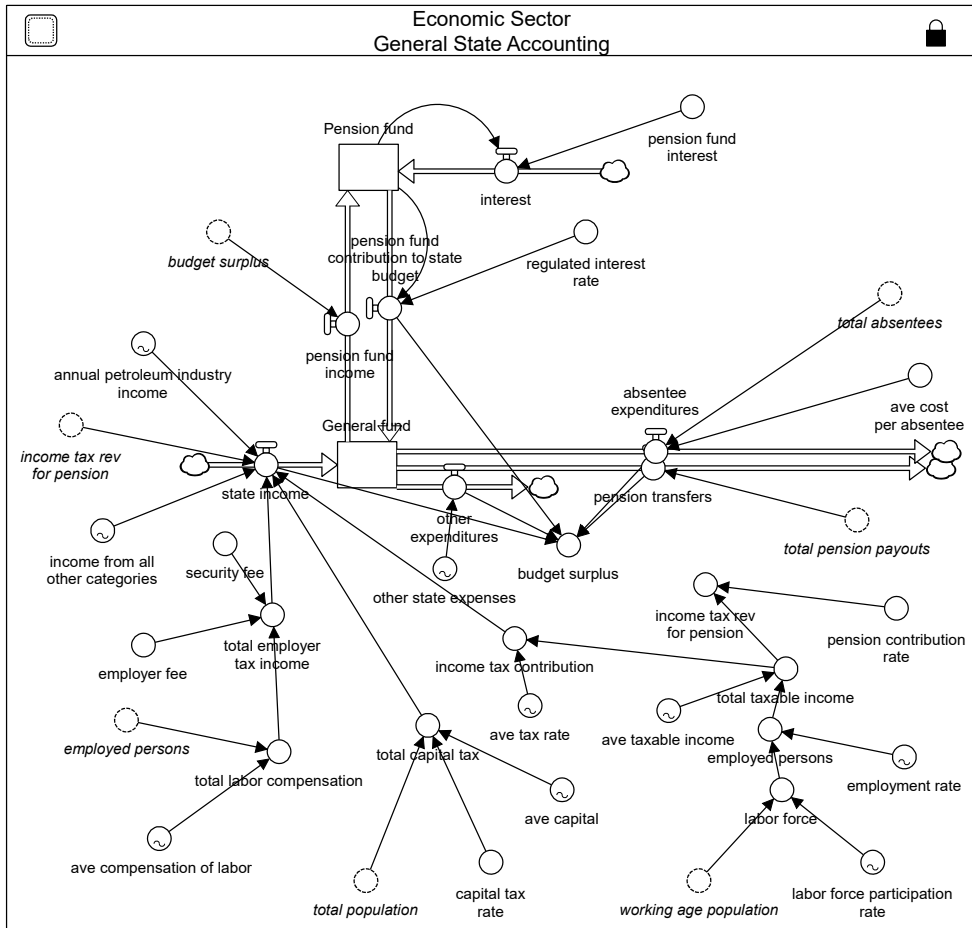*Figure 14: SFD of the demography sector of the model.*

Figure 15: SFD of the General State Accounting sector of the model, NB! "Pension fund" refers to the "Pension Fund Global".

Once these basic model structures were built and adequately reproducing actual system behavior (reference mode behavior), welfare system structures could begin to be developed. Many early models were developed to test different model designs. During these early model developments, decisions about which demographic challenges to include in this PhD project were made.

The next two sections discuss the two welfare state systems that this PhD project investigates and the demographic challenge they are presented with: Pension and Gender; and Absenteeism and Gender. Each section explains the model that was built to investigate these systems and the academic articles that were developed on these topics.

4.4 Pension and Gender

The Norwegian pension system had not been, until this PhD project, studied using dynamic modeling to investigate the challenges that gender inequality poses; however structural gender inequality when it comes to pensions is not a new topic. Men and women in Norway have unequal pensions, and there are three main reasons that make this so: 1) male- and female-dominated professions having different salary levels; 2) the wage gap; 3) and women working more often part-time compared with men. Because social investment strategy and child care policy is connected to the issue of part-time work, and it had not been dynamically modeled and is underdeveloped in the literature, the role of part-time work in relation to unequal pensions between the genders was investigated in this PhD project.

Many model iterations were developed and presented to Nordic welfare state experts[2]. The stock and flow diagram (SFD) of the final model is shown in Figure 16. It is important to note that although there were many model iterations in the model development stage, this is considered a first-generation model. There are no previously published dynamic models of pensions and gender. As mentioned earlier, models are built upon in the literature, and over time, models become much more developed and robust. Referring to Figure 16 as the final model, only means that this was the published first-generation model.

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[2] See section 3.1.2 for more information. For Pension and Gender modeling, Ann-Zofie Duvander (Stockholm University) at SNoW 2015 in Shanghai commented on early drafts of the model and paper.

The goal of the pension and gender study within the larger PhD project was to gain unique insight into a well-documented gender issue using dynamic modeling. The point of departure for this study was a report by the Nordic Council of Ministers indicating that female part-time work has no effect on their pension amount compared to their full-time female counterpart (Lanninger & Sundström, 2013). This is misleading, not because their findings are incorrect, but because they are asking the wrong questions when it comes to investigating gender and pensions. The report compares women who work part-time with their female full-time counterpart. Not only do you need to compare them to their male counterpart, but the issue lies in how women are pushed into part-time work more than men. Social investment strategy, upon which the Norwegian welfare state is built, requires the dual-earner and the shared-carer roles for both men and women. There is universal, high quality childcare available in Norway, allowing women to gain full-time employment. This raises the question: how is it that women are still working more part-time than men?

This study addresses this topic by evaluating how shared care hours, which are the hours not covered by state childcare resources, affect female position percent (stillingsprosent). Through the dynamic modeling of this system, an important feedback loop was uncovered, labeled as B in Figure 16 as an SFD and in Figure 17 as a CLD. This is a balancing feedback loop that explains that only women that completely outsource their childcare are rewarded with greater financial security when they retire. However, they will not come close to their male counterpart, even without a wage gap, unless men increase their number of shared care hours, as this is what this model indicates is pushing women into part-time work (although more model development must be undertaken to support this finding). This is related to the concept of husbandry, where care is understood as a human trait, and men are not living their fullest life by being simply defined as the "economic man" (Nelson, 2016). This study labels the Norwegian pension system as a "masculine pension system" because the pension system provides the highest benefits for those assuming the role of the "man" in the male-breadwinner model (those

working full-time for 40 years). To be gender neutral, the pension system must reward in addition those assuming the role of the "woman" in the male-breadwinner model, where the social contribution of unpaid childcare work earns pension benefits.
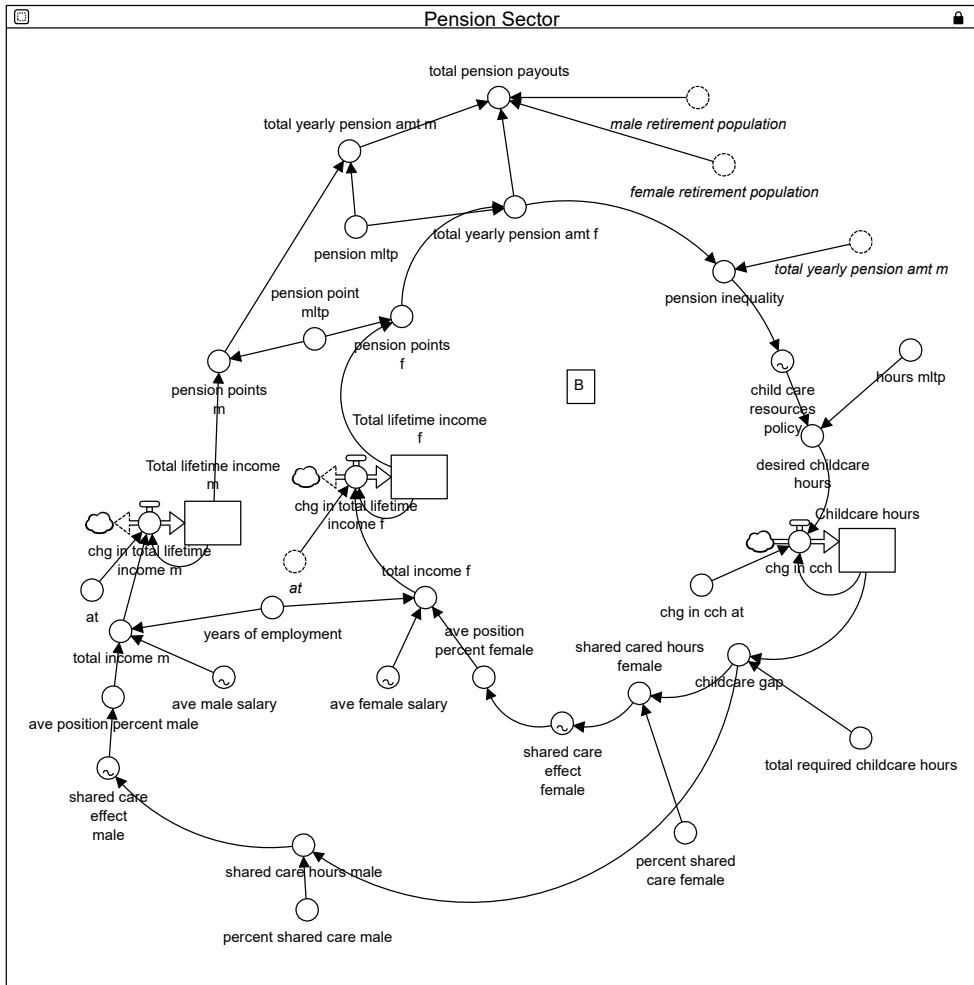

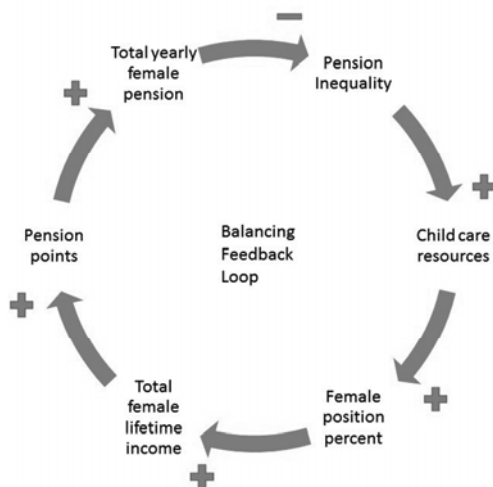*Figure 16: SFD of the Pension sector of the model*

Figure 17: CLD showing the balancing feedback loop in the pension system structure

There are noted limitations to this model as stated in the academic article, and the strict boundaries leave many parts of this system unexplored. Because this is a macro-level model, several important details are not investigated; specifically, women who earn pension points when their children are under six years of age if they have low or no income. Another important limitation of the model is that childrearing does not affect the male position percent. This is not accurate, but was modeled in this way for simplicity. To understand the relationship between shared child care hours and the effect on the working lives of men, this model needs to be further developed in another study (which develops this model into a second-generation model).

4.5 Absenteeism and Gender

Absenteeism in Norway is a significant problem, which now stands at 120 Billion NOK annually (SSB, 2016c) or 5% of GDP (OECD, 2010) (included in this amount is sickness

benefits, disability benefits, vocational rehabilitation allowance, work assessment allowance and rehabilitation allowance (SSB, 2013a)). On top of this, there is a gender gap in male/female absenteeism rates; currently, 4% and 7.5% of employed men and women respectively are on sick leave (SSB, 2016c). It should be noted that absenteeism rates do not include shorter illnesses, where salary is covered by the employer, and all data in this study has been normalized for seasonal influenza. There are many competing theories about why women are more absent from work than men in Norway. The double burden theory, which states that care work at home on top of a full-time job leads to burnout, is argued in the literature as leading to a higher level of female absenteeism (Kostøl, 2010). There is very little empirical evidence for this however (Ose et al., 2014). Another theory for the high female absenteeism rate is that women have a higher disease risk in various illness categories, e.g. mental health (Eaton et al., 2007). The difference between male- and female-dominated professions has also been cited a reason for higher absenteeism rates for women (Campos-Serna et al., 2013), with care work (female-dominated profession) being more physically demanding than engineering (male-dominated profession) for example.

Because of the evidence of the lack of male shared care hours negatively affecting female working life in the pension system study in this PhD project, as well as evidence in the literature, the double burden theory was initially tested in the first model iteration of the absenteeism system model sector. Like other empirical studies of this theory, this study also failed to show support for the double burden leading to a higher absenteeism rate for women. The double burden theory in this study was modeled with a burnout model structure, which means that the more hours one works (either paid or unpaid), the higher the likelihood for becoming burned out and absent from work. The reason this model structure failed to show support for the double burden theory is because women have a high rate of part-time work in childbearing and rearing years which reduces the number of total weekly working hours (paid and unpaid). This should not be taken as proof that the double burden does not lead to higher absenteeism rates in care work however,

merely a failure to show support for the double burden theory because there are many different model designs to investigate this theory, and this study only tests the theory with the burnout model structure.

In the next model iteration of the absenteeism system, the model included structure that investigated the profession category with the highest representation of women: care work. In this study, care work includes: nurses, teachers, and elder and child care workers. The SFD of the model is shown in Figure 18, and like the pension system, this is a first-generation model: developed without an existing model structure in the literature. The identification of three inter-connecting feedback loops is the unique insight this study contributes to gender issues in absenteeism rates in Norway. A CLD of these feedback loops is shown in Figure 19 The Part-time Work Reinforcing Loop, the Fatigue Reinforcing Loop and the Hiring Balancing Loop interact explaining that as the number of women in part-time work increases, the level of decision-making involvement decreases, which increases the number of absentees. As absenteeism increases, so does understaffing, which leads to more turnover and more part-time work.

Childbearing/rearing also keeps part-time work high. In addition to this, understaffing leads to higher fatigue and high rates of absenteeism, creating another reinforcing loop (Fatigue Reinforcing Loop). These two reinforcing loops are kept from continually increasing the absenteeism rate by the Hiring Balancing Loop. As absenteeism increases, the more people are hired to replace them, which reduces understaffing. There is a hiring delay however, which keeps hiring from eliminating understaffing.

Although the double burden theory was not supported in early model iterations in this study, the final model casts two other theories for the high rate of female absenteeism in a new light. The most important outcome of this study is the following:

> *Choice of profession and differing disease risks are two separate theories for the higher rate of female absenteeism. The outcome of this model indicates that these are two parts of a more complicated story. Choice of profession dictated by strict gender roles in the*

labor market leads to the high representation of women in care work. This is reinforced by the need for more part-time employees in care work because of understaffing, which women are more likely to be. The weakened position women have in the labor market carries over into the work place with this high propensity to work part-time, leading to loss of control in their working life because of low involvement in decision-making. Both the fatigue from understaffing and loss of control leads to illness; how it manifests in the individual is proportional to the overall sick rate for each diagnosis category.

(Palmer, 2017b; p.10)

This is not however a definitive conclusion. As mentioned, this is a first-generation model, which was partially exploratory, meant to test mathematically the existing theories of female absenteeism rates. Many assumptions need to be addressed in further model iterations, in addition to the other model limitations.
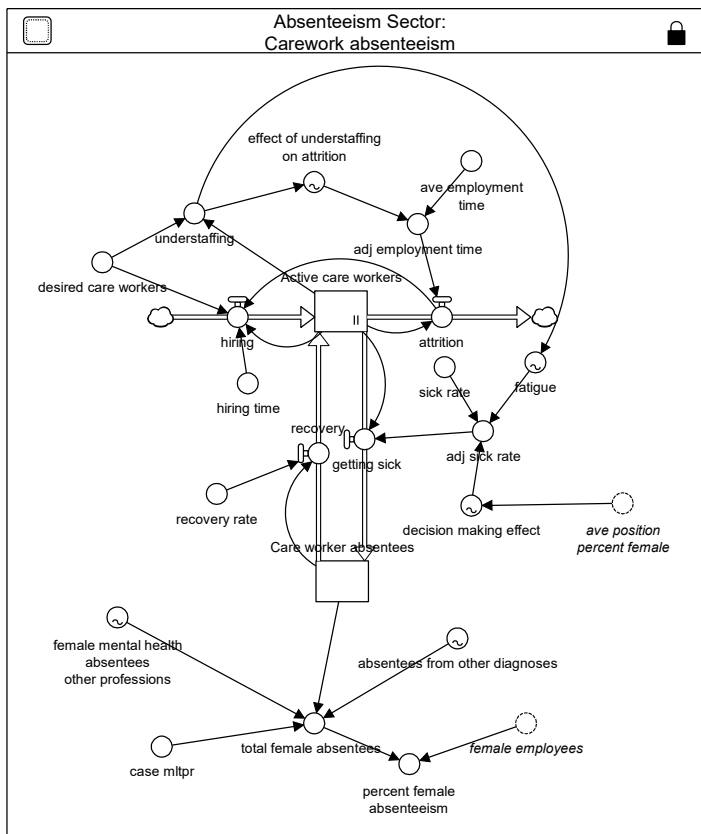
Figure 18: SFD of the absenteeism sector of the model
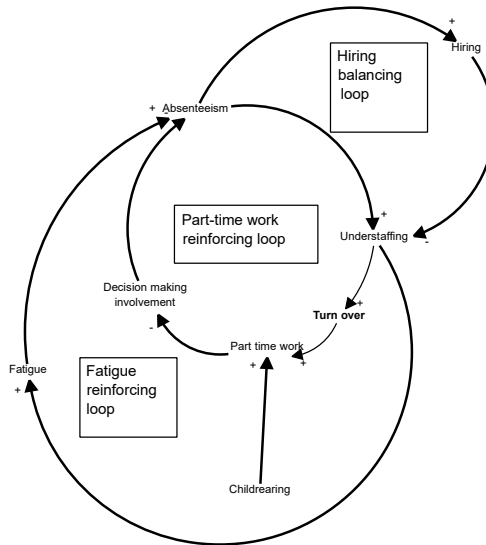
Figure 19: CLD of the absenteeism system structure showing interaction of three feedback loops

Besides the methodological limitations that were discussed in section 3.3, there are also specific model limitations in this study[3]. Concerning the limiting nature of the model boundaries, this study does not address the gender gap in the absenteeism rates between men and women, but instead investigates how women experience such a high level of absenteeism in Norway using care work as a case study. This study needs to be built upon by investigating how men achieve their level of absenteeism in addition to expanding the profession category beyond care work. Another important limitation of this study is that the model's focus on care work and drawing conclusions concerning gender. The model assumes that all care workers are women when in reality it is 86% (SSB, 2010b). In terms of future model development, with the aging population, the number of care workers is likely to increase. This has the potential to increase absenteeism costs to the state and

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[3] It should be noted that this model was partially validated by receiving feedback from welfare state experts. This includes: Stein Kuhnle (University of Bergen), by presenting the model to the Welfare State Research Center at the University of Southern Denmark, and Carina Schmitt (University of Bremen) at NordWel 2016.

threaten the sustainability of the Norwegian welfare state as a whole because of the already high cost of the absenteeism system.

5.0 Contribution and Conclusion

The development of this PhD project did not take a linear path. There were many "let's start again" moments in the model design phase, and there were many research paths that led to dead ends in the pursuit of addressing the research questions. In the end, however, four academic articles were produced, and along with this PhD summary (Part I), these addressed the research questions of this PhD project.

