Models with Men and Women: Representing Gender in Dynamic Modeling of Social Systems

Erika Palmer[1] • Benedicte Wilson[2]

1 Department of Comparative Politics, University of Bergen, Postbox 7802, 5020 Bergen, Norway

2 System Dynamics Group, University of Bergen, Postbox 7802, 5020 Bergen, Norway

Abstract:

Dynamic engineering models have yet to be evaluated in the context of feminist engineering ethics. Decision-making concerning 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.

Keywords: applied feminist engineering ethics; gender; population modeling; policy; unintended consequences

Introduction

Dynamic engineering models, such as agent-based models, dynamic structural equation models 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. As the application of dynamic models in the analysis of gender issues has made some inroads (see Bleijenbergh et al. (2008) and Bleijenbergh and Van Engen (2015)), two issues are immediately apparent: first, dynamic modeling brings clarity to how the gender dimension in social systems works operationally while synthesizing many gender theories; and secondly, despite the distinct potential of using dynamic modeling in researching gender issues, there is very little research on such issues in the literature. In addition to this, regardless of the application area of the dynamic models, it is of growing importance, ethically, for all dynamic modelers to understand how their model design decisions regarding gender can negatively affect men and women.

Many dynamic models are built to show human behavior, but more often than not, the behavior of men represents that of all genders. When men and women are represented separately, it is in most cases in order to show the biological capacity of women (as in dynamic population models). In some cases, models could be improved by the addition of the concept of gender. In an effort to contribute to developing the literature on issues in applied feminist engineering ethics, this study seeks to put a focus on how dynamic models can be strengthened by being aware of and including the concept of gender where it is reasonable, as well as arguing for the application of feminist engineering ethics in modeling decision-making

This study goes beyond the application of dynamic models that have the specific purpose of analyzing gender issues. We specifically address the issue of how gender is represented in any dynamic model and the ethical issues regarding gender that arise in model design decision-making regardless of the research topic. This may not seem an obvious problem to address. Dynamic models are concerned with operational behavior, and men and women are represented in models when they are necessary to be included in the system structure. Nevertheless, we argue that the representation of men and women in many dynamic models lacks a gender perspective and that there is strong need for addressing ethical concerns regarding gender in model design decision-making. We illustrate this with the example of population modeling using system dynamics.

The research questions specifically addressed in this study are: *how is the concept of gender left out of dynamic modeling, and how could gender be included to increase model validity?* In order to address these questions, we first explain how the study illustrates an example of applied feminist engineering ethics and why it matters to those using dynamic modeling. We then use the example of a system dynamics model of a population aging chain to illustrate how gender is left out of models.

Feminist Engineering Ethics and Dynamic Model Design

The research question addressed in this study involves several ethical issues coming from various ethical perspectives. The dynamic model presented in this study gives an illustration of an applied engineering ethical issue. Dynamic models are tools best described as engineering artifacts (Olaya 2014), which when used, affect society. Which and how assumed causal relationships are represented in these models is a concern of modeling ethics in engineering (Herkert 2000). For example, the model scope defined by the model boundaries is a modeling ethics issue. A fundamental concept in dynamic modeling is design. There are nearly limitless ways to design a system of interest in a dynamic model. The modeler must make decisions about what to include in the model and how to represent the social elements that are included. The result of these decisions shapes the focus of the research, and if policy is designed based on the dynamic model, then the modeling decisions will influence society once the policy has been implemented.

Given that the dynamic models representing society can potentially have negative consequences (either unwanted or unintended), consequentialist ethics is also relevant. 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 (citation: anonymous for peer review). The net benefit of a decision is the result of positive and negative consequences of making the decision. In dynamic modeling, policy decisions for example are meant to increase the desirable dynamics of the system. However, there can be negative consequences as a result of implementing policies based on the chosen model design. All the consequences of a modeling decision cannot be known before a decision is made. These consequences can be limited, however, by consciously making decisions to include and accurately represent vital social elements in a dynamic model (such as gender) when they are an important part of the system of interest.