Part I of this PhD dissertation provided an introduction to the project, the theoretical foundation and ethical concerns, the methodology and the results of the project. Although this project was partly exploratory (where ethics became an important part), the results showing the outcome of the analysis is the core of this project. Section 4.0, along with the academic articles 2 and 3, were devoted to addressing the first research question: *How does gender pose systemic challenges to the Norwegian welfare state?* Although the Norwegian pension and absenteeism systems were a decided focus early in this project, gender was not initially the intended focus for the demographic challenges aspect of this PhD project. It is easy to have mental models of how systems operate, which are often influenced by the media. Although models are not free of bias, the early model iterations in this project provided a clearer picture of how welfare systems operate, and where dynamic modeling divorced mental models from public perceptions about welfare state systems. This is also a benefit that addresses the second research question.

Sections 2.2 and 2.3 of Part I, along with academic articles 1 and 4, set out to address the second research question: *How and to what benefit can systems engineering methods be used in the analysis of systemic challenges in social systems?* However, all four articles are relevant. The "how" part of this question is what was raised in the ethical discussions. Dynamic modeling can be applied to any social system, but there are ethical issues in doing so. Article 1 provides ethical questions that modelers should ask themselves in the model building process to address ethical concerns. Article 4 shows how to represent

gender in dynamic modeling, and highlights ethical issues that modelers should be aware. The "benefit" part of this research question is highlighted in the articles at the core of the analysis: articles 2 and 3; specifically, the identification of structural feedback mechanisms. Article 2 contradicts findings in recent research concerning pension and gender, which could only have been identified through dynamic modeling. Article 3 fails to show support for an established theory of the high rate of female absenteeism, while bringing together existing theories to show that they are explaining different sides of the same story. Neither of these findings could have been accomplished without dynamic modeling. Before this PhD project, only one system dynamics model had been used in welfare state research, a master thesis on the Dutch welfare system (Logtens, 2011). It is intended this dissertation will foster the use of not only dynamic modeling in the social sciences but also other systems engineering tools and methods.

Much of the behavior that the models in this project reproduced supported already well-documented arguments in social science literature. The unique insight to these systems gained from this PhD project was the identification of feedback loops operating in the systems' structure. This insight is the direct result of using dynamic modeling. This is important for a very specific reason: any social policy that is developed and implemented must address structural mechanisms (such as feedback loops) to achieve the desired behavior in society. Using dynamic modeling and other systems engineering methods to aid social policy analysis and development facilitates policy development by identifying structural mechanisms in social systems. Systems engineering methods have much to offer the social sciences, but the social sciences have much to offer in return. As an offshoot of this PhD project, research is now being conducted concerning how system engineering processes are embedded in sociological systems.

Many disciplines have a systems approach, and very often different disciplines use different words to explain the same system concepts. "Research silos" are common, even within the same university; yet innovation can sometimes be waiting to brew just by opening the door to colleagues of a different background. There is such a strong focus on

inter-/trans-/multi-disciplinary research, but very often, this gets very little traction on the ground. This PhD project shows that systems engineering and the social sciences have a lot to gain through cooperation.

The models presented in this thesis are in a constant state of development. As mentioned, models are never finished. Although the future research for the individual Norwegian welfare state system models investigated as part of this PhD project is presented at the end of sections 4.4 and 4.5, the larger PhD project laid the groundwork for a research project concerning myths and realities of welfare states. As discussed throughout Part I of this dissertation, many initial model iterations investigated various perceived demographic challenges to the Norwegian welfare state. Public perception towards various demographic groups varies over time, which is influenced by various forms of media. Comparing the level of positive and negative sentiment towards different demographic groups in media, especially immigrants, in relation to the actual net economic benefit of different demographic groups to the welfare state, is the point of departure for a project directly influenced by the results of this PhD project. Separating fact from fiction, especially in this era of "fake news" and "alternative facts," has never been more important for the development of social policy, not just in Norway, but the rest of Europe and the world.

6.0 Works Cited

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Part II: The Academic Articles

Part II of this PhD dissertation includes the four academic articles that were produced as part of this PhD project. Each article has either been published, is in press or is currently in review. Three of the articles are written independently, and one is written with a co-author (co-author declaration submitted).

1) Palmer, E. (2017). Beyond Proximity: Consequentialist Ethics and System Dynamics. *Nordic Journal of Applied Ethics*. 1: 89-105. DOI: 10.5324/eip.v11i1.1978

2) Palmer, E. (2017). Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System. *Social Sciences*. 6(1): 22. DOI: 10.3390/socsci6010022

3) Palmer, E. (2017). The heavy cost of care: Systemic challenges in Norwegian work absenteeism. In review, *Policy and Politics*.

4) Palmer, E. and Wilson, B. (2017). Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems. *Journal of Science and Engineering Ethics*, In press. DOI: 10.1007/s11948-017-9923-1

Article 1: Palmer, E. (2017). Beyond Proximity: Consequentialist Ethics and System Dynamics. *Nordic Journal of Applied Ethics*. 1: 89-105. DOI: 10.5324/eip.v11i1.1978

Beyond Proximity: Consequentialist Ethics and System Dynamics

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Abstract

Consequentialism is a moral philosophy that maintains that the moral worth of an action is determined by the consequence it has to the welfare of a society. Consequences of model design are a part of the model lifecycle that is often neglected. This discussion investigates this issue using system dynamics modeling. As a system dynamics model is a product of the modeler's decision-making in design, the modeler should consider the life cycle consequences of using the model. In this light, the consequences of the policy developed from system dynamics models are what determines the moral value of a model (ethical/unethical) in a consequentialist perspective. This concept is explored by discussing model uncertainty in an engineering perspective. In this perspective, the ethical considerations shift from the behavior of the modeler (away from validation) to the model itself and the model's inherent uncertainty. Given that the ethical considerations are taken away from the modeler and placed on what the model does, the ethical boundaries are extended beyond the proximity of the model. This discussion renews the ethics conversation in system dynamics by considering this shift in philosophical perspective and investigates the application of consequentialist moral philosophy to the modeling process and in communication with decision-makers. A model of social assistance in Norway in light of immigration pressure illustrates possibilities for addressing these ethical concerns. This paper argues for an ethical framework, or at the very least, an ethical conversation within the field of system dynamics.

Introduction

System dynamics is a field that applies systems modeling to a variety of contexts (environmental, organizational, societal, etc.) in order to develop policy to address problematic behavior in the system. There is a dearth of system dynamics literature that explicitly addresses ethics outside of validation. However, there are important ethical considerations that fall outside the domain of validation. The use of system dynamics modeling in public policy is an area in which the topic of ethics should be renewed. In public policy decision-making, system dynamics modeling will have an effect on society. The modeler must consider the effect their decisions about subjective elements and relationships will have for those affected by the policy. The ethical concerns go beyond the normative considerations of model and policy design (the purpose of the model and policy) to the assumed causality that is necessary when making decisions in system dynamics modeling. How does one know when a model represents reality accurately enough to build policy? What happens to society if policy is built and implemented from a model that produces the correct behavior, but in the wrong way? This discussion explores these ethical concerns.

What is system dynamics?

System dynamics is a relatively new discipline, which began to develop in the mid-20th century with the publication of Industrial Dynamics by Jay Forrester (Forrester, 1961). The term "system dynamics" is used when analyzing problems as a system to understand the feedback within the system in order to develop solutions. The methodology was originally developed at MIT by a group dedicated to this academic pursuit (Meadows, 2008). System dynamics is an iterative, interdisciplinary process, which views problems holistically. Essentially, using system dynamics involves identifying elements, subsystems, and the systems' context, boundaries and properties. System dynamics is both systematic and systemic in that there are systematic processes that can design complex systems, but it is rooted in systemic thinking in order to recognize and solve complex problems by seeing the whole instead of only the parts (Haskins, 2008).

System dynamics can be applied to any problem to investigate how elements operate and interact in a system. System dynamics modeling is based on ordinary differential equations. The elements in a system dynamics model consist of stocks, flows and variables (in a "stock and flow diagram"). Stocks are an accumulation of flows over time, and flows represent addition and subtraction to the stock over time. Variables in stock and flow models are elements that affect the inflows and outflows. The variables are linked to other variables and flows through instantaneous causal links. The accumulated causal behavior in the stock is affected by the flows, which are in turn affected by the variables.

The structure of a system leads to the behavior over time (accumulated in stocks), and the goal is to research all the elements and relationships in a system and put it together in order to reproduce the reference mode behavior (actual system behavior). In system dynamics models, there are "endogenous" and "exogenous" elements. Endogenous elements are incorporated in the model structure in relation to other structure elements. Exogenous elements are variables that contain data that is directly imported into the model structure.

Ethics in system dynamics

Ethical issues in system dynamics are complicated by the philosophical foundation of the field. It is most often understood in the context of the philosophy of science, whereby system dynamics scientifically analyzes a problem through model development. Ethical questions in system dynamics are concerned with the behavior of the modeler in the context of validation. Are the actions of the modeler ethically right or wrong when making subjective decisions about the model? Consider however that it is not just the behavior of the modeler that is in question, but the model itself. A developing argument in the field concerns whether system dynamics would be better considered as an engineering endeavor, meaning that system dynamics models are engineered artifacts. This artifact is then used to design another artifact (the policy). The result of using this artifact (the implemented policy) causes the consequences for society (good or bad). It is not only the model/policy purpose that is ethically in question, however, but the natural uncertainty in system dynamics models because they are built on assumed causality. Given that system dynamics falls within the realm of engineering, the ethical discussion must consider the

consequences of design because of this uncertainty. The point of departure for this discussion is the consequentialist ethical considerations in system dynamics modeling in an engineering context. However, placing system dynamics in an engineering context is debatable within the field of system dynamics. Because this placement is an important cornerstone of this ethical discussion, system dynamics as an engineering endeavor is further explored in the section "System dynamics modeling in an engineering context."

Renewing the ethical discussion

There is no standard procedure in system dynamics for making ethical decisions when setting model boundaries and making data and parameter assumptions or a stated requirement that this must be transparent in communicating with decision-makers. The purpose of this paper is to renew and further develop the ethics conversation within system dynamics concerning both the modeling process and in communicating with decision-makers. Developing a basic ethical foundation in system dynamics is necessary for systematically dealing with ethical considerations in modeling, which in turn further enhances the credibility of the field.

The focus of this discussion is the shift in philosophical perspective for system dynamics (from science to engineering) and how this affects the ethical considerations in modeling. However, there is no general understanding within system dynamics that ethics needs to be discussed or even that uncertainty in modeling exists. The first section of this paper discusses uncertainty and transparency issues in modeling as grounds for having an ethical conversation in system dynamics. Next, the discussion explores how system dynamics' philosophical foundation frames the ethical discussion, which calls for ethical questions to be thought of in a new context-consequentialism. This is then illustrated with a model of social assistance in Norway in light of immigration pressure, ending with a discussion of topics for further research.

Uncertainty and transparency

The nature of system dynamics modeling breeds uncertainty; whether this uncertainty is made transparent is decided by the modeler, which is an issue that deserves attention. Transparency depends on the ethical behavior of the modeler, though it is the model itself that is ethically charged. There are many reasons why a modeler would not want to communicate the uncertainty of their model. The audience is funding the project; the modeler does not want to show weakness; the modeler has an ulterior agenda. The issue under discussion is not how this uncertainty is evaluated (see Walker, Harremoës, Rotmans, van der Sluijs, van Asselt, Janssen, and Krayer von Krauss (2003) for a framework in which to address this), but why modelers must consider uncertainty beyond the validation of their models.

Assumed causality and validation

The issue of causality is blurry in system dynamics, especially when communicating with those outside of system dynamics. System dynamics models represent "operational behavior"; modelers observe relationships in a system and make assumptions about instantaneous causal relationships, which goes against scientific principles of causality. Using the word "causality" creates communication problems with decision-makers as well because the scientific meaning is often assumed. The system dynamics causality issue is both semantic and philosophical. What system dynamicists mean by "causal" is different than the scientific definition (a natural law). System dynamics models show how variables operate in relation to flows. Models are one possible structural explanation and not a causal declaration, meaning the models show the "how" (and only one possible how) and not the "why." This does not mean that system dynamics methods should be practiced any differently than what is now current practice; it does, however, mean that we need to think about the methods differently, and this is the philosophical part of the issue.

Models, as a set of aggregated causal assumptions ("observed operational relationships") is why (regardless of validation) they must be uncertain-causality is assumed. We speak of "robustness" when evaluating the uncertainty in system dynamics models. To make a model as robust as

possible, modelers validate the model. There are various levels for validating models from the technical validation to the justification of variables. It is assumed that modelers will make sure that their models are as robust as possible (least amount of uncertainty as possible) through validation, and decision-makers assume that the modeler has done this. Because of this, the model's robustness and issues surrounding this are therefore not necessarily communicated to those making decisions based on the outcome of the model.

There are no ethical guidelines for system dynamics, which begs the question: how can the field of system dynamics trust practitioners to do the right thing? How is the decision-maker to understand that the causality is assumed? What level of transparency is shown by practitioners in reality? How is the field of system dynamics to know that everyone is practicing the same "brand" of system dynamics (acting as ethically as possible)? As explained by Forrester (2007), many people building models are not skilled system dynamics practitioners. Because system dynamics software is so easily learned, and many people outside of the system dynamics community use system dynamics modeling, would it not strengthen the field to have ethical guidelines that system dynamicists must follow in order to call themselves system dynamicists?

Many in the field may think that ethical considerations are not an issue. "Show me a model that has had a negative effect on society." "Professional system dynamics practitioners already follow validation procedures." These are two criticisms I have heard about even discussing ethical issues in system dynamics. However, is validation enough to remove uncertainty? Valid models still assume causality. Does the nature of system dynamics, with its assumed causal relationships, require further ethical consideration concerning the societal impact of the model? No matter how valid or robust a model is, the model has aggregated causal assumptions. This does not mean that the model is wrong or not useful; it does however mean that system dynamicists must consider the model in a different light and ask different ethical questions.

Ethical concerns in modeling are also important to consider because of a lack of policy design and implementation focus in system dynamics modeling. Explanatory models may be uncertain, but this is not the main problem for these models in terms of potential consequences for society because of the frequent absence of developed policy model structure built to change behavior, as explained in the following section.

Policy design and implementation

Wheat (2010) explains that system dynamics models are very often not concerned with policy implementation, merely policy design as parameter testing. At best, adjusting parameters as policy design means poor feasibility and possible policy implementation failure. At worst, it means negative consequences for society. However, it is not just building policy structure beyond parameter testing that must be done to avoid either scenario, understanding inherent uncertainty and communicating this must be considered as well.

Uncertainty is outside of the ethical realm of the policy model's purpose. "Model purpose" holds normative ethical considerations that do not include uncertainty. The focus of this discussion is the uncertainty in every system dynamics model, which has the possibility of negative consequences for society regardless of the normative implications of the policy purpose. The ethical issue at hand concerns the consequences, or the unintended effects of an implemented policy, produced from a model where subjective elements and relationships were established by the modeler as causal when in reality they are not.

System dynamics modeling produces just one possible design to explain behavior, and policy models designed from the explanatory models will only be successfully implemented if the explanatory model's assumptions are correct (and if implementation issues are fully considered). Because there is no way to remove the uncertainty (and nor does it need to be in order to be useful), this must be made transparent to those that make decisions about policy implementation.

System dynamics modeling in an engineering context

Within system dynamics, models are considered causal mathematical models that represent a theory of an actual system. Each causal claim in the model must be supported, and if critics disagree with one equation, then the entire model is disregarded (Barlas, 1990). Therefore from the perspective of the philosophy of science, seeking justification for causal claims in a system dynamics model can be difficult. How does one ever truly know when a relationship is causal, and how far does one have to go to support the causal claim? The truth is we, as modelers,

cannot know if we have represented causal relationships in our models. We assume causality in our models, which gives rise to one of many designs of the structure that produces the behavior.

Science aims to understand ("to know") a system, whereas engineering is steeped not in the true or falsehood of a system, but in how it operates ("the how"); the *knowledge that* versus the *knowledge how* (Schmidt, 2012). System dynamics models are designed to understand *how* a system works, not to understand *that* (why) is works. Olaya (2014) explains how science is very different from engineering (although it contributes to science-i.e. contributes to the scientific method, but does not use the scientific method itself), and that system dynamics is in fact an engineering enterprise. System dynamics was born out of engineering and applied to management science. However, system dynamics has deviated from its engineering heritage by seeking to justify itself as science (i.e. uses the scientific method). If system dynamics is an engineering endeavor, the model does not intend to claim causality. The model is used to understand how the system works (one way among many structural designs), making it useful to decision-makers as a tool for gaining insight into complex systems.

Because engineering and system dynamics are both concerned with design, system dynamics should concern itself with the operations of the system not the causal relationships. Olaya (2012) states:

> *Operational thinking opposes to mere theorizing activities based on data-analysis, which happens to be the fashionable way (and the "scientific" style in many cases) to study social systems. Instead of developing knowledge by observation to generate general statements through induction, the production of knowledge through operational modeling does not rest on data in order to bring understanding or explanation. Rather, it relies on the generation of dynamic hypotheses that explain the performance of a system in function of its structure that is generated by its operations. Such an approach recognizes human systems as systems that change through time according to free actions of decision makers* (2).

System dynamicists design models that represent social systems in order to develop policy to improve a system. The models are "intangible artifacts" designed by the modeler, and this artifact is then used to design other artifacts. Models are used to design policy; policy includes an entire array of artifacts: regulations, plans, organizational structure, etc. Trademarks of

engineering include first and foremost design and operations (knowledge how), but also: using heuristics, making decisions, being creative, using trial and error methodology, having purpose versus being impartial and being particular rather than universal (Goldman, 2004). All of these are also trademarks of system dynamics. Because of this, the link between system dynamics and engineering is easily seen (Olaya, 2014). This paper does not attempt a full-scale examination of whether system dynamics is engineering or science. However, if we think of system dynamics as engineering, how does this impact validation and ethics?

Science is very concerned with ethics regarding the behavior of the scientist and the validation of their methods. Validation is irrelevant in engineering. An engineered artifact is not true or false. It either technically works or it does not. In engineering, ethical considerations fall outside of validation and the behavior of the practitioner. The purpose of the artifact and uncertainty (robustness) in design are the ethical concerns in engineering. Why was the artifact designed, and how will this affect society (the purpose)? Because the artifact does not claim knowledge of why cause and effect occurs, what is the risk of consequences to society from the uncertainty (robustness) in design? As mentioned earlier, the normative implications of model purpose are not under examination in this paper, as this concerns the nature of specific case studies. In the more general examination of moral philosophy and system dynamics, given that the field's philosophical foundation is engineering, system dynamicists must consider the consequences of the uncertainty in their models on society.

Consequentialism and system dynamics modelling

Given that system dynamics is an engineering enterprise, what ethical issues must be considered? And why does uncertainty take center stage?

In an engineering context, the ethical dilemmas of the modeling process concern the consequences that arise because of model design, which only surface after the recommended policies of the model have been implemented in society. System dynamics modeling of social systems is no easy task. There is uncertainty in many variables, making this a difficult ethical undertaking.

There are various moral philosophies that could be taken when evaluating decision-making in modeling. This paper does not attempt to explain these different philosophies and how they can be used in system dynamics. The intent of this paper is to illustrate the societal consequences due to the nature of system dynamics modeling, i.e. a consequentialist approach. Pruyt and Kwakkel (2007) provide a good overview of different moral philosophy approaches in system dynamics.

The foundation for ethical exploration in this discussion is consequentialism. The discussion does not intend to provide a comprehensive explanation of consequentialism and it merits and criticisms. Consequentialism serves in this discussion as a basis for understanding the ethical issues in system dynamics modeling, and a brief overview of the concept of consequentialism is provided.