Encompassing both modeling ethics and consequentialist ethical issues in model design in this study highlighting the representation of gender in model design is the concept of applied feminist engineering ethics. As mentioned, feminist engineering ethics is a very new concept, and in this study, we explore this by applying it to a hypothetical population model. Although a hypothetical model is used to highlight feminist engineering ethics in decision-making in design, the model structures in the example are commonly used system structures in population studies. The modeling example was developed to highlight both how gender can easily be excluded when it is necessary to address a research problem and how it can easily be misrepresented when it is included in the model boundary. The effect of either not including or misrepresenting gender in model design can have serious consequences for men and women. Decision-making in model design concerning gender may involve a host of feminist ethical concerns. This study focuses on just one: *the difference between sex and gender*. In gender theory, 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 and Ferree 2015). Gender is therefore 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).

Why does this difference matter? 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 and 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 and etc. in many countries (Celis *et al*. 2013). Today, the importance of gender is widely acknowledged and recognized as a key focus area both on national and international levels, for governments as well as for organizations. Key international organizations such as the World Bank, OECD and the EU have developed strategies and initiatives with the common goal of closing the persistent gap in gender equality between women and men worldwide (World Bank 2016a; OECD 2016; European Union 2016). On the state level, governments are focusing their attention on national gender issues. Examples such as social policies for family balance found in the Nordic countries (Heikkila *et al.* 2002) and the United States initiative for gender equality in science, technology, engineering and mathematics (White House 2016) illustrate the variety in policy-making related to gender issues.

Dynamic modeling is often used to develop policy. Decision-making in model design regarding gender affects how policy solutions are designed. Regardless of whether the policy in question is related to health, welfare or taxes, if it does not take gender into account, it may create a variety of unintended negative consequences. These consequences take many forms, but are commonly affecting women’s lives in different ways than men’s, and many policies contribute to gender inequality. Examples range from abortion policy that leaves women without choice in determining their own life paths (Pop-Eleches 2006; Getgen 2008), family tax reforms that heavily tax the second earner (most often women) (Stotsky 1996; Cass and Brennan 2003), to welfare policy aimed at families but which fail to include fathers (Stapleton 1999; Brown *et al.* 2009). In light of feminist engineering ethical concerns in the model design phase, the modeler must consider the downstream effects of their decision-making in the representation of gender. The implications for policy that were designed without gender in mind -but that affect the genders differently- are often inefficient and contribute to undesirable system behavior.

For example, a policy that bans abortion compromises women's health by forcing them to seek illegal and unsafe abortions as well as burdening families with children they cannot support financially and thus increasing child poverty. A tax policy that heavily taxes the second earner can work as an incentive for women to stay away from paid work, which in turn leads to a decrease of the total labor force, a larger financial burden on men (which can take away from men the time and ability to build relationships with their families) but also creates large gender inequalities in terms of pensions. Welfare family policy that fails to include fathers upholds gender inequality by keeping fathers out of the home and mothers out of the workforce, not recognizing the importance of both genders when it comes to raising children. All of these examples indicate why feminist engineering ethics should form part of the ethical considerations in the design of both social and institutional modeling elements of dynamic models.

Given these policy examples, modelers who are working closely with policy-makers must include feminist engineering ethics as part of the model process and be aware of the implications of excluding gender from policy models. As food for thought, there is the econometrics model, pointed out by Barry Richmond (1993) about future milk production, which did not include the cows. This example can be viewed as a lesson, as highlighted by Olaya (2012), of the importance of operational thinking. Because those using dynamic modeling tools understand how important operational thinking is, why is the behavior of men taken as a representation of the behavior of all genders and the behavior specific to women often not included, even when if forms part of the operation? The following section demonstrates how dynamic models can lack a gender dimension even when it could be beneficial to include it.

Example: Population modeling

The representation of gender in terms of females versus women and males versus men in dynamic modeling is well illustrated with a system dynamics population model, i.e. the aging chain stock and flow structure. In Figure 1, there is a simple example of a population aging chain, without migration, based in the Norwegian context (the model is built using Norwegian population data, but the issues raised in this modeling example are not specific to Norway.) The female population is represented as a percentage of the fertile population (age 15-49). In this example, women are arguably represented, i.e. the modeler can point to the variable representing women. However, this is only representing human females, not the gender classification of woman. What is represented in the aging chain is the biological ability to have children. At first glance, this may not be perceived as a problem. Operationally, for example, population aging chains are used to understand birth rates. In the sense of "walking the line"-which is an important step in system dynamics methods- females are necessary for reproduction, and females are represented.