Consequentialism is a moral philosophy where, in its simplest and purist from, the best decision in any given situation is the one that provides the greatest benefit overall, as judged from an objective standpoint (Scheffler, 1988). In this way, the moral value of a decision is based on the net benefit it has for those affected by the decision. Many different moral theories are considered consequentialist, which are more or less born out of "classic utilitarianism" (Sinnott-Armstrong, 2003). Utilitarianism holds that the moral worth of an action is determined by maximizing the good and minimizing the bad. However, what is considered good? In a hedonistic view, the moral worth of an action is determined by the amount of pleasure it produces and the amount of pain it avoids. This is rather simplistic and leads to situations that are morally irresolvable (Sinnott-Armstrong, 1988). In a pluralistic view of consequentialism (or rather "pluralistic utilitarianism,") many goals can be used to assess the moral value of a decision, which helps to alleviate morally irresolvable dilemmas in "hedonistic utilitarianism."

There is also the issue of what is considered a "consequence." Classic utilitarianism requires all consequences of a decision to be known before a decision is made. This is impossible, and various theories of consequentialism have fashioned ways to reconcile this problem. Of importance to this discussion of uncertainty and modeling however is the distinction between "unwanted" versus "unintended" consequences (Koehn, 2010). Unwanted consequences are foreseen consequences, and the decision-maker chooses to avoid them (morally good) or not (morally bad). Unintended consequences, however, are unforeseen consequences that the

decision-maker cannot control. In the case of system dynamics modeling, unintended consequences are the result of uncertainty in the model.

Models cannot be 100% robust, with all uncertainty removed, because the nature of system dynamics requires assumed causality. Therefore all models have the potential for harm (i.e. negative unintended consequences due to uncertainty). This is why communicating uncertainty to decision-makers is essential. Practitioners can only give the best of what system dynamics can offer (unbiased, well-researched models); decision-makers have the moral responsibility of policy implementation, and they must understand the risk of implementing policy built and tested on models that have inherent uncertainty.

Validation of causal claims is a matter of professional ethics found in the sciences, which concerns the behavior of the scientist. The outcome of the causal assumptions in system design and what this means for citizens and society is a matter of consequentialist ethics in engineering. In an engineering perspective, system dynamics models do not need to be validated because they do not attempt to explain causality. Using the same perspective however, system dynamics models must be designed with the least amount of uncertainty to avoid negative downstream societal consequences. This is where the ethical distinction is made between the modeler and the model. In engineering, the modeler's behavior is no longer called into question concerning methods, but instead the model itself is called into question for the potential impact it could have on society.

The distinction between the modeler versus the model concerning where the ethical issues lie is less of a problem in engineering disciplines compared with the field of system dynamics. In engineering, the relationship between engineering models and moral philosophy is represented at least to some extent in the literature (e.g. Herkert, 2000; Jenkins, 2015; Katz, 2011). System dynamics is however considered a field of scientific study, and as such finds itself lacking in its exploration of ethics in an engineering context. It may not seem immediately apparent why this ethical discussion should focus on uncertainty in models and the consequences it has for society. Uncertainty in modeling is nothing new, and a system dynamics model can suffer from a host of ethical concerns in addition to uncertainty; such as individual bias (which can never be fully avoided), the issue of sponsorship of the modeling project and a lack of transparency with

decision-makers. However, these are ethical concerns related to the behavior of the scientist (modeler), not the artefact (model).

As mentioned, system dynamics has a dearth of ethical literature, and ethical concerns related to the behavior of the scientist should also be explored. However, system dynamicists must also go beyond their own ethical behavior and consider the model an "ethically charged artifact" because of the potential harm this may have for society, which is why consequentialism is relevant in this discussion. Even though a modeler may be acting as ethically as humanly possible (unbiased and completely transparent in an objective environment), once the model leaves their hands and is used by decision-makers, the model is a tool that can produce harm. It should also be noted that it is very easy for system dynamicists to fall into the trap of believing their model is 100% robust with no uncertainty once the model is validated. Uncertainty is always present, and the model may have unintended consequences for society once it becomes independent of the modeler.

Placing the focus away from the modeler and onto the model requires the modeler to expand their ethical awareness beyond the modeling process. In engineering, this is termed the "product life cycle." So too should system dynamicists consider their model's life cycle.

Beyond proximity

As the model is a product of the modeler's decision-making in design, the modeler should consider the "life cycle consequences" of using the model. In this light, the consequences of the policy (given the model's level of uncertainty on which it is built) is what determines the moral value (ethical/unethical) of the model in a consequentialist perspective. Philosophy of engineering ethical considerations relate to the constructed artifact and the effect this has on society. When engineering social systems, the model and the policy are the artifacts. The consequences of the model design serves as the modeler's ethical guide-What are the causal assumptions? What other design options are possible? What are the risks if the assumptions are wrong (i.e. will it be used to develop policy)? Will the policy developed from it create harm for society if there are indeed incorrect assumptions? It is not always possible to know these answers, but the modeler should ask them and believe that the model is as unbiased as possible

with the greatest amount of input from all relevant sources. This may be taken as a given for professional system dynamics practitioners. However, as mentioned above, not all people using system dynamics are professional practitioners.

Given that the ethical considerations are taken away from the model itself and placed on what the model does, the "ethical boundaries" are extended beyond the proximity of the model.

The concept of ethical boundaries is very well expressed by Bowen (2009):

> *It may be proposed that the articulation of an aspirational engineering ethic can be facilitated by extending the I-You vocabulary beyond proximity, to include a relationship with people who may be distant in place and/or distant in time. Thus, the task of the engineer may be viewed as the development of technical knowledge and technical activities, the world of I-It, in response to an I-You concern for those benefiting from the technical advance. The people affected by the activities may be located far from the place where the engineering work is conceived and planned. In some cases, they may be far from the place where the engineering artefacts are constructed or even far from the place where the completed, engineered artefacts are located* (140).

In avoiding downstream negative consequences, and hence attempting to gain moral value, it all comes back to the issue of communication. Decision-makers claim the ethical role in policy implementation. They must know what the causal assumptions are in both the explanatory and policy models. When justification in design is difficult, the modeler may be less inclined to make this known to the client or to their peers. Making these justification break-offs explicit in the communication of the model and a part of the ethical considerations in design, however, is essential. In the words of Ulrich (1987): "As long as he does not learn to make transparent to himself and to others the justification break-offs flowing into his designs, the applied scientist cannot claim to deal critically with the normative content of these designs" (277).
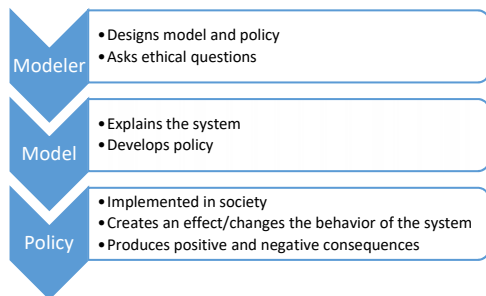
Figure 1: The modeler's behavior leading to artifacts and the effect of these artifacts on society.

Figure 1 illustrates the expansion of the "ethical horizon" and the distancing of ethics from the modeler to the model and policy. The artifacts (model and policy) themselves are neutral in the philosophy of science. Scientific artifacts (theories) are either right or wrong, not ethically good or bad. Ethics in this sense comes back to the behavior of the scientist, not the theory itself. This is the opposite in engineering, where the artifacts themselves are ethically charged.

Asking the ethical questions: System dynamics and the Norwegian welfare state

Expanding the boundaries of what is under ethical consideration is easy for a philosophical discussion, but what would this look like in practice? The following list is an example of possible ethical questions that consider the consequences of model design.

In designing and building the model, modelers must ask:	How well supported are the causal assumptions? What other structural options are there to produce the behavior?
	Have I used all possible input to the model to make it as objective as possible?
	Have I introduced bias into the model? How accurate a representation of society is the model? What is the level of uncertainty (robustness)?
Pushing beyond proximity (beyond the initial artifacts) requires us as modelers to ask questions such as:	What will the policy do to society if the causal assumptions in the structure are wrong? What is the level of risk that the model is inaccurate?
	Have I communicated the uncertainty to decision-makers?
	Does the policy produce the good for which it was intended? Are there unintended negative side effects?
	Do the side effects of implemented policy indicate that the model design is inaccurate?

Armed with these questions, let us take a closer look at how this would be applied in a project about the Norwegian welfare state.

Norwegian social assistance and immigration

A model of Norwegian social assistance in light of immigration patterns illustrates the application of these questions. As in all modeling projects, this study requires making decisions about subjective elements and relationships in the system and subsystems.

Consider the following simple model of the number of people on social assistance (unemployment support) in Norway with a focus on immigration (figure 2).
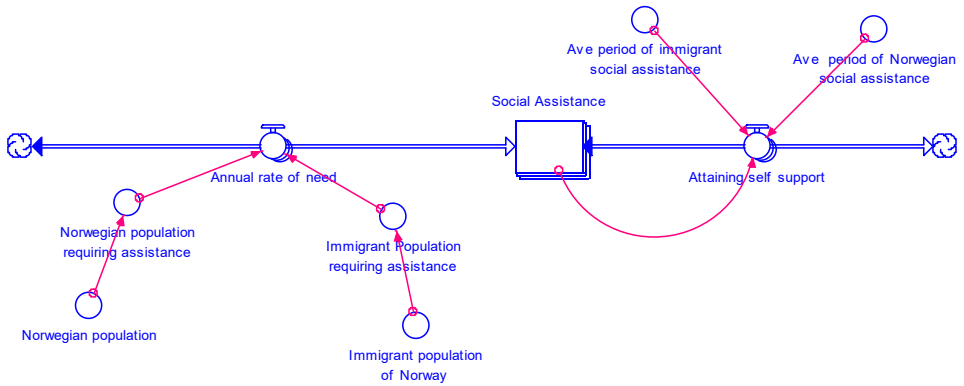
Figure 2: Simple stock and flow representation of the cost of social assistance in Norway, split between Norwegian and immigrant populations.

Building a simple model, and aggregating many variables, makes subjective decisions not just implicit, but invisible. For example, decision-making concerning the variable "Immigrant population" makes the assumption that all immigrants are homogeneous. Immigrants can be refugees, labor migrants, students or migrating for family reunification purposes.
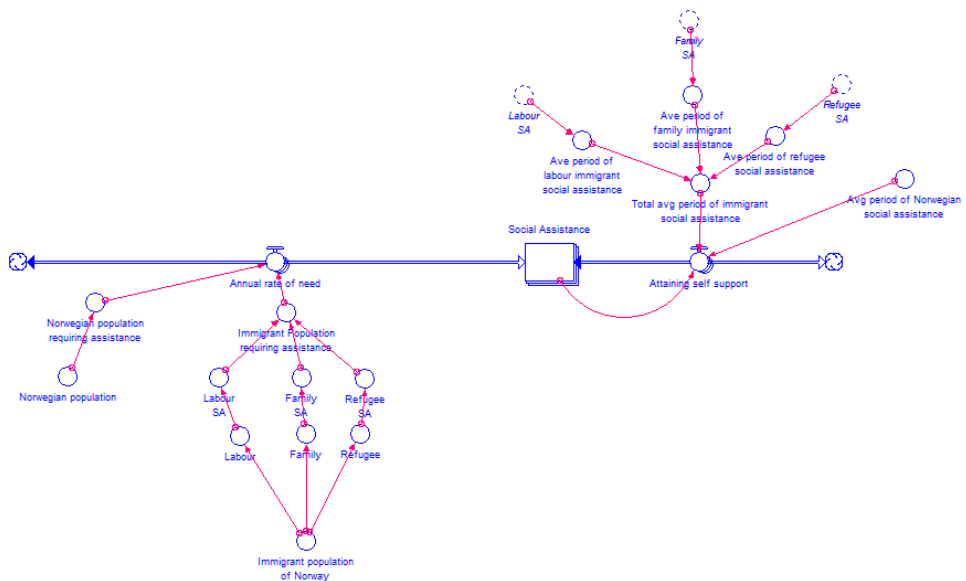
Figure 3: Disaggregation of the variable "Immigrant fraction requiring assistance"

In the above model (figure 3), the immigrant population is disaggregated. Student immigrants are taken out because they are usually not eligible for social assistance in Norway (they must prove they have sufficient funding before they are granted a visa.) Refugee regulations explain that refugees are completely supported by social assistance when they arrive, and there is no maximum time for receiving support; therefore they are assumed to have a high dependence on social assistance. It is assumed that those with family reunification visas have a low social assistance dependence because in order to get a visa they must show they have economic support from the family member in Norway. Labor immigrants are also assumed to have low social assistance dependence because the labor immigrants have work contracts when they arrive in Norway. All of these assumptions are supported by Norwegian immigration regulation (i.e. the assumptions are justified).

For the purposes of this discussion, let us assume that all other variables besides labor, family and refugees, accurately reflect reality, and the model behavior replicates the system behavior

even with the assumptions made for labor, family and refugees. Let us also assume that this model resonates with the research team, and technical validation protocol has been fulfilled.

The desired state of the system is a lower amount of people on social assistance, so a policy is introduced to the model that speeds up the process of getting refugees off social assistance through an enhanced assimilation program (assimilation support is already available for refugees in Norway-this policy strengthens it). Figure 4 shows this policy structure in red (the variable represents a larger policy structure.)
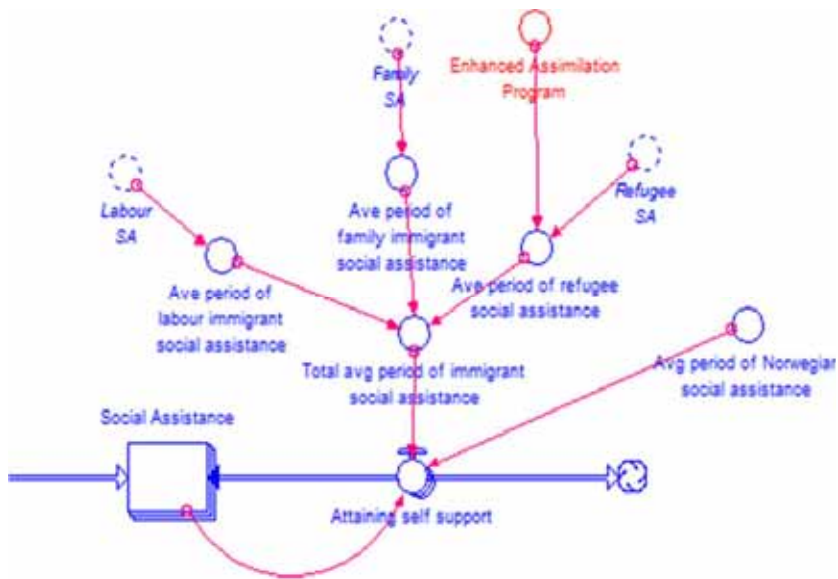
Figure 5: Cut-out of model showing the "enhanced assimilation program" policy

Let us assume that this policy has then been implemented in the Norwegian welfare system. However, the total number of people on social assistance has *increased* after implementation. The length of time that refugees are on social assistance has appeared to stay the same as indicated by unchanged unemployment rates among refugees, but for some reason the number of people needing social assistance has increased (controlled for population increase).

In this example, the artifact (the model) is designed by the modeler, which produces an artifact (the enhanced assimilation program) that may have produced negative consequences for society. There are a couple options for a next step. The modeler could return to the model and make more assumptions about the system in order to develop a new policy. This would change the original artifact. The modeler could change the policy structure to produce the desired effect, changing the product of the original artifact. However, using an ethical framework in the first design process could have improved the probability of avoiding the negative effect (see figure 5). Using the questions mentioned at the beginning of this section is a place to start.

- How well supported are the causal assumptions? What other structural options are there to produce the behavior?
  Labor and family populations were assumed to have low rates of social assistance, and refugees were assumed as having a high rate of social assistance. This is supported from immigration regulation in what is required for visa applications. What other academic disciplines would have data concerning this? What research is produced by sociology on rates of social assistance usage by immigrant type?
- Have I used all possible inputs to the model to make it as objective as possible?
  How I reached out to the refugee/labor/family immigrant populations to understand what their needs are? Is there a possibility for group model building to understand personal thresholds for seeking social assistance?
- Have I introduced bias into the model? How accurate a representation of society is the model? What is the level of uncertainty (robustness)?
  Are there cultural factors missing because the modeler is from a different culture than the immigrant populations? For example, is there a social stigma associated with seeking social assistance found in some cultures and not in others? Have all alternative explanations been researched? Is labor migrant social assistance higher perhaps because workers are coming on short term work contracts? Perhaps it is better financially to receive social assistance in Norway than to earn a normal wage in their home country. Could refugee social assistance drop substantially after an initially high period of public support?

- What will the policy do to society if the causal assumptions in the structure are wrong? What is the level of risk that the model is inaccurate?

  What is the possible risk of harm to the system by implementing the policy because of uncertainty in the model representing society? If the causal assumptions are incorrect, in addition to the cost to the state, how will refugees and social support agencies suffer through an enhanced assimilation program?

- Have I communicated the uncertainty to decision-makers?

  Do social support administration and funding agencies and refugee support agencies (i.e. the decision-makers) know that this model is only one of many structural designs that could lead to the system behavior? Even if the policy option of an enhanced assimilation model was the decision-maker's idea, they must be made to understand that it was tested on a structure built with assumed causality (i.e. a level of uncertainty, not completely robust).

- Does the policy produce the good for which it was intended? Are there unintended negative side effects?

  In this example, the answer to the first question is no. The policy did not reduce the number of people on social assistance. The amount of people on social assistance is rising; so the answer to the second question is yes, there are possible unintended side effects. The rising number of people on social assistance could however be from another reason altogether.

- Do the side effects of implemented policy indicate that the model design is inaccurate?

  This should always be explored as a possibility. There is no definitive way of knowing whether the model perfectly represents reality.

The answers to these questions and the ethical concerns raised seem obvious because this is a simple model built for explanatory purposes. Imagine, however, a large complex model or practitioners that have only just begun using system dynamics methods or students learning how to build system dynamics models. Would it not in these cases help to have an ethical foundation in system dynamics?

Considering ethical issues must become part of the modeling process. These procedural (modeling) questions lead to the ethical questions. Figure 5 illustrates the relationships between asking ethical questions and the modeling process.
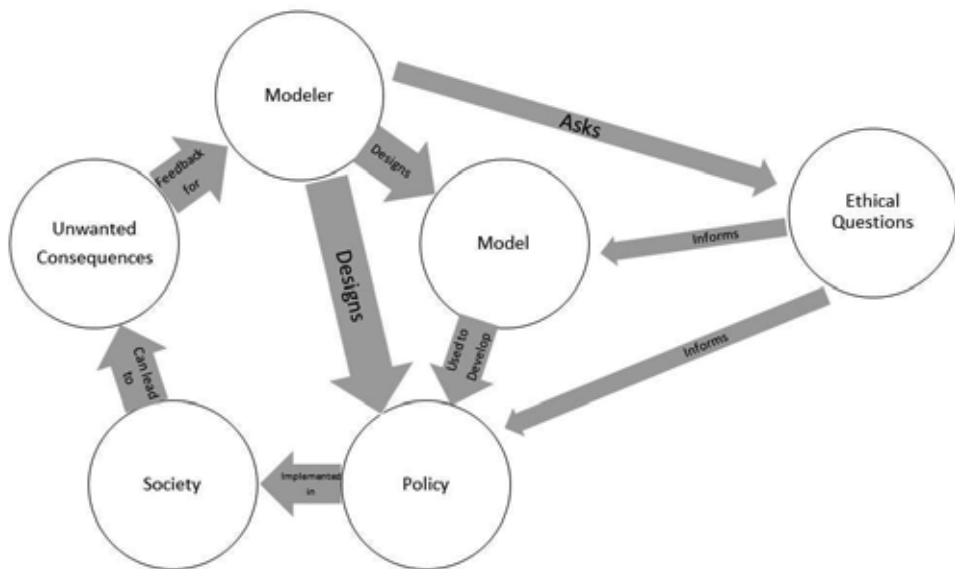

Figure 5: Relationships between the modeling process and ethical questions

Stepping Forward-The Ethical Conversation in System Dynamics

This discussion argues for an ethical framework, or at the very least, an ethical conversation within the field of system dynamics. The road to an ethical framework in system dynamics must be developed over time through discussions in moral theory and practical application. It is with hope that over time a framework will develop into established norms, where each practitioner knows what is ethically expected of them, and those new to system dynamics are expected to uphold a certain ethical standard. Because there are many different approaches to system dynamics methodology and many people are practicing system dynamics that are not in the

system dynamics community, a strategy for cohesion could be through ethical standards of practice.

Further Research

This discussion has centered on uncertainty and how to handle it from an ethical point of view. However, it should be noted that, while many system dynamics practitioners validate their models to reduce uncertainty, there are methods in system dynamics that embrace uncertainty and use it as grounds for exploration (i.e. Exploratory System Dynamics Modelling and Analysis (ESDMA)). Further system dynamics research in ethics could investigate different system dynamics methods and the implications they have for society. "Group model building" (the users of the model form an active part of building the model) is another system dynamics methodology that is worth investigating from an ethical perspective. It can be argued that those that build and then use their own models are "making their bed and lying in it," meaning that the consequences from the policy implementation resulting from the model design would be affecting the designers. This leaves the possibility for an ethical loop-hole whereby the system dynamicists could assign the group the ethical responsibility instead of themselves or to the model itself.

Conclusion

Engineering philosophy provides a unique perspective on ethics in system dynamics. Uncertainty in design has been addressed in system dynamics as something that must be reduced through validation. However, since structural design is variable (even if valid), modelers must ask ethical questions regarding the consequences of design uncertainty; and as a minimum, modelers must make the uncertainty transparent. The extension of ethical boundaries from the modeler to the model leads to tighter control over the societal impact of system dynamics models. It is no longer a question of whether a model is scientifically valid, but a question of whether the model has the potential for harm. Considering the arguments explored in this discussion, it is imperative that the field of system dynamics continues the discussion of ethics for the sake of the field's own credibility across disciplines.

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II

Structural Disadvantage: Evidence of Gender Disparities in the Norwegian Pension System

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Abstract: Norway is a world leader in gender equality according to sustainable development performance indicators. This study goes beyond these indicators to investigate systemic economic disadvantages for women, focusing specifically on the Norwegian pension system. System dynamics modeling is used to understand how gender disparity is built into social systems. A significant contributor to the gender inequality in pensions is the difference in lifetime working hours due to childbearing/rearing. There are childcare policies in place to equalize lifetime working hours between the genders; however, these policies require women to conform to the pension system structure and outsource their childcare. The system dynamics modeling illustrates how social investment strategy requires women to conform to a masculine pension system if they want equivalent financial security when they reach retirement.

1. Introduction

1.1. Norway, Gender, and Sustainable Development

Norway is considered a leader in gender equality and progressive in its commitment to sustainable development [1,2]. Social sustainability in particular is strongly supported with Norway's implementation of social investment strategy in its welfare state policies. Many dimensions of social inequality are eased by policies that focus on early childhood education for example, which is a major pillar of social investment strategy. With this focus on early childhood education and other social investment policies, gender equality is often ranked high compared to other countries around the world [3]. It may be surprising that a study should focus on gender issues in a country that appears to be doing well according to most sustainable development performance indicators [4,5]. The point of departure for this study is to go beyond current performance indicators and investigate gender inequality in a way that data and indicators cannot. It must be mentioned that even though Norway ranks among the highest in the world for gender equality, Norway does recognize that more work needs to be done [4]. This study highlights a place to start.

1.2. Gender Disparities in the Norwegian Pension System

Men receive on average higher pensions than women in Norway. There are three main forces at work that make this so: wage inequality, lower salaries in female dominated professions, and more women in part time work than men. As wage disparity converges over time and as women are encouraged to enter

male dominated professions (and vice versa), it can be too easily assumed that the difference in pension earnings will eventually disappear. This assumption simplifies how the pension system works operationally [6]. In addition to this, there are more elderly (67+) women than men in Norway, which increases the imperative to understand how this large demographic group experiences gender inequality systemically.

Within Norway, the pension system receives a lot of attention because of the aging population. The system is based on labor force participation, and when the rate of elderly population growth outpaces that of the working age population, funding problems are seen on the horizon. There are studies that have dynamically modeled the pension system in Norway, and these indicated economic sustainability given the changes in demography [7]. The social sustainability of the Norwegian pension system is another matter, and this is especially important for the pension system's largest group of beneficiaries: women [6]. Lower pensions for women lead to a higher degree of social isolation and poor housing and health [8]. This study, through the use of system dynamics modeling, analyzes the structure of the Norwegian pension system, specifically highlighting how pension payments are determined for men and women.

There are several categories of pensions in Norway. This study investigates the public "Old Age Pension" (Alderspensjon), where pension payments are based on pension points. The Old Age Pension structure requires the accrual of pension points over 40 years of working life to receive maximum pension. There is also a minimum pension safety net to avoid elderly abject poverty. Pension points are earned through how much income a person has earned in their lifetime. In this way, the time in which the income is earned does not matter. This is a major difference from pension schemes in other countries such as the UK, for example [9]. Women on average start their careers later due in large part to longer educations and childbearing/rearing [10]. The time that a person invests in their pension account corresponds to large differences in pension payments even if accumulated lifetime incomes are equal. Norway avoids this problem because of the pension point system. The only factor that matters is total accumulated income, not when it was earned. It should also be noted that Norwegian pensions have been reformed in recent years, with the new regulations encouraging people to remain in the labor force for a longer time (although this does not affect the historical behavior investigated in this study). This reform was needed to make the pension system economically sustainable with an increasing elderly population and a decreasing juvenile population [7].

A recent report through the Nordic Council of Ministers [11] has indicated that part time work during childbearing/rearing years has no significant effect on state pension payments for women in the Nordic countries. However accurate their economic forecasting may be, this conclusion does not address the core gender issues in Nordic pension systems. In order to identify and analyze these issues, this study investigates gender disparities in the Norwegian pension system from the point of view of female labor force participation using system dynamics modeling.

Female labor force participation helps protect pension systems threatened by aging populations. Norway has, among developed nations, very generous childcare resources available to enable women to enter the workforce quickly after their parental leave. These childcare resources include nursery care after parental leave ends and before and after school care once the child is of school age. This can be argued as a very important policy for gender equality. It helps to raise a woman's lifetime income to a level that gives women a pension closer to that of men. The purpose of this study is to analyze how this policy works operationally; examining how gender differences in pension develop over time, how this is related to accumulated lifetime income, and how childcare policies affect this. It is important to note that this study examines childcare policy in the form of pre-school daycare offered by the state after parental leave ends. Paid parental leave does not affect pension payments, and for this reason has been left out of this study.

It is very well-established in the literature that women are disadvantaged in many pension systems because of the wage gap, the salary gap between male/female-dominated professions and higher rates of female part time work. What is lacking in the literature is an investigation of the systemic forces that make

this so. This study specifically addresses how policy operationally leads to this disadvantage, focusing on part time work. In addition to this, there is no dynamic modeling of gender and pensions in the literature, not just in Norway but in any country. Dynamic modeling has made few inroads into the evaluation of social policy, and part of the novelty of this study is the application of new methods to a well-established body of literature.

The first section of this paper provides a short background on the system dynamics methodology and feedback theory. System dynamics modeling is then used to examine the following research question: *are there structural disadvantages for women in the Norwegian pension system?* This is illustrated and explained through the use of a stock and flow diagram. Simulations of the stock and flow diagram, represented through graphs, are presented in the results section. A causal loop diagram is also presented with the results, and is used as the focal point for the discussion due to its simplicity. The discussion section explores how the Norwegian pension system structure, in light of social investment strategy, operationalizes a structural social and economic disadvantage for women. Appendix A provides additional information on the model, validation, and limitations.

2. Methods

System dynamics is a relatively new discipline that saw its formation in the mid-20th century and began to spread with the publication of *Industrial Dynamics* by Jay Forrester [12]. System dynamics is used when analyzing a domain as a system to understand the feedback within the system in order to develop solutions to inherent problems versus symptoms. The methodology was originally developed at MIT by a group dedicated to this academic pursuit [13] and engaged by the Club of Rome to create the World3 model, which has been a cornerstone of sustainability and climate change analysis [14]. System dynamics is an iterative, interdisciplinary process that views problems holistically. Essentially, using system dynamics involves identifying elements, subsystems, and the systems' context, boundaries and properties of the system under investigation. System dynamics is both systematic and systemic in that there are systematic processes, and it is rooted in systemic thinking in order to recognize and solve complex problems by seeing the whole instead of only the parts [15]. System dynamics is often preferred over other analysis methods because of its underlying computational rigor—see Appendix A.

System dynamics is applied in this study to the Norwegian pension system in order to understand how elements in this system operate and interact. System dynamics modeling is aided by the use of software (this study uses iThink, see Appendix A.) The elements in a system dynamics model consist of stocks, flows, and variables (stock and flow diagram). Stocks are an accumulation of its flows over time, and flows represent addition and subtraction to the stock over time. Variables in stock and flow models are elements that affect the inflows and outflows. The variables are linked to each other and flows through instantaneous causal links. The accumulated causal behavior in the stock is affected by the flows, which are in turn affected by the variables.

The structure of a system yields the behavior over time (accumulated in stocks), and the goal is to discover all the elements and relationships in a system and reproduce the observable reference mode behavior (actual system behavior). In system dynamics models, there are endogenous and exogenous elements. Endogenous elements are incorporated in the model structure in relation to other structural elements. Exogenous elements are variables that contain data that are directly imported into the model structure.

Feedback Theory

A fundamental concept in system dynamics is feedback theory. In the evaluation of the relationships between elements in a system, there are often feedback loops operating in a system [16]. A feedback loop is the interconnection of variables in a system that feeds back into itself. This is a closed loop system. Open loop systems do not have a feedback loop, and often the policy goal in these systems is to close the loop, especially in environmental management systems. Open loop systems have exogenous variables that influence the system structure from outside the system to generate the system behavior. Closed loop systems have endogenous variables, where the behavior is influenced by forces within the system. An example of this is climate change variables. When modeling societal collapse in history (e.g., the classic Mayans), climate change (drought) influenced societal collapse. Climate change is exogenous in this example because the population was not causing the drought. However, when modeling human-induced climate change in contemporary societies, climate change is endogenous because human activity influences climate change and climate change, in turn, affects human societies.

A causal loop diagram (CLD) of the stock and flow diagram shows the relationships between elements in a system (the feedback loop), which can be either positive or negative. A positive relationship means the elements develop in the same direction (when one increases, so does the other), and a negative relationship means the elements develop in opposite directions (when one increases, the other decreases). A balancing feedback loop means that the relationships between the elements keep the accumulated elements (stocks) at equilibrium. In addition to the balancing feedback loop, there is also a reinforcing feedback loop, where the behavior of the stock does not find an equilibrium and continues to increase or decrease over time.

One of the major goals of system dynamics is to understand the structure of the system that results in the observable behavior. This is the motivation for using system dynamics as the methodology for this study. The goal of this study is to understand how policy structure produces gender disparity in the pension system. Representing the pension system mathematically is an approach that serves to complement other methodological approaches. For more information about system dynamics modeling and its limitations, please see Appendix A.

3. Results

The model presented in Figure 1 is one part of a larger model. This section presents the stock and flow diagram of the Norwegian pension system (representing its structure). This is only a portion of the system however, and represents how income is accumulated over time (see Appendix A for an expanded description of the model). Total lifetime income is the largest determining factor of pension payments. There are policies in place to equalize the pension payments between men and women. The main structural policy is the provision of childcare resources (i.e., pre-school daycare).

The stock and flow structure only represents childcare resources after parental leave ends. During parental leave, parents earn the same amount of pension points as they did before parental leave. The model only represents how women are enabled to enter the labor force after parental leave ends (the availability of childcare resources), and how this in turn affects income and pension. Only labor force participants who have worked 40 years (regardless of position percent/full time vs. part time) are represented in this model. This model assumes that the male position percent is not affected by child rearing, and this is recognized as a limitation of the model. Also, although this study only investigates pension transfers from the state, the pension system also includes a mandatory occupational pension. In addition to this, pensioners may have invested in private pension accounts to supplement their income at retirement. Therefore, the model does not represent total pension income, only total pension amount received from the state (in the Old Age Pension category).

The CLD of the system is presented in this section as well as the behavior (in the form of graphs) produced from the structure.
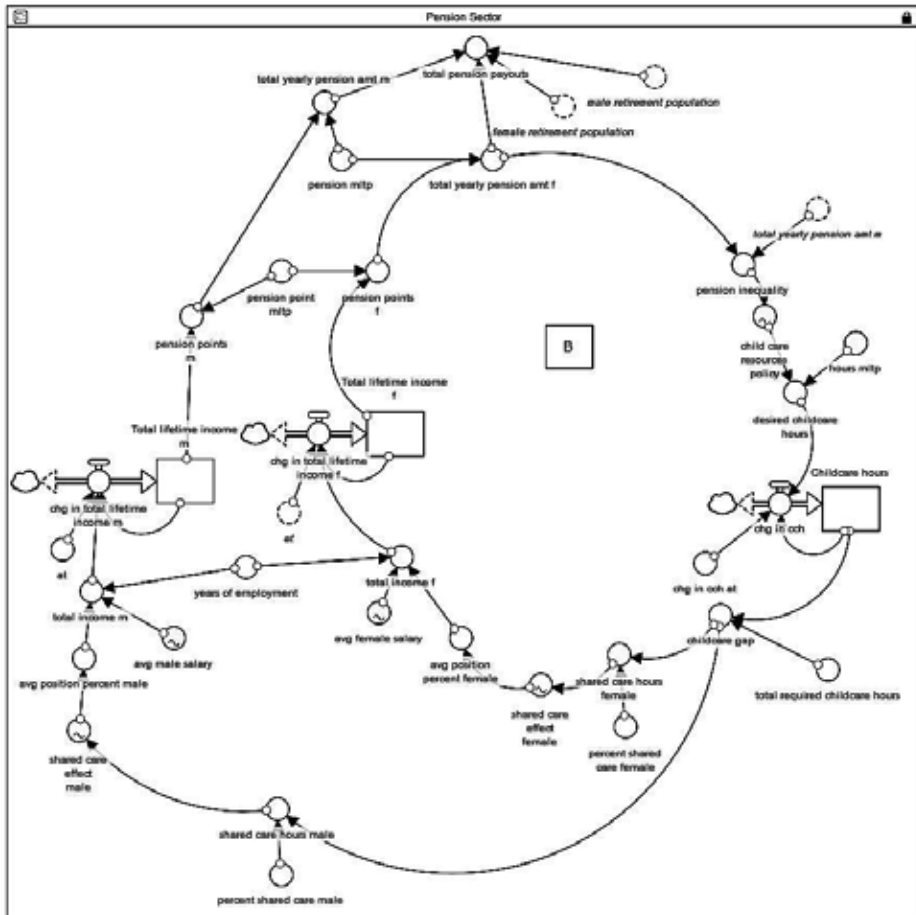

Figure 1. Stock and flow diagram of a section of the Norwegian pension system. The "B" shows the location of the balancing feedback loop, shown as a causal loop diagram (CLD) in the Results section. The boxes are stocks, and the flows are the large arrows going into and out of the stocks. Variables are the circles, and the small arrows connecting all the elements are the causal links. Each variable and flow represents either data or an equation. "avg" is a short form of average, and "chg" is the short form of change.

3.1. Stock and Flow Diagram of the Norwegian Pension System

Figure 1 shows the stock and flow diagram of the section of the Norwegian pension system that represents how total lifetime income is accumulated for men and women. Total lifetime income for men is the stock on the left, and total lifetime income for women is the stock on the right. Total lifetime income is the largest determining factor for pension payments. Men and women earn different levels of pension as

shown in Figure 2. Total yearly pension payments are simulated in the model in Figure 2 (blue-men and red-women) with the historical data (pink-men, green-women, no data before 2006).

The total lifetime income for men and women (Figure 3) differs because of several factors. There is wage inequality between men and women, which is around 83–87% female/male income, although this has been decreasing with time [10]. Another factor that affects the total lifetime income is the salary difference in male versus female dominated fields. Male dominated fields, such as engineering, have much higher salaries than typically female dominated fields, such as teaching [10]. Wage inequality and male/female dominated fields are factors that are aggregated in the variables "avg male salary" and "avg female salary" in the model.
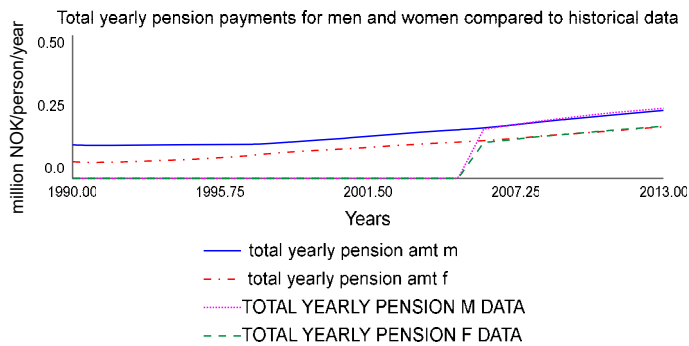
Figure 2. Total yearly pension payments for men (blue-simulation, pink-historical data) and women (red-simulation, green-historical data) in Million NOK/person/year.
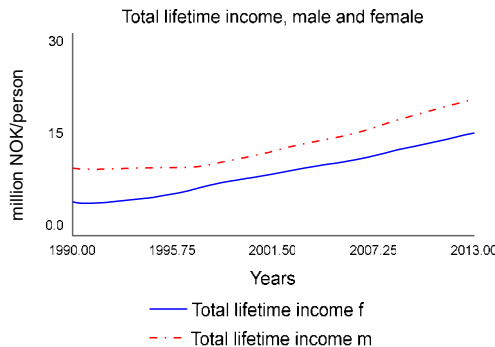
Figure 3. Total lifetime income for women (blue) and men (red) in Million NOK/person.

The purpose of this model is to investigate how state policies have worked to reduce pension inequality between men and women. As stated, there are policies to reduce wage inequality and goals to encourage women to enter male dominated fields. However, even if these inequalities disappear, the average position percent (full time position equals 100%) is still affected for women in childbearing/rearing

years by a significant amount (ca. 20%). All else being equal, this large gap leads to major differences in pension, which is why the policies regarding this are investigated in this model.

Parental leave in Norway allows for men and women to stay home for 36 or 46 weeks[4] after the birth of a child (number of weeks depends on whether they take 100% or 80% salary). Of these, the father must take 10 weeks of this, and the mother cannot take leave for the father [17]. Parents receive pension points during this time. By the age of one, the child has a right to a place in daycare [18]. This system allows for women (mothers are much more likely to be the parent taking the majority of parental leave) to be back at work as early as possible to start/resume earning income and pension points again.

Women are most likely to work part time versus full time (represented as "position percent" in the model), and this is usually due to childbearing and rearing even with childcare resources in place. Norwegian childcare resources include income for women who stay home with children and do not hold a job, but these women do not receive pension points for this (and this income is not included in the model.) This tendency to work part time is represented in the stock and flow diagram in Figure 1. The "average position percent female" variable is affected by shared care hours. "Shared care hours" are the number of unpaid childcare hours parents must provide, which are not available to be outsourced to state childcare services. Either the mother or the father can provide unpaid childcare work, but this is (as a societal norm) usually provided by the mother. "Childcare resources policy" is a non-linear graphical function that states: as pension inequality increases, the childcare resources increase in availability in order to reduce pension inequality. This is a model assumption to represent policy decision-making. In short, policy makers will offer more childcare resources when pension inequality is higher. As pension inequality approaches 1, childcare resources increase by a decreasing percentage. In this sense, pension inequality between the genders is used as *one* performance indicator of gender inequality in general. The representation of this in the model does not mean that the only influence on childcare resources is pension inequality. Many variables not investigated in this model influence the level of childcare resources, which is a supply and demand dynamic referred to as the childcare gap [19]. Please see Appendix A concerning assumptions in system dynamics modeling.

"Pension inequality" is the ratio between male and female pensions. The goal is to have this equal 1 (equal female/male pensions). The graph in Figure 4 shows the behavior of this over time. The simulation runs until 2013, with the ratio at 0.75.

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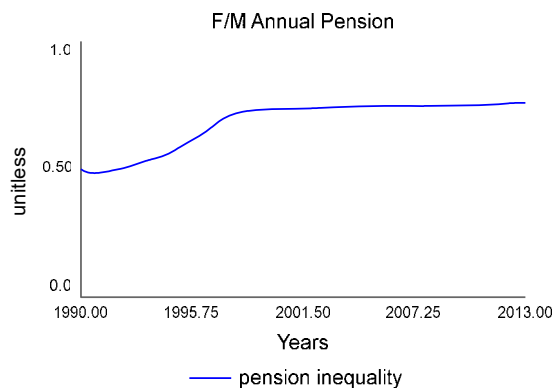
[4] At the time of writing, 2016.

Figure 4. Pension inequality-the relationship between female and male pensions.

3.2. Causal Loop Diagram

The relationship between the variables in the stock and flow diagram forms a balancing feedback loop, which is represented in the CLD in Figure 5.

The CLD explains that as pension inequality increases, the amount of childcare resources increases. This increases the position percent (full versus part time work) that women are available to take. A higher position percent gives a higher total female lifetime income, which means more pension points for women. The more pension points women earn, the higher the pension they receive at retirement. As women receive higher pensions, pension inequality is reduced.
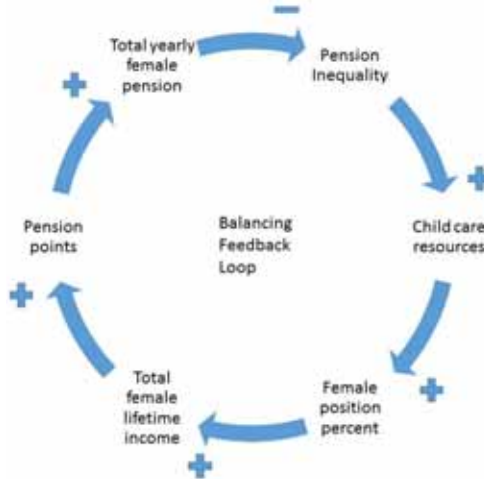
Figure 5. Balancing feedback loop showing how the system reacts to gender inequality in pensions.

It seems from the CLD that the policy (childcare resources) in place helps to alleviate the pension inequality. As is often the case in policy implementation, as one problem is fixed, another arises. The next section discusses why this policy helps fix the problem, but with structural consequences for women.

4. Discussion

One important variable that is left out of the CLD is unpaid childcare work. The childcare policy relies on the importance of the dual earner household, but does not address the issue of shared caregiver, which is the other side of the dual earner relationship. This section explains how this structural oversight in policy leaves women disadvantaged.

There is a social dilemma with having children in Norway and most modern societies because of the large economic burden for the parents; yet children are valuable and necessary for the society [20]. Having children is not a rational economic choice for women, but it is rational as a societal choice. Norway has an interest in keeping the fertility rate from dropping and socially investing in children because the welfare system depends on labor force participation. Therefore, investing in the welfare of the young supports the welfare of the elderly in this model [18]. This is social investment strategy represented in the Norwegian

pension system. However, the focus on children and childcare resources to increase female labor force participation (which increases the pension payment and hence female elderly welfare) keeps women locked into the balancing feedback loop shown in the CLD in Figure 5. Is this fair? It is not a rational economic choice (in terms of pension) for women to provide their own childcare versus having it provided by the state. I am not indicating that most women that use state provided childcare resources would rather stay home with their children (though some most likely would), but many do choose to stay home either full time or part time and are not rewarded (in terms of their pension) for their contribution to the social investment (as shown in Figure 2).

The "new gender contract," advocated by Gøsta Esping-Andersen is the concept that welfare states should support a child-centered social investment strategy, where female labor force participation is necessary for the sustainability of the political economy [21]. Norway's social welfare policy has focused on making this a reality, and women are needed in the labor force to do so, making gender equality both an economic issue and a social issue [22]. Increasing female labor force participation leads to what Esping-Andersen calls "female life course masculinization," and men should hopefully adopt (and must in order for the new gender contract to work) a more "feminine life course" (higher rate of care duties at home). However, a more feminine life course for men is not easily achieved, and has as yet not been achieved to the level where childbearing/rearing does not affect female position percent (level of part time work). Although feminists are skeptical of the focus on children in social investment strategy having a positive outcome for women [23], this problem with the new gender contract and social investment strategy should instead call for the revival of the concept of husbandry [24]. Husbandry is a richer gender identity for men, where they identify beyond "the economic man." Husbandry is not "a male mother;" and women need not become an "honorary man" or adhere to female life course masculinization. The argument in the revival of husbandry is that caring is a human trait, where men are leading less full lives without having it as part of their gender identity.

The CLD in Figure 5 indicates that women are at a structural disadvantage in terms of future pension payments. Only those women who want to contribute to the welfare system with labor force participation (and hence contributing to social investment strategy) will achieve higher pensions. Women must adhere to social investment strategy with labor force participation, where there is the defamilialization of care [23]; and if they choose not to adhere and provide childcare themselves, their lifetime earnings and hence pension will suffer. Even if women do adhere, care work at home is still largely the responsibility of mothers, which leads to higher rates of female part time work in childbearing/rearing years.

Regarding the recent report by the Nordic Council of Ministers [11] mentioned at the beginning of this paper, their assertion that part time work during childbearing/rearing years has no significant effect on the pension payment for women (using economic forecasting) is a very simplistic view of the systemic forces at work in the Norwegian pension system. Because of the methodological differences and points of departure between that study and the one presented in this paper, different elements of this issue are highlighted. The Nordic Council of Ministers research highlights that female part time work does not economically influence the level of pension compared to her full time counterpart (not a male/female comparison). This study identifies the systemic forces that make this so (and compares her to her male counterpart) and argues that these forces are what leads to the structural disadvantage for women in the Norwegian pension system. The two main systemic forces that lead to this disadvantage are the policy requirement of outsourcing childcare to enable female labor force participation (female life course masculinization) and the policy requirement of the shared caregiver (male life course feminization-which is a hopeful, not a strategic policy requirement). It is this policy that determines whether or not a woman's pension payment equals or comes close to her full time counterpart, but it is the policy requirements that are the disadvantage for women.

Though not coming from a systemic perspective, Jensen [23], in an analysis of gender issues in social investment strategy, explains that structural factors (devaluation of women in the welfare system) must be

attended to instead of worked around (male life course feminization). The structure of a system causes the behavior. Any realistic policy must address the structure to create real change [25]. As an extension of "female life course masculinization," the Norwegian pension system is considered a "masculine pension system" because there is a requirement of labor force participation to receive pension points [26]. Women do not earn pension points for unpaid childcare work in the years after parental leave ends unless they are in paid employment. Women must "act like a man" and enter the labor force full time as soon as parental leave ends if they do not want to see a reduction in their pensions. However, there are only so many hours in the day, and women caught in this policy will never achieve maximum pension if men do not share childcare responsibilities. Because the policy relies on hope and not strategy to fulfill this shared caregiver requirement, in the evaluation of social investment strategy and its policies in regards to pension, the effect of solely focusing on children to enhance elderly welfare leaves women at a structural disadvantage.

This study does not model the Norwegian labor force and does not address the salary gap between male and female dominated professions, nor does it address the wage gap. This is important to address in relation to this study because labor force dynamics have a relationship with gender identity, as women are much more represented in care professions, and these are considered of lower value even when they are highly-skilled (such as nurses and teachers) [27].

5. Concluding Remarks

This study uses system dynamics modeling to explore how the Norwegian pension system in its implementation of social investment strategy traps women in a structurally disadvantaged situation. There is no attempt in this paper to give policy recommendations, as is so often the purpose of system dynamics modeling studies, because further research must be done before policy can be addressed. This includes, for example, analyzing the results in relation to various household structures (e.g., single men and women, couples without children, couples with many children versus one child). This study assumes equal pension levels for men and women as the desired system behavior, which corresponds to Norwegian equality goals, and further analysis must address several policy scenarios to achieve this. For example, if the male population contributes unpaid childcare hours and this achieves the desired behavior, what are the possible side effects of this and are the implementation challenges insurmountable? To be relevant for Norway, policy analysis must include a thorough evaluation of implementation challenges and feasibility. The model presented in this paper is the first system dynamics model that focuses on gender and pension in Norway. Labor force dynamics and childcare gap dynamics beyond pension are important future model developments that will give new insight into Norwegian gender issues.

Supplementary Materials: All model equations and data are available online at www.mdpi.com/link.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A. Model Building and Validation

*All model equations and data are available in the supporting material.

Appendix A.1. Notes on Model Building

The model in this study was built using iThink 10.1 from isee systems. The time horizon is 1990–2013. The year 1990 was chosen because of data availability and because the 1990s shows the start of the effect of childcare policy implementation. The year 2013 was chosen because this was the last common year data that was available for all variables in the model. The portion of the model shown in the paper is one part of a larger model. The total model includes dynamic demography modeling and state accounting modeling. The population model is broken up into four age cohorts (0–14, 14–49, 50–66, and 67+). Immigration also forms part of the demography model as a separate inflow into each age cohort corresponding to the percentage of immigrants belonging to each age group. The working age population (the sum of the 14–49 and 50–66 population stocks) is linked to state income, whereby labor force participation is calculated and then linked (with the unemployed removed) to the state income section of the model. The state income portion of the model has several elements. All income to the state that is connected to the labor force is disaggregated (e.g., pension contribution, income tax, employer fees and social security fees) and connected to the demography modeling. There is also an individual capital tax that is linked to the total population. All oil related income is disaggregated though not linked to any other part of the model.

The state income portion of the model also includes the Norwegian pension fund stock. Though not relevant to the discussion in this paper, the model has a reinforcing feedback loop involving the state general fund and the Norwegian pension fund. The general fund stock is a state accounting stock (state income minus expenditures). In Norway, this stock is always (in the model's time horizon) positive. All surplus income is invested in the Norwegian pension fund. This stock has nothing do with the pension system and is the new name for the Norwegian Petroleum Fund. There are discretionary drawdowns on this interest-bearing fund where the maximum annual drawdown is 4%, though the fund consistently yields higher returns, thus creating the reinforcing loop in the Norwegian pension fund.

In the state expenditures portion of the model, only pension expenditures (named pension transfers in the model) are disaggregated, making two outflows from the general fund stock: pension transfers and other expenditures. Pension transfers are linked to the 67+ population stock, with males and females disaggregated. This population and the pension transfers are linked to the portion of the model discussed in this paper.

*Appendix A.2. Notes on Data and Support for Variables and Relationships*

The demography sector data was retrieved from Statistics Norway (SSB). The state accounting sector data was retrieved from the Norwegian National Budget (Statsbudsjettet), which is an online database of state budget information. The pension sector includes data from SSB and Statsbudsjettet, but several relationships assumptions are made. The most important relationship assumption is the childcare resources policy, which is explained in the paper (see Section 3.1). This variable was also subjected to a sensitivity analysis (see below). The other assumption was pension inequality, and how it is represented and why is also explained in the paper (see Section 3.1).

Appendix A.3. Notes on Validation

Validation of the model presented in this paper took several forms. On the most superficial level, face validity of the model architecture was achieved by presenting the model and paper with Nordic welfare state experts in the Sino-Nordic Welfare Research Network (SNoW).

The model validation process involved comparing simulations to historical data. Model behavior is compared to several different sets of historical data (the reference modes). The main reference mode along with the simulated behavior is shown in Figure 2. Several reference modes were chosen in the population

and state accounting systems to validate the model, including: population stocks (total Norwegian population and working age population), the Norwegian pension fund, annual pension transfers and annual state income. These simulations along with the historical data are shown below in Figure A1. It should be noted that in Graphs 4 and 5 in Figure A1, there are no available data before 2000 and 1995 respectively. The data variables are set to 0 in the graphs when no data is available in order to make the data gaps transparent.
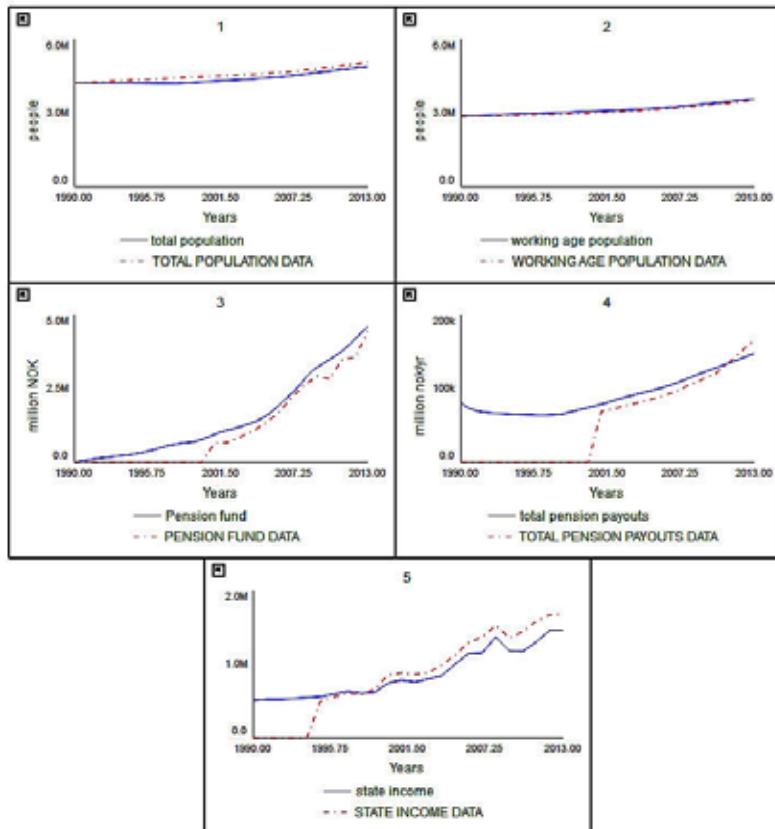
Figure A1. Other supporting reference modes used for validation. 1 = Total Norwegian population; 2 = Working age population; 3 = Norwegian pension fund; 4 = Pension transfers; 5 = State income. All simulations are in blue, and all historical data are in red.

Appendix A.4. Sensitivity Analysis

The pension sector is dependent on an assumption in the variable "Childcare resources policy." As stated in the paper, this is a non-linear graphical function that states as pension inequality increases, the childcare resources increase in availability in order to reduce pension inequality. This is a model assumption to represent policy decision-making. In short, policy makers will offer more childcare resources

when pension inequality is higher. As pension inequality approaches 1, childcare resources increase by a decreasing percentage. In this sense, pension inequality between the genders is used a one performance indicator of gender inequality in general. The graphical function is shown in Figure A2.

Because the pension sector of the model is dependent on this assumption, a sensitivity analysis was needed. The results of the sensitivity analysis are shown in Figure A3. The effect of the childcare resources policy non-linear graphical function was reduced and increased by 25%, and results in Figure A3 show the effect on total yearly female pension payment. Run 1 is the reduction of 25%; Run 2 is the same as in the model simulation presented in the paper; and Run 3 is the increase of 25%. Total yearly female pension payment is the variable most affected by this assumption in the childcare resources policy, in addition to being the focus of the model, which is why it was chosen for the sensitivity analysis.
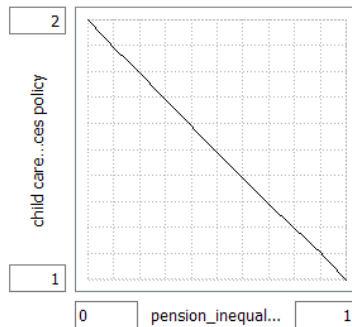
Figure A2. Childcare resources policy variable: non-linear graphical function.
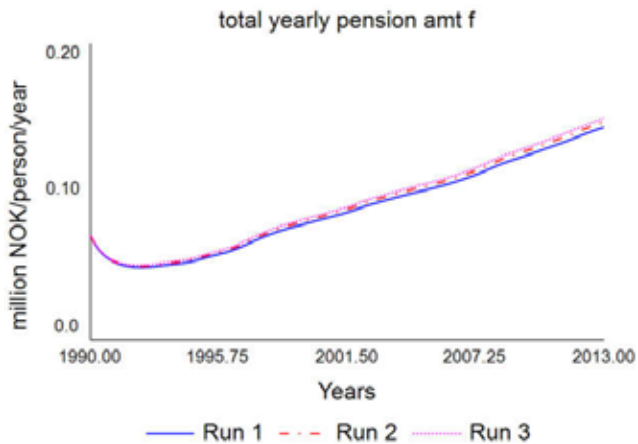
Figure A3. Childcare resources policy sensitivity test and the effect on total female yearly pension payment.

Appendix A.5. Methodological Limitations

System dynamics modeling is not without its limitations. All forms of mathematical modeling are simplifications of reality. While models are still useful in their simple and abstract representation of actual

system structure, this does limit their usefulness. Although there are validation tests that evaluate the robustness of the model, as in the sensitivity analysis shown in Appendix A4, uncertainty is never fully resolved. System dynamics modeling can be taken as a very deterministic method, especially when uncertainty is not made transparent, and modelers must take extreme care of not assuming or influencing others to believe that the assumed causality represented in the model structure are actual causal relationships. System dynamics models are engineering tools, where system model design can be represented in nearly limitless ways. Just because one system design shows a certain outcome, this does not mean that a different model design of the same system will replicate that outcome.

This is of specific concern in a study of the type presented in this paper because of the limited application of system dynamics modeling in welfare state policy analysis. Models evolve over time, and the novelty of this study is that this is a first iteration model, meaning there are no published models on which the model in this study could be built. Because of this, there are issues regarding not only robustness, but also of model scope. The model boundaries are rather limiting in this model; salary and wage gaps are not represented endogenously, and this must be further developed in future iterations of the model. Childcare resources are only endogenously affected by pension inequality, and it would be very useful to extend the model boundaries to see dynamics between other influential variables. As models evolve over time, with many modelers of different backgrounds developing them, the robustness of the model is strengthened and the scope is widened, making the model outcome much more supported.

In addition to this, and related to robustness, is that one of the strengths of system dynamics modeling is also one of its weaknesses. System dynamics modeling is largely secondary analysis, but when there are literature gaps about system structure, system dynamics modeling has techniques to cope with this shortcoming. Graphical functions, e.g., the childcare resources graphical function presented in this paper, are able to approximate relationships between variables when there is a dearth of literature. System dynamics models are engineering models that do not attempt to make causal claims [28]. In doing so, literature justification gaps are supported by model validation. Although graphical functions are a useful technique, it must be used with caution and tested, with its limitations made transparent. In this model, this was done with the sensitivity analysis for the childcare resources non-linear graphical function. It is recognized that further model development is needed to strengthen the understanding of this system.

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III

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IV

Appendix

Appendix A: Model Documentation

The model documentation includes background information about the models in this PhD project, including the stock equations, and a copy of all the model variable values and equations. The primary form of model validation is comparing historical data to simulated behavior, and this is shown in the model documentation for several variables in all model sectors. Testing in the form of sensitivity analysis is also presented for key variables in two model sectors: pension and absenteeism.

A.1 General Model Information

The system dynamics model presented in this study was built using Stella Architect 1.0 from isee systems. The total model includes dynamic demography, general state accounting, pension and absenteeism system modeling. The population model is broken up into four age cohorts (0-14, 15-49, 50-74 and 74+). Immigration also forms part of the demography model as a separate inflow into each age group corresponding to the percentage of immigrants belonging to each age group. The working age population (the sum of the 14-49 and 50-74 population stocks, with retirees between 67 and 74 removed) is linked to state income, whereby labor force participation is calculated and then linked (with the unemployed removed) to the state income section of the model. The state income portion of the model has several elements. All income to the state that is connected to the labor force is disaggregated (e.g. pension contribution, income tax, employer fees and social security fees) and connected to the demography modeling. There is also an individual capital tax that is linked to the total population. All oil related income is disaggregated though not linked to any other part of the model.

The state income portion of the model also includes the Norwegian pension fund stock (Pension Fund Global). The model has a reinforcing feedback loop involving the state general fund and the Norwegian pension fund. The general fund stock is a state

accounting stock (state income minus expenditures). In Norway, this stock is always (in the model's time horizon) positive. All surplus income is invested in the Norwegian pension fund (Pension Fund Global). This stock has nothing do with the pension system and is the new name for the Norwegian Petroleum Fund. There are discretionary drawdowns on this interest-bearing fund where the maximum annual drawdown is 4%, though the fund consistently yields higher returns, thus creating the reinforcing loop in the Norwegian pension fund.

In the state expenditures portion of the model, only pension expenditures (named pension transfers in the model) and absenteeism expenditures are disaggregated, making three outflows from the general fund stock: pension transfers, absenteeism expenditures and other expenditures. Pension transfers are linked to the 74+ population stock (and retiree portion in late adult population stock), with males and females disaggregated. Absenteeism expenditures is linked to care work absentees in the absenteeism model sector (together with other absentees and average cost per absentee).

The pension sector of the model is where part-time work for women is calculated. Pension is largely determined by lifetime accumulated income, which for women is affected by the wage difference in female-dominated professions, the male/female wage gap and part-time work. Shared-cared hours and childcare hours covered by the state are used to dynamically determine part-time work for women over time. Women are most likely to work part-time versus full-time, and this is usually due to childbearing and rearing even with childcare resources in place. The part-time work variable is affected by shared care hours. "Shared care hours" are the number of unpaid childcare hours parents must provide, which are not available to be outsourced to state childcare services. Either the mother or the father can provide unpaid childcare work, but this is (as a societal norm) usually provided by the mother. The part-time work variable is connected to the absenteeism sector of the model.

The time horizon for the model is 1990-2013. This was chosen because this is the maximum number of years that data is available for the majority of the key variables (those represented in the reference modes.)

The demography sector data was retrieved from SSB. The state accounting sector data was retrieved from the Norwegian National Budget (Statsbudsjettet), which is an online database of state budget information. The pension sector also includes data from SSB and the Norwegian National Budget. The absenteeism model includes data from NAV and SSB. Direct links to the data sources for each variable are given in section A.5.

A.2 Model Equations

This section provides the model equations for the model used in the systemic evaluation of the Norwegian welfare state systems of pension and absenteeism. Documentation for the other model-based academic articles (number 4 in the article list), which does not form part of the systemic evaluation of the Norwegian welfare state, is available in the appendix the article. Although documentation for the pension and absenteeism system models is also available in the appendices of their respective articles as well, these models all form part of the same larger model, and their documentation is put together in this appendix to reflect this. The larger model consists of four sectors (demography, state accounting, pension and absenteeism) and includes 12 stocks, 29 flows and 112 converters (variables). There are 37 constants (either data or assumed values), 104 equations and 36 graphical functions. Below are the stock equations, and the complete model documentation is given in section A.5.

Stock Equations:

Where $t = time$

$$Active\ care\ workers(t) = Active\ Care\ workers(t - \Delta t) +$$
$$\begin{pmatrix} hiring\ +\ recovery\ - \\ attrition\ -\ getting\ sick \end{pmatrix} * \Delta t \qquad (1)$$

$$Care\ worker\ absentees(t) = Care\ worker\ absentees(t - \Delta t) + \qquad (2)$$
$$\begin{pmatrix} getting\ sick \\ -\ recovery \end{pmatrix} * \Delta t$$

$$Childcare\ hours(t)$$
$$= Childcare\ hours(t - \Delta t) + (change\ in\ childcare\ hours) * \Delta t \qquad (3)$$

$$General\ fund(t)$$
$$= General\ fund(t - \Delta t)$$
$$+ \begin{pmatrix} pension\ fund\ contribution\ to\ state\ budget \\ +\ state\ income\ -\ other\ expenditures \\ -\ pension\ fund\ income\ -\ pension\ transfers\ - \\ absentee\ expenditure \end{pmatrix} * \Delta t \qquad (4)$$

$$Pension\ fund(t)$$
$$= Pension\ fund(t - \Delta t)$$
$$+ \begin{pmatrix} pension\ fund\ income \\ +\ interest\ -\ pension\ fund\ contribution\ to\ state\ budget \end{pmatrix} * \Delta t \qquad (5)$$

$$Immigrants(t) = Immigrants(t - \Delta t) + (immigrating\ -\ emigrating) * \Delta t \qquad (6)$$

$Juvenile\ population\ 0\ to\ 14\ (t)$

$$= Juvenile\ population\ 0\ to\ 14(t\ -\ \Delta t)$$

$$+ \begin{pmatrix} birth\ +\ juvenile\ immigrants\ +\ maturation\ 1 \\ -\ juvenile\ death \end{pmatrix} *\ \Delta t \qquad (7)$$

$Young\ adult\ population\ 15\ to\ 49(t)$

$$= Young\ adult\ population\ 15\ to\ 49(t\ -\ \Delta t)$$

$$+ \begin{pmatrix} maturation\ 1\ +\ young\ immigrants\ -\ maturation\ 2 \\ -\ young\ adult\ death \end{pmatrix} *\ \Delta t \qquad (8)$$

$Late\ adult\ population\ 50\ to\ 74\ (t)$

$$= Late\ adult\ population\ 50\ to\ 74(t\ -\ \Delta t)$$

$$+ \begin{pmatrix} maturation\ 2\ +\ late\ adult\ immigrants \\ -\ maturation\ 3\ -\ late\ adult\ death \end{pmatrix} *\ \Delta t \qquad (9)$$

$Retirement\ age\ population\ 74\ plus(t)$

$$= Retirement\ age\ population\ 74\ plus(t\ -\ \Delta t)$$

$$+ (maturation\ 3 + retirement\ age\ immigrants\ -\ death) *\ \Delta t \qquad (10)$$

$Total\ lifetime\ income\ female(t)$

$$= Total\ lifetime\ income\ female(t\ -\ \Delta t)$$

$$+ (change\ in\ total\ lifetime\ income\ female) *\ \Delta t \qquad (11)$$

$Total\ lifetime\ income\ male(t)$

$$= Total\ lifetime\ income\ male(t\ -\ \Delta t)$$

$$+ (change\ in\ total\ lifetime\ income\ male) *\ \Delta t \qquad (12)$$

A.3 Validation

A.3.1 Demography, General State Accounting and Pension

Validation of the model took several forms. On the most superficial level, face validity of the model architecture was achieved by presenting the model and early article drafts with Nordic welfare state experts in the Welfare State Research Center at the University of Southern Denmark and at the Nordic Centre of Excellence: The Nordic Welfare State – Historical Foundations and Future Challenges (NordWel), 2015 and 2016.

The model validation process involved comparing simulations to historical data. Model behavior is compared to several different sets of historical data (the reference modes). The pension model was the first model sector to be built upon the background model sectors (demography and state accounting), and in figure 20, pension, demography and state accounting reference modes are presented together. It should be noted that historical data are set to 0 to make data gaps transparent, and this is the reason simulated behavior does not match actual system behavior before the year 2000 and 1995 in graphs 4 and 5 respectively in Figure 20.
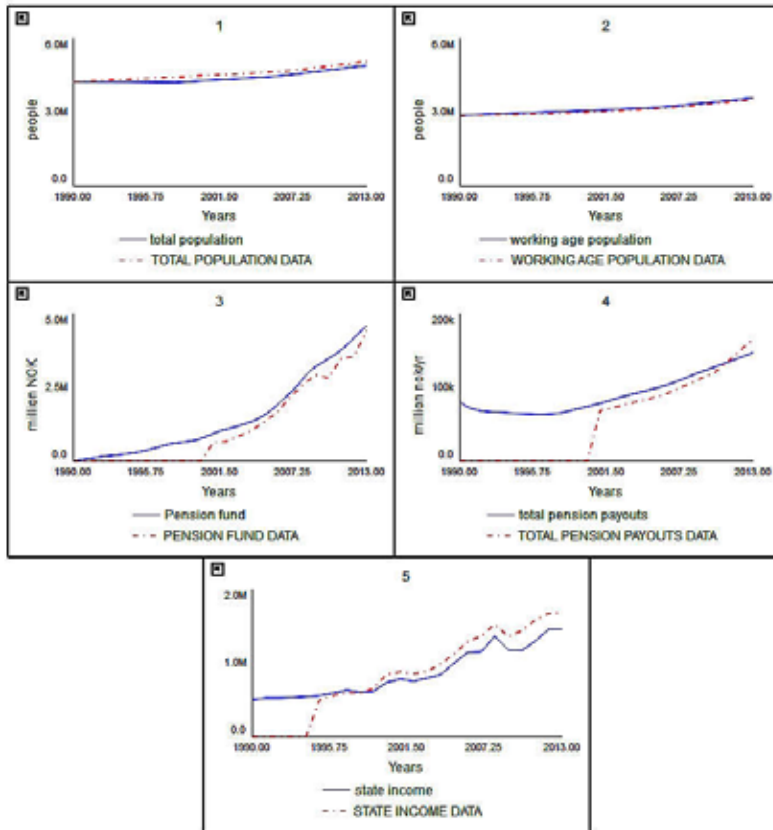
Figure 20: Supporting reference modes used for validation. 1= Total Norwegian population (persons/year), 2= Working age population (persons/year), 3=Norwegian pension fund (million NOK/year), 4= Pension transfers (million NOK/year), 5=State income (million NOK/year). All simulations are in blue, and all historical data are in red.

A.3.2 Absenteeism

The following graph (Figure 21) shows the overall behavior of the model (simulated behavior) compared to the actual system behavior in the absenteeism model sector.
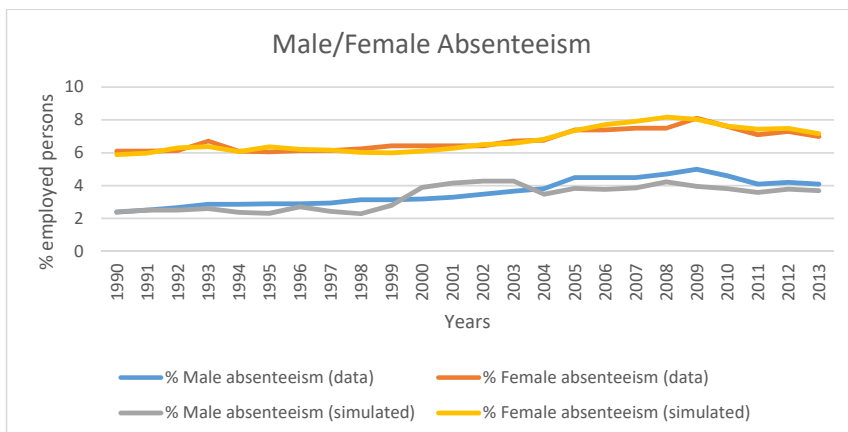
Figure 21: Reference mode and simulated behavior of male (blue-data, grey-simulation) and female (orange-data, yellow-simulation) absenteeism rates (in percent).

A.4 Sensitivity Analysis

A.4.1 Pension

The pension sector is dependent on an assumption in the variable "Childcare resources policy." This is a model assumption to represent policy decision-making. In short, policy makers will offer more childcare resources when pension inequality is higher. As pension inequality approaches 1, childcare resources increase by a decreasing percentage. In this sense, pension inequality between the genders is used as one performance indicator of gender inequality in general. The graphical function is shown in Figure 22.

Because the pension sector of the model is dependent on this assumption, a sensitivity analysis was needed for this variable. The results of the sensitivity analysis are shown in Figure 23. The effect of the childcare resources policy non-linear graphical function was reduced and increased by 25%, and results in Figure 23 show the effect on total yearly female pension payment. Run 1 is the reduction of 25%; Run 2 is the same as in the model simulation presented in the paper; Run 3 is the increase of 25%. Total yearly female

pension payment is the variable most affected by this assumption in the child care resources policy, in addition to being the focus of the model, which is why it was chosen to show the effect of the sensitivity analysis.
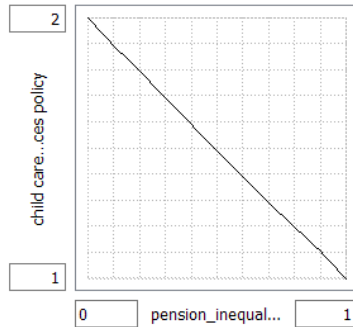
Figure 22: Childcare resources policy variable: non-linear graphical function.
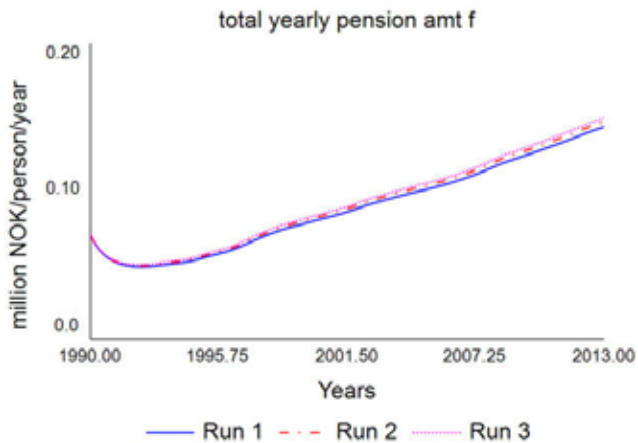
Figure 23: Childcare resources policy sensitivity test and the effect on total yearly pension payment female.

A.4.2 Absenteeism

Because of the model assumption concerning the decision-making effect in the absenteeism model sector, which is important for the model behavior, a sensitivity test was performed on this variable. This effect was modeled as shown in Figure 24. The

effect was increased and decreased by 25% in the sensitivity test. The results on the reference mode behavior are shown in Figure 25.
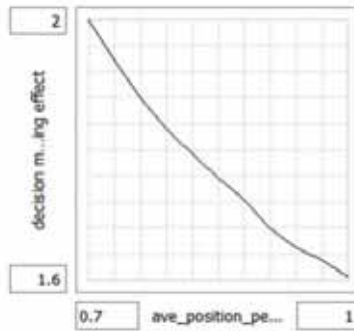
Figure 24: Decision-making effect non-linear graphical function, explaining: as the average position percent decreases (more part-time work), the decision-making effect increases (which increases the sick rate).
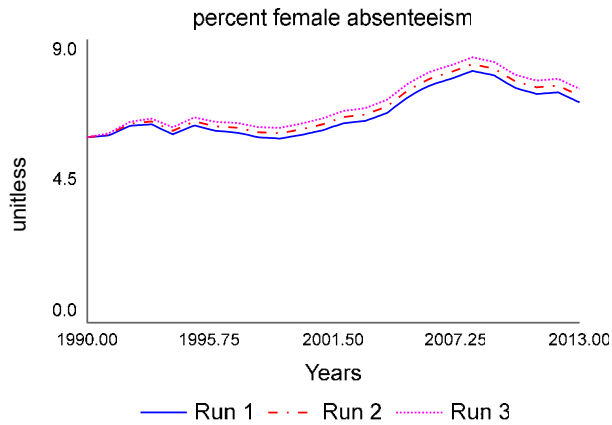
Figure 25: Sensitivity test of the non-linear graphical function shown in Figure 24. Run 1 is a decrease of 25% of the effect, Run 2 is same behavior shown in the reference mode in Figure 1, and Run 3 is an increase of 25% of the effect.

A.5 Copy of All Model Equations, Values and Data

This section provides all the equations, values and data used for each stock, flow and variable in the model. The equations are standard formulas for calculating their respective parameters. The variable assumptions were explained and tested in section A.4. Many of the variables represent constant parameter values. These values do not contain data but are required in the calculation of other variables. For example, in demography, the fertility period is 29 years. This is the number of years that the grouped fertile age categories add up to, and this value is a required value for the calculation of the annual fertility rate. In addition to equations, assumptions and values, many variables contain data. Although information about the data imported into the model has been explained throughout (SSB, Statsbudsjettet and NAV), the direct sources to the data are provided in this section. Only the variables with imported data (not equations, assumptions and values) have links to data sources.

A.5.1 Demography

annual_fertility_rate = total_fertility_rate/fertility_period

ave_juvenile_immigrant_% = 0.21
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

ave_la_immigrant_% = 0.014
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

ave_ra_immigrant_% = 0.001
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

ave_young_immigrant_% = 0.775
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

fertility_period = 29

fraction_female = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 0.505499022), (1990.95833333, 0.505628696), (1991.91666667, 0.505489005), (1992.875, 0.505387904), (1993.83333333, 0.505498385), (1994.79166667, 0.5055073), (1995.75, 0.505545478), (1996.70833333, 0.505512082), (1997.66666667, 0.505363434), (1998.625, 0.505197703), (1999.58333333, 0.504936589), (2000.54166667, 0.504533649), (2001.50, 0.504442685), (2002.45833333, 0.504397604), (2003.41666667, 0.504299221), (2004.375, 0.504148935), (2005.33333333, 0.50390682), (2006.29166667, 0.503157141), (2007.25, 0.501877809), (2008.20833333, 0.500952857), (2009.16666667, 0.500483204), (2010.125, 0.499858444), (2011.08333333, 0.498809435), (2012.04166667, 0.497966751), (2013.00, 0.497473897)

Immigrants(t) = Immigrants (t - dt) + (immigrating - emigrating) * dt

    INIT Immigrants = 150973
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

    INFLOWS:

        immigrating = total_immigration_all_categories

    OUTFLOWS:

        emigrating = total_emigration_all_categories

juvenile_death_rate = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=dode&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 0.000944505), (1991.00, 0.000608287), (1992.00, 0.000540565), (1993.00, 0.000416055), (1994.00, 0.000366845), (1995.00, 0.000389443), (1996.00, 0.00032462), (1997.00, 0.000306517), (1998.00, 0.000306517), (1999.00, 0.000306517), (2000.00, 0.000306517), (2001.00, 0.000306517),

(2002.00, 0.000306517), (2003.00, 0.000306517), (2004.00, 0.000306517), (2005.00, 0.000306517), (2006.00, 0.000306517), (2007.00, 0.000306517), (2008.00, 0.000306517), (2009.00, 0.000306517), (2010.00, 0.000306517), (2011.00, 0.000306517), (2012.00, 0.000306517), (2013.00, 0.000306517)

Juvenile_population_0_to_14(t) = Juvenile_population_0_to_14(t - dt) + (birth + juvenile_immgrants - maturation_1 - juvenile_death) * dt

   INIT Juvenile_population_0_to_14 = 805486
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

     TRANSIT TIME = 15

     CAPACITY = INF

     INFLOW LIMIT = INF

   INFLOWS:

     birth = young_adult_females*annual_fertility_rate

     juvenile_immgrants = net_yearly_migration*ave_juvenile_immigrant_%

   OUTFLOWS:

     maturation_1 = CONVEYOR OUTFLOW

     juvenile_death = LEAKAGE OUTFLOW

      LEAKAGE FRACTION = juvenile_death_rate

late_adult_death_rate = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=dode&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1.000, 0.00959598), (1.100, 0.007606802), (1.200, 0.006257955), (1.300, 0.005527259), (1.400, 0.005530952), (1.500, 0.005362506), (1.600, 0.00539485), (1.700, 0.005418383), (1.800, 0.005418383), (1.900, 0.005418383), (2.000, 0.005418383)

Late_adult_population_50_to_74(t) = Late_adult_population_50_to_74(t - dt) + (maturation_2 + late_adult_immigrants - maturation_3 - late_adult_death) * dt

   INIT Late_adult_population_50_to_74 = 918718
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

    TRANSIT TIME = 25

  INFLOWS:

    maturation_2 = CONVEYOR OUTFLOW

    late_adult_immigrants = net_yearly_migration*ave_la_immigrant_%

  OUTFLOWS:

    maturation_3 = CONVEYOR OUTFLOW

    late_adult_death = LEAKAGE OUTFLOW

     LEAKAGE FRACTION = late_adult_death_rate

life_expectancy_at_74 = 8
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=dode&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

net_yearly_migration = (immigrating-emigrating)

Retirement_age_population_74_plus(t) = Retirement_age_population_74_plus (t - dt) + (maturation_3 + retirement_age_immigrants - death) * dt

   INIT Retirement_age_population_74_plus = 556319
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

    TRANSIT TIME = life_expectancy_at_74

INFLOWS:

maturation_3 = CONVEYOR OUTFLOW

retirement_age_immigrants = net_yearly_migration*ave_ra_immigrant_%

OUTFLOWS:

death = CONVEYOR OUTFLOW

total_emigration_all_categories = GRAPH(TIME) [http://www.ssb.no/en/befolkning/statistikker/flytting]

(1990.00, 9768), (1991.00, 8357), (1992.00, 8057), (1993.00, 10451), (1994.00, 9583), (1995.00, 8992), (1996.00, 10032), (1997.00, 10034), (1998.00, 12005), (1999.00, 12690), (2000.00, 14931), (2001.00, 15216), (2002.00, 12273), (2003.00, 14345), (2004.00, 13856), (2005.00, 12628), (2006.00, 12490), (2007.00, 13324), (2008.00, 15158), (2009.00, 18381), (2010.00, 22496), (2011.00, 22883), (2012.00, 21298), (2013.00, 25036)

total_fertility_rate = GRAPH(TIME) [https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=fodte&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 1.930), (1991.00, 1.920), (1992.00, 1.880), (1993.00, 1.860), (1994.00, 1.870), (1995.00, 1.870), (1996.00, 1.890), (1997.00, 1.860), (1998.00, 1.810), (1999.00, 1.850), (2000.00, 1.850), (2001.00, 1.780), (2002.00, 1.750), (2003.00, 1.800), (2004.00, 1.830), (2005.00, 1.840), (2006.00, 1.900), (2007.00, 1.900), (2008.00, 1.960), (2009.00, 1.980), (2010.00, 1.950), (2011.00, 1.880), (2012.00, 1.850), (2013.00, 1.780)

total_immigration_all_categories = GRAPH(TIME): [https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=innvbef&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 11055), (1991.00, 11089), (1992.00, 12234), (1993.00, 16773), (1994.00, 11348), (1995.00, 10222), (1996.00, 9675), (1997.00, 11541), (1998.00, 14359), (1999.00, 22237), (2000.00, 18964), (2001.00, 17365), (2002.00, 22673), (2003.00, 19795), (2004.00, 21218), (2005.00, 23910), (2006.00,

29504), (2007.00, 44253), (2008.00, 48410), (2009.00, 43762), (2010.00, 50251), (2011.00, 54319), (2012.00, 56592), (2013.00, 54394)

total_population =
Juvenile_population_0_to_14+Young_adult_population_15_to_49+Late_adult_population_50_to_74+Retirement_age_population_74_plus

TOTAL_POPULATION_DATA = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 4233116), (1991.00, 4249830), (1992.00, 4273634), (1993.00, 4299167), (1994.00, 4324815), (1995.00, 4348410), (1996.00, 4369957), (1997.00, 4392714), (1998.00, 4417599), (1999.00, 4445329), (2000.00, 4478497), (2001.00, 4503436), (2002.00, 4524066), (2003.00, 4552252), (2004.00, 4577457), (2005.00, 4606363), (2006.00, 4640219), (2007.00, 4681134), (2008.00, 4737171), (2009.00, 4799252), (2010.00, 4858199), (2011.00, 4920305), (2012.00, 4985870), (2013.00, 5051275)

WORKING_AGE_POPULATION_DATA = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 2869311.0), (1991.00, 2874830.0), (1992.00, 2883629.0), (1993.00, 2893209.0), (1994.00, 2907091.0), (1995.00, 2918264.0), (1996.00, 2930775.0), (1997.00, 2943055.0), (1998.00, 2959590.0), (1999.00, 2977974.0), (2000.00, 3000841.0), (2001.00, 3019514.0), (2002.00, 3040080.0), (2003.00, 3068589.0), (2004.00, 3096463.0), (2005.00, 3127144.0), (2006.00, 3162792.0), (2007.00, 3202340.0), (2008.00, 3254045.0), (2009.00, 3306922.0), (2010.00, 3356935.0), (2011.00, 3406589.0), (2012.00, 3458409.0), (2013.00, 3503314.0)

working_age_population = Young_adult_population_15_to_49+Late_adult_population_50_to_74

young_adult_death_rate = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=dode&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

(1990.00, 0.001291134), (1991.00, 0.001258465), (1992.00, 0.001279504), (1993.00, 0.001105854), (1994.00, 0.000946978), (1995.00, 0.00096055), (1996.00, 0.00086333), (1997.00, 0.000872981), (1998.00, 0.000872981), (1999.00, 0.000872981), (2000.00, 0.000872981), (2001.00, 0.000872981), (2002.00, 0.000872981), (2003.00, 0.000872981), (2004.00, 0.000872981), (2005.00, 0.000872981), (2006.00, 0.000872981), (2007.00, 0.000872981), (2008.00, 0.000872981), (2009.00, 0.000872981), (2010.00, 0.000872981), (2011.00, 0.000872981), (2012.00, 0.000872981), (2013.00, 0.000872981)

young_adult_females = Young_adult_population_15_to_49*fraction_female

Young_adult_population_15_to_49(t) = Young_adult_population_15_to_49(t - dt) + (maturation_1 + young_immigrants - maturation_2 - young_adult_death) * dt

   INIT Young_adult_population_15_to_49 = 1950593
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=folkemengde&CMSSubjectArea=befolkning&PLanguage=1&checked=true]

     TRANSIT TIME = 35

   INFLOWS:

     maturation_1 = CONVEYOR OUTFLOW

     young_immigrants = net_yearly_migration*ave_young_immigrant_%

   OUTFLOWS:

     maturation_2 = CONVEYOR OUTFLOW

     young_adult_death = LEAKAGE OUTFLOW

       LEAKAGE FRACTION = young_adult_death_rate

A.5.2 General State Accounting

annual_petroleum_industry_income = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 30000), (1991.00, 37718), (1992.00, 29264), (1993.00, 34686), (1994.00, 33444), (1995.00, 36717), (1996.00, 58672), (1997.00, 82862), (1998.00, 46516), (1999.00, 51113), (2000.00, 156851), (2001.00, 188562), (2002.00, 148297), (2003.00, 163919), (2004.00, 194968), (2005.00, 268379), (2006.00, 342106), (2007.00, 299970), (2008.00, 397452), (2009.00, 304500), (2010.00, 287900), (2011.00, 313000), (2012.00, 412800), (2013.00, 401200)

ave_capital = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0.120634920635), (1991.00, 0.120634920635), (1992.00, 0.130158730159), (1993.00, 0.136507936508), (1994.00, 0.133333333333), (1995.00, 0.139682539683), (1996.00, 0.136507936508), (1997.00, 0.152380952381), (1998.00, 0.155555555556), (1999.00, 0.15873015873), (2000.00, 0.15873015873), (2001.00, 0.15873015873), (2002.00, 0.165079365079), (2003.00, 0.180952380952), (2004.00, 0.184126984127), (2005.00, 0.196825396825), (2006.00, 0.190476190476), (2007.00, 0.209523809524), (2008.00, 0.215873015873), (2009.00, 0.225396825397), (2010.00, 0.2333), (2011.00, 0.2316), (2012.00, 0.2448), (2013.00, 0.2677)

ave_compensation_of_labor = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0.203174603175), (1991.00, 0.203174603175), (1992.00, 0.209523809524), (1993.00, 0.209523809524), (1994.00, 0.228571428571), (1995.00, 0.228571428571), (1996.00, 0.222222222222), (1997.00, 0.228571428571), (1998.00, 0.234920634921), (1999.00, 0.24126984127), (2000.00, 0.247619047619), (2001.00, 0.260317460317), (2002.00, 0.260317460317), (2003.00, 0.2714), (2004.00, 0.2805), (2005.00, 0.3067), (2006.00, 0.2936), (2007.00, 0.3225), (2008.00, 0.3453), (2009.00, 0.3467), (2010.00, 0.3589), (2011.00, 0.3763), (2012.00, 0.3917), (2013.00, 0.4071)

ave_cost_per_absentee = .915
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=nav_statres&CMSSubjectArea=sosiale-forhold-og-kriminalitet&PLanguage=1&checked=true]

ave_tax_rate = GRAPH(TIME) [compiled from state budgets and revised state budgets 2002-2013; before 2002 behavior trends were followed to understand approximate model behavior: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0.023), (1991.00, 0.023), (1992.00, 0.023), (1993.00, 0.0231), (1994.00, 0.024), (1995.00, 0.0246), (1996.00, 0.025), (1997.00, 0.0255), (1998.00, 0.0254), (1999.00, 0.0252), (2000.00, 0.025), (2001.00, 0.0256), (2002.00, 0.0244), (2003.00, 0.0246), (2004.00, 0.0234), (2005.00, 0.0253), (2006.00, 0.0253), (2007.00, 0.0253), (2008.00, 0.0247), (2009.00, 0.0252), (2010.00, 0.0254), (2011.00, 0.0253), (2012.00, 0.0254), (2013.00, 0.0254)

ave_taxable_income = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0.146031746032), (1991.00, 0.165079365079), (1992.00, 0.165079365079), (1993.00, 0.165079365079), (1994.00, 0.177777777778), (1995.00, 0.184126984127), (1996.00, 0.190476190476), (1997.00, 0.203174603175), (1998.00, 0.203174603175), (1999.00, 0.209523809524), (2000.00, 0.209523809524), (2001.00, 0.215873015873), (2002.00, 0.215873015873), (2003.00, 0.234920634921), (2004.00, 0.234920634921), (2005.00, 0.247619047619), (2006.00, 0.275), (2007.00, 0.2933), (2008.00, 0.3138), (2009.00, 0.3237), (2010.00, 0.3319), (2011.00, 0.3456), (2012.00, 0.3607), (2013.00, 0.3751)

budget_surplus = (state_income+pension_fund_contribution_to_state_budget)-(other_expenditures+pension_transfers+absentee_expenditures)

capital_tax_rate = 0.01 [http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

employed_persons = labor_force*employment_rate

employer_fee = 0.141 [http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

employment_rate = GRAPH(TIME) [https://www.ssb.no/en/arbeid-og-lonn/statistikker/aku/kvartal]

(1990.00, 0.947712418), (1991.00, 0.944967074), (1992.00, 0.94084507), (1993.00, 0.940403566), (1994.00, 0.946071595), (1995.00, 0.95105215), (1996.00, 0.951785714), (1997.00, 0.959772628), (1998.00, 0.968144641), (1999.00, 0.968281183), (2000.00, 0.965531915), (2001.00, 0.964845404), (2002.00, 0.961312027), (2003.00, 0.955368421), (2004.00, 0.95549958), (2005.00, 0.95375), (2006.00, 0.965658217), (2007.00, 0.965149651), (2008.00, 0.965658217), (2009.00, 0.97447148), (2010.00, 0.974141258), (2011.00, 0.968339768), (2012.00, 0.963873943), (2013.00, 0.967287942)

General_fund(t) = General_fund (t - dt) + (pension_fund_contribution_to_state_budget + state_income - other_expenditures - pension_fund_income - pension_transfers - absentee_expenditures) * dt

INIT General_fund = 0

INFLOWS:

pension_fund_contribution_to_state_budget = Pension_fund*regulated_interest_rate

state_income =
income_from_all_other_categories+total_employer_tax_income+annual_petroleum_industry_income+income_tax_contribution+total_capital_tax+income_tax_rev_for_pension

OUTFLOWS:

other_expenditures = other_state_expenses

pension_fund_income = IF budget_surplus > 0 THEN budget_surplus ELSE 0

pension_transfers = total_pension_payouts

absentee_expenditures = ave_cost_per_absentee*total_absentees

income_from_all_other_categories = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 355222.35), (1991.00, 362889.4), (1992.00, 368000), (1993.00, 370555.3), (1994.00, 370555.3), (1995.00, 375667.05), (1996.00, 385889.4), (1997.00, 391000), (1998.00, 393555.3), (1999.00, 393555.3), (2000.00, 406332.95), (2001.00, 408889.4), (2002.00, 421667.05), (2003.00, 439010.2), (2004.00, 450264.1), (2005.00, 515127.55), (2006.00, 582588.85), (2007.00, 606726.2), (2008.00, 703775.85), (2009.00, 594652.35), (2010.00, 587679.9), (2011.00, 679230.25), (2012.00, 723990.55), (2013.00, 720545.15)

income_tax_contribution = total_taxable_income*ave_tax_rate

income_tax_rev_for_pension = total_taxable_income*pension_contribution_rate

labor_force = working_age_population*labor_force_participation_rate

labor_force_participation_rate = GRAPH(TIME) [https://www.ssb.no/en/arbeid-og-lonn/statistikker/aku/kvartal]

(1990.00, 0.692), (1991.00, 0.685), (1992.00, 0.684), (1993.00, 0.682), (1994.00, 0.686), (1995.00, 0.696), (1996.00, 0.712), (1997.00, 0.725), (1998.00, 0.733), (1999.00, 0.733), (2000.00, 0.734), (2001.00, 0.735), (2002.00, 0.735), (2003.00, 0.729), (2004.00, 0.726), (2005.00, 0.724), (2006.00, 0.720), (2007.00, 0.728), (2008.00, 0.720), (2009.00, 0.728), (2010.00, 0.739), (2011.00, 0.728), (2012.00, 0.719), (2013.00, 0.714)

other_state_expenses = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 272037.35), (1991.00, 314156.6), (1992.00, 330023.82), (1993.00, 353985.44), (1994.00, 366248.5), (1995.00, 350483.11), (1996.00, 353264.44), (1997.00, 383874.44), (1998.00, 427891.01), (1999.00, 446288.35), (2000.00, 445673.79), (2001.00, 462213.39), (2002.00, 520042), (2003.00, 520353.6), (2004.00, 561007.07), (2005.00, 582121.38), (2006.00, 614128.9), (2007.00, 642946.27), (2008.00, 707581.71), (2009.00, 806667.08), (2010.00, 822964.31), (2011.00, 895817.29), (2012.00, 940457.43), (2013.00, 1029443.45)

pension_contribution_rate = 0.08 [http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

Pension_fund(t) = Pension_fund (t - dt) + (pension_fund_income + interest - pension_fund_contribution_to_state_budget) * dt

  INIT Pension_fund = 0

  INFLOWS:

    pension_fund_income = IF budget_surplus > 0 THEN budget_surplus ELSE 0

    interest = Pension_fund*pension_fund_interest

  OUTFLOWS:

    pension_fund_contribution_to_state_budget = Pension_fund*regulated_interest_rate

PENSION_FUND_DATA = GRAPH(TIME) [https://www.nbim.no/en/the-fund/market-value/]

(1990.00, 0), (1991.00, 0), (1992.00, 0), (1993.00, 0), (1994.00, 0), (1995.00, 0), (1996.00, 0), (1997.00, 0), (1998.00, 0), (1999.00, 0), (2000.00, 0), (2001.00, 649750), (2002.00, 666000), (2003.00, 856614),

(2004.00, 1053063), (2005.00, 1335291), (2006.00, 1669755), (2007.00, 2182000), (2008.00, 2594000), (2009.00, 2915000), (2010.00, 2824000), (2011.00, 3481000), (2012.00, 3543000), (2013.00, 4426000)

pension_fund_interest (average) = 0.05 [https://www.nbim.no/en/the-fund/market-value/key-figures/]

regulated_interest_rate = 0.04 [http://www.statsbudsjettet.no/Statsbudsjettet-2013/Statsbudsjettet-fra-A-til-A/Handlingsregelen-retningslinjer-for-budsjettpolitikken/]

security_fee = 0.081 [http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

STATE_INCOME_DATA = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0), (1991.00, 0), (1992.00, 0), (1993.00, 0), (1994.00, 0), (1995.00, 498966), (1996.00, 554180), (1997.00, 597481), (1998.00, 586383), (1999.00, 654994), (2000.00, 845756), (2001.00, 877398), (2002.00, 855218), (2003.00, 883513), (2004.00, 986211), (2005.00, 1120291), (2006.00, 1290887), (2007.00, 1362449), (2008.00, 1520367), (2009.00, 1354127), (2010.00, 1433283), (2011.00, 1580595), (2012.00, 1664677), (2013.00, 1679327)

total_capital_tax = total_population*ave_capital*capital_tax_rate

total_employer_tax_income = total_labor_compensation*employer_fee+total_labor_compensation*security_fee

total_labor_compensation = employed_persons*ave_compensation_of_labor

total_taxable_income = employed_persons*ave_taxable_income

A.5.3 Pension

at = 1

ave_female_salary = GRAPH(TIME)
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=selvangivelse&CMSSubjectArea=inntekt-og-forbruk&PLanguage=1&checked=true]

(1990.00, 0.131), (1991.00, 0.142), (1992.00, 0.146), (1993.00, 0.157), (1994.00, 0.161), (1995.00, 0.179), (1996.00, 0.190), (1997.00, 0.21702), (1998.00, 0.233016), (1999.00, 0.242292), (2000.00, 0.254556), (2001.00, 0.26598), (2002.00, 0.284832), (2003.00, 0.295308), (2004.00, 0.306948), (2005.00, 0.31716), (2006.00, 0.331836), (2007.00, 0.349644), (2008.00, 0.372684), (2009.00, 0.384), (2010.00, 0.4008), (2011.00, 0.4176), (2012.00, 0.4368), (2013.00, 0.450)

ave_male_salary = GRAPH(TIME)

[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=selvangivelse&CMSSubjectArea=inntekt-og-forbruk&PLanguage=1&checked=true]

(1990.00, 0.241), (1991.00, 0.245), (1992.00, 0.248), (1993.00, 0.252), (1994.00, 0.252), (1995.00, 0.252), (1996.00, 0.252), (1997.00, 0.259284), (1998.00, 0.278724), (1999.00, 0.2904), (2000.00, 0.304896), (2001.00, 0.3192), (2002.00, 0.339348), (2003.00, 0.35046), (2004.00, 0.362604), (2005.00, 0.374412), (2006.00, 0.392064), (2007.00, 0.41484), (2008.00, 0.438384), (2009.00, 0.4536), (2010.00, 0.4716), (2011.00, 0.4896), (2012.00, 0.5052), (2013.00, 0.5244)

ave_position_percent_female = shared_care_effect_female

ave_position_percent_male = shared_care_effect_male

chg_in_cch_at = 1

child_care_resources_policy = GRAPH(pension_inequality)

(0.000, 2.000), (0.100, 1.893), (0.200, 1.796), (0.300, 1.694), (0.400, 1.592), (0.500, 1.490), (0.600, 1.393), (0.700, 1.291), (0.800, 1.199), (0.900, 1.107), (1.000, 1.000)

childcare_gap = total_required_childcare_hours-Childcare_hours

Childcare_hours(t) = Childcare_hours (t - dt) + (chg_in_cch) * dt

  INIT Childcare_hours = 0

  INFLOWS:

    chg_in_cch = (desired_childcare_hours-Childcare_hours)/chg_in_cch_at

desired_childcare_hours = MIN((child_care_resources_policy) *hours_mltp, 36)

hours_mltp = 12

female_retirement_population = total_pensioners*percent_elderly_female

late_adult_pensioners = Late_adult_population_50_to_74*pensioner_percent_62_to_73

male_retirement_population = total_pensioners*percent_elderly_male

pension_inequality = total_yearly_pension_amt_f/total_yearly_pension_amt_m

pension_mltp = .007

pension_point_mltp = 1.675

pension_points_f = pension_point_mltp*Total_lifetime_income_f

pension_points_m = pension_point_mltp*Total_lifetime_income_m

percent_shared_care_female = 1

percent_shared_care_male = 0

pensioner_percent_62_to_73 = .35
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=nav_statres&CMSSubjectArea=sosiale-forhold-og-kriminalitet&PLanguage=1&checked=true]

percent_elderly_female = .52 [https://www.ssb.no/en/befolkning/statistikker/folkemengde]

percent_elderly_male = .48 [https://www.ssb.no/en/befolkning/statistikker/folkemengde]

shared_care_effect_female = GRAPH(shared_cared_hours_female)

(0.00, 0.9864), (1.01265822785, 0.9848), (2.0253164557, 0.9773), (3.03797468354, 0.97425), (4.05063291139, 0.9682), (5.06329113924, 0.9636), (6.07594936709, 0.9591), (7.08860759494, 0.9561), (8.10126582278, 0.9515), (9.11392405063, 0.9485), (10.1265822785, 0.9424), (11.1392405063, 0.9394), (12.1518987342, 0.9364), (13.164556962, 0.9326), (14.1772151899, 0.9288), (15.1898734177, 0.9212),

(16.2025316456, 0.9174), (17.2151898734, 0.9136), (18.2278481013, 0.9106), (19.2405063291, 0.9076), (20.253164557, 0.9015), (21.2658227848, 0.8955), (22.2784810127, 0.8909), (23.2911392405, 0.8894), (24.3037974684, 0.8833), (25.3164556962, 0.8803), (26.3291139241, 0.8788), (27.3417721519, 0.8742), (28.3544303797, 0.8712), (29.3670886076, 0.8697), (30.3797468354, 0.8667), (31.3924050633, 0.8621), (32.4050632911, 0.8606), (33.417721519, 0.8545), (34.4303797468, 0.8485), (35.4430379747, 0.8394), (36.4556962025, 0.8288), (37.4683544304, 0.8258), (38.4810126582, 0.8197), (39.4936708861, 0.8182), (40.5063291139, 0.8152), (41.5189873418, 0.8106), (42.5316455696, 0.8045), (43.5443037975, 0.7985), (44.5569620253, 0.7955), (45.5696202532, 0.7909), (46.582278481, 0.7864), (47.5949367089, 0.7803), (48.6075949367, 0.7788), (49.6202531646, 0.7758), (50.6329113924, 0.7712), (51.6455696203, 0.7682), (52.6582278481, 0.7621), (53.6708860759, 0.7576), (54.6835443038, 0.7545), (55.6962025316, 0.7530), (56.7088607595, 0.7500), (57.7215189873, 0.7439), (58.7341772152, 0.7394), (59.746835443, 0.7364), (60.7594936709, 0.7348), (61.7721518987, 0.7318), (62.7848101266, 0.7288), (63.7974683544, 0.7258), (64.8101265823, 0.7235), (65.8227848101, 0.7212), (66.835443038, 0.7167), (67.8481012658, 0.7121), (68.8607594937, 0.70985), (69.8734177215, 0.7045), (70.8860759494, 0.7030), (71.8987341772, 0.6985), (72.9113924051, 0.6955), (73.9240506329, 0.6924), (74.9367088608, 0.6879), (75.9493670886, 0.6773), (76.9620253165, 0.6727), (77.9746835443, 0.6712), (78.9873417722, 0.6682), (80.00, 0.6515)

shared_care_effect_male = GRAPH(shared_care_hours_male)

(0.00, 1.0000), (1.01265822785, 0.9967), (2.0253164557, 0.9951), (3.03797468354, 0.9935), (4.05063291139, 0.9919), (5.06329113924, 0.9886), (6.07594936709, 0.9853), (7.08860759494, 0.9805), (8.10126582278, 0.9788), (9.11392405063, 0.9740), (10.1265822785, 0.9674), (11.1392405063, 0.9658), (12.1518987342, 0.9609), (13.164556962, 0.9593), (14.1772151899, 0.9544), (15.1898734177, 0.9495), (16.2025316456, 0.9414), (17.2151898734, 0.9381), (18.2278481013, 0.9316), (19.2405063291, 0.9267), (20.253164557, 0.9219), (21.2658227848, 0.9170), (22.2784810127, 0.9121), (23.2911392405, 0.9105), (24.3037974684, 0.9056), (25.3164556962, 0.9007), (26.3291139241, 0.8958), (27.3417721519, 0.8926), (28.3544303797, 0.8909), (29.3670886076, 0.8877), (30.3797468354, 0.88445), (31.3924050633, 0.8812), (32.4050632911, 0.8714), (33.417721519, 0.868133333333), (34.4303797468, 0.864866666667), (35.4430379747, 0.8616), (36.4556962025, 0.8519), (37.4683544304, 0.8453), (38.4810126582, 0.8388), (39.4936708861, 0.8323), (40.5063291139, 0.8307), (41.5189873418, 0.8274), (42.5316455696, 0.8258), (43.5443037975, 0.8226), (44.5569620253, 0.8193), (45.5696202532, 0.8177), (46.582278481, 0.8160), (47.5949367089, 0.8112), (48.6075949367, 0.8079), (49.6202531646, 0.8047), (50.6329113924, 0.7998), (51.6455696203, 0.7949), (52.6582278481, 0.7916), (53.6708860759, 0.7867),

(54.6835443038, 0.7819), (55.6962025316, 0.7786), (56.7088607595, 0.7770), (57.7215189873, 0.7721), (58.7341772152, 0.7688), (59.746835443, 0.7656), (60.7594936709, 0.7623), (61.7721518987, 0.7591), (62.7848101266, 0.7526), (63.7974683544, 0.7460), (64.8101265823, 0.7347), (65.8227848101, 0.7265), (66.835443038, 0.7216), (67.8481012658, 0.7167), (68.8607594937, 0.7135), (69.8734177215, 0.7070), (70.8860759494, 0.7037), (71.8987341772, 0.6972), (72.9113924051, 0.6907), (73.9240506329, 0.6858), (74.9367088608, 0.6809), (75.9493670886, 0.6777), (76.9620253165, 0.6744), (77.9746835443, 0.6712), (78.9873417722, 0.6647), (80.00, 0.6500)

shared_care_hours_male = percent_shared_care_male*childcare_gap

shared_cared_hours_female = childcare_gap*percent_shared_care_female

total_income_f = ave_female_salary*years_of_employment*ave_position_percent_female

total_income_m = ave_position_percent_male*ave_male_salary*years_of_employment

Total_lifetime_income_f(t) = Total_lifetime_income_f (t - dt) + (chg_in_total_lifetime_income_f) * dt

   INIT Total_lifetime_income_f = 6
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=selvangivelse&CMSSubjectArea=inntekt-og-forbruk&PLanguage=1&checked=true]

   INFLOWS:

     chg_in_total_lifetime_income_f = (total_income_f-Total_lifetime_income_f)/at

Total_lifetime_income_m(t) = Total_lifetime_income_m (t - dt) + (chg_in_total_lifetime_income_m) * dt

   INIT Total_lifetime_income_m = 10
[https://www.ssb.no/statistikkbanken/selecttable/hovedtabellHjem.asp?KortNavnWeb=selvangivelse&CMSSubjectArea=inntekt-og-forbruk&PLanguage=1&checked=true]

   INFLOWS:

   chg_in_total_lifetime_income_m = (total_income_m-Total_lifetime_income_m)/at

total_pension_payouts = ((total_yearly_pension_amt_m*male_retirement_population)
+(total_yearly_pension_amt_f*female_retirement_population))

total_required_childcare_hours = 84

total_yearly_pension_amt_f = pension_mltp*pension_points_f

total_yearly_pension_amt_m = pension_points_m*pension_mltp

total_pensioners = late_adult_pensioners+Retirement_age_population_74_plus

TOTAL_PENSION_PAYOUTS_DATA = GRAPH(TIME) [compiled from state budgets and revised state budgets 1990-2013: http://www.statsbudsjettet.no/Statsbudsjettet-2013/]

(1990.00, 0), (1991.00, 0), (1992.00, 0), (1993.00, 0), (1994.00, 0), (1995.00, 0), (1996.00, 0), (1997.00, 0), (1998.00, 0), (1999.00, 0), (2000.00, 0), (2001.00, 68659), (2002.00, 72440), (2003.00, 77128), (2004.00, 81113), (2005.00, 85457), (2006.00, 90382), (2007.00, 97311), (2008.00, 105221), (2009.00, 112789), (2010.00, 120592), (2011.00, 134693), (2012.00, 150704), (2013.00, 164763)

TOTAL_YEARLY_PENSION_F_DATA = GRAPH(TIME) [https://www.ssb.no/statistikkbanken/SelectVarVal/Define.asp?MainTable=PensjInnt05&KortNavnWeb=ifhus&PLanguage=1&checked=true]

(1990.00, 0.0), (1991.00, 0.0), (1992.00, 0.0), (1993.00, 0.0), (1994.00, 0.0), (1995.00, 0.0), (1996.00, 0.0), (1997.00, 0.0), (1998.00, 0.0), (1999.00, 0.0), (2000.00, 0.0), (2001.00, 0.0), (2002.00, 0.0), (2003.00, 0.0), (2004.00, 0.0), (2005.00, 0.0), (2006.00, 0.125264), (2007.00, 0.134188), (2008.00, 0.144669), (2009.00, 0.152585), (2010.00, 0.160481), (2011.00, 0.168335), (2012.00, 0.175145), (2013.00, 0.182435)

TOTAL_YEARLY_PENSION_M_DATA = GRAPH(TIME) [https://www.ssb.no/statistikkbanken/SelectVarVal/Define.asp?MainTable=PensjInnt05&KortNavnWeb=ifhus&PLanguage=1&checked=true]

(1990.00, 0.0), (1991.00, 0.0), (1992.00, 0.0), (1993.00, 0.0), (1994.00, 0.0), (1995.00, 0.0), (1996.00, 0.0), (1997.00, 0.0), (1998.00, 0.0), (1999.00, 0.0), (2000.00, 0.0), (2001.00, 0.0), (2002.00, 0.0), (2003.00, 0.0), (2004.00, 0.0), (2005.00, 0.0), (2006.00, 0.17215), (2007.00, 0.185097), (2008.00, 0.197944), (2009.00, 0.208961), (2010.00, 0.219765), (2011.00, 0.22945), (2012.00, 0.237064), (2013.00, 0.245067)

years_of_employment = 40

A.5.4 Absenteeism

absentees_from_other_diagnoses = GRAPH(TIME)

[https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

(1990.00, 150000), (1991.00, 150000), (1992.00, 160000), (1993.00, 162000), (1994.00, 155000), (1995.00, 169000), (1996.00, 169000), (1997.00, 174000), (1998.00, 174000), (1999.00, 174000), (2000.00, 179000), (2001.00, 186000), (2002.00, 195000), (2003.00, 195000), (2004.00, 205000), (2005.00, 225869), (2006.00, 243895), (2007.00, 258651), (2008.00, 268471), (2009.00, 274188), (2010.00, 265809), (2011.00, 256590), (2012.00, 258294), (2013.00, 247488)

Active_care_workers(t) = Active_care_workers (t - dt) + (hiring + recovery - attrition - getting_sick) * dt

 INIT Active_care_workers = 250000

 INFLOWS:

  hiring = (desired_care_workers-Active_care_workers)/hiring_time + attrition

  recovery = Care_worker_absentees*recovery_rate

 OUTFLOWS:

  attrition = (Active_care_workers)/adj_employment_time

  getting_sick = Active_care_workers*adj_sick_rate

adj_employment_time = effect_of_understaffing_on_attrition*ave_employment_time

adj_sick_rate = (sick_rate*(decision_making_effect*decision_making_effect_sen_test)) *fatigue

ave_employment_time = 40

Care_worker_absentees(t) = Care_worker_absentees (t - dt) + (getting_sick - recovery) * dt

   INIT Care_worker_absentees = 25000 [https://www.ssb.no/en/arbeid-og-lonn/statistikker/aku/kvartal]

  INFLOWS:

    getting_sick = Active_care_workers*adj_sick_rate

  OUTFLOWS:

    recovery = Care_worker_absentees*recovery_rate

case_mltpr = .27

decision_making_effect = GRAPH(ave_position_percent_female)

(0.7000, 2.0000), (0.7300, 1.9380), (0.7600, 1.8800), (0.7900, 1.8330), (0.8200, 1.7942), (0.8500, 1.7573), (0.8800, 1.7243), (0.9100, 1.6796), (0.9400, 1.6505), (0.9700, 1.6311), (1.0000, 1.6058)

decision_making_effect_sen_test = 1

desired_care_workers = 250000

effect_of_understaffing_on_attrition = GRAPH(understaffing)

(0.000, 0.000), (0.100, 0.091), (0.200, 0.172), (0.300, 0.230), (0.400, 0.276), (0.500, 0.329), (0.600, 0.414), (0.700, 0.490), (0.800, 0.543), (0.900, 0.686), (1.000, 1.000)

fatigue = GRAPH(understaffing)

(0.9, 1.986), (0.90625, 1.986), (0.9125, 1.957), (0.91875, 1.933), (0.925, 1.910), (0.93125, 1.886), (0.9375, 1.862), (0.94375, 1.848), (0.95, 1.833), (0.95625, 1.824), (0.9625, 1.819), (0.96875, 1.819), (0.975, 1.814), (0.98125, 1.810), (0.9875, 1.805), (0.99375, 1.800), (1, 1.781)

female_employee_percent = .47 [https://www.ssb.no/en/arbeid-og-lonn/statistikker/aku/kvartal]

female_employees = employed_persons*female_employee_percent

female_mental_health_absentees_other_professions = GRAPH(TIME)
[https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

(1990.00, 18000), (1991.00, 18000), (1992.00, 17700), (1993.00, 17600), (1994.00, 17500), (1995.00, 18000), (1996.00, 18100), (1997.00, 17900), (1998.00, 17700), (1999.00, 17600), (2000.00, 18100), (2001.00, 18200), (2002.00, 18500), (2003.00, 19300), (2004.00, 19400), (2005.00, 18800), (2006.00, 20080.5), (2007.00, 21195), (2008.00, 23065), (2009.00, 23107), (2010.00, 23637.5), (2011.00, 22647.5), (2012.00, 22633.5), (2013.00, 23177.5)

hiring_time = 0.5

male_employee_percent = .53 [https://www.ssb.no/en/arbeid-og-lonn/statistikker/aku/kvartal]

male_employees = employed_persons*male_employee_percent

percent_female_absenteeism = (total_female_absentees/female_employees) * 100

percent_male_absenteeism = (total_male_absentees/male_employees) * 100

recovery_rate = .114 [https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

sick_rate = .0052 [https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

total_female_absentees = (Care_worker_absentees+absentees_from_other_diagnoses+female_mental_health_absentees_other_professions) * case_mltpr

total_absentees = total_female_absentees+total_male_absentees

TOTAL_FEMALE_ABSENTEEISM_DATA = GRAPH(TIME)
[https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

(1990.00, 6.10), (1991.00, 6.10), (1992.00, 6.14), (1993.00, 6.71), (1994.00, 6.10), (1995.00, 6.05), (1996.00, 6.14), (1997.00, 6.14), (1998.00, 6.24), (1999.00, 6.43), (2000.00, 6.43), (2001.00, 6.43), (2002.00, 6.43), (2003.00, 6.71), (2004.00, 6.76), (2005.00, 7.40), (2006.00, 7.40), (2007.00, 7.50), (2008.00, 7.50), (2009.00, 8.10), (2010.00, 7.60), (2011.00, 7.10), (2012.00, 7.30), (2013.00, 7.00)

TOTAL_MALE_ABESENTEEISM_DATA = GRAPH(TIME)

[https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

(1990.00, 2.38), (1991.00, 2.52), (1992.00, 2.67), (1993.00, 2.86), (1994.00, 2.86), (1995.00, 2.90), (1996.00, 2.90), (1997.00, 2.95), (1998.00, 3.14), (1999.00, 3.14), (2000.00, 3.19), (2001.00, 3.29), (2002.00, 3.48), (2003.00, 3.67), (2004.00, 3.81), (2005.00, 4.50), (2006.00, 4.50), (2007.00, 4.50), (2008.00, 4.70), (2009.00, 5.00), (2010.00, 4.60), (2011.00, 4.10), (2012.00, 4.20), (2013.00, 4.10)

total_male_absentees = GRAPH(TIME)

[https://www.nav.no/no/NAV+og+samfunn/Statistikk/Sykefravar+-+statistikk/Sykefravar]

(1990.00, 24000), (1991.00, 25000), (1992.00, 25000), (1993.00, 26000), (1994.00, 24000), (1995.00, 24000), (1996.00, 29000), (1997.00, 27000), (1998.00, 26000), (1999.00, 32000), (2000.00, 44860), (2001.00, 48051), (2002.00, 49734), (2003.00, 49278), (2004.00, 40324), (2005.00, 44441), (2006.00, 44605), (2007.00, 46993), (2008.00, 51575), (2009.00, 49878), (2010.00, 49608), (2011.00, 46284), (2012.00, 48754), (2013.00, 48189)

understaffing = Active_care_workers/desired_care_workers