If a research question or model purpose only calls for a simple aging chain showing fertility as exogenous, then gender can arguably be given little to no attention in model design. However, if you are investigating and/or developing policy for any area that affects women, then the lack of gender in the model is a problem and feminist engineering ethical concerns should be addressed in the model design.

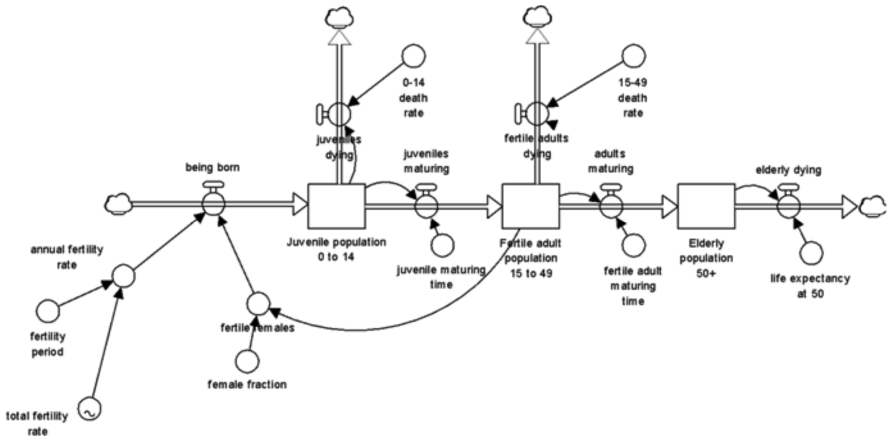


Figure 1: Basic population aging chain

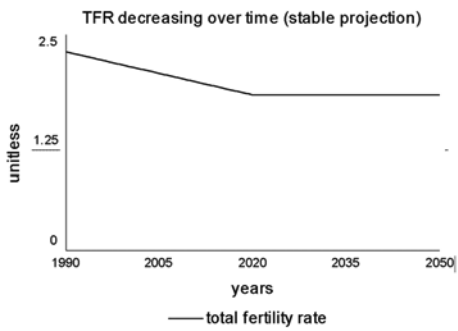


Figure 2: Total fertility rate leading to a decreased population over time (Figure 3)

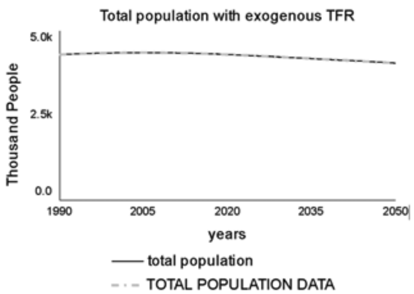


Figure 3: Total population compared with total population data

In the example shown in Figures 1, 2 and 3, the population behavior is decreasing over time. The total fertility rate (TFR) is decreasing over time and stabilizes at 1.8 in 2015, which is among the higher TFRs for Europe, but in this example, let us say that the problem is that the TFR is too low. After 2015, the model assumes an "all else being equal" scenario, meaning that the TFR is not expected to further decrease. Not all the women have children, and it should be noted that the TFR is an average for all women in the model. Some women have no children or fewer than the average, some have more than the average. Because TFR is exogenous, data is used for the TFR variable, leading to a perfect match of the simulation and actual system behavior shown in Figure 3. All model parameter settings and equations are listed in the Appendix.

Problem: who is it a problem for? Before addressing the feminist engineering ethical concerns in the design of the model, simply stating that the TFR is too low as a problem is indicative of a genderless perspective. A population decrease over time is not necessarily a problem for men or women. A society that produces fewer children could alter gender identity over time with a result that is more favorable for both genders. This is well illustrated by research that indicates that an increase in education levels for women leads to lower fertility rates (Jejeebhoy 1995). Education has long been acknowledged as a basic right for women (UN 1948), and getting access to education quite simply leaves women in a more favorable position than without it (World Bank 2016b). Keeping this in mind when considering the following decline in fertility that goes with it, it seems fair to conclude that women do not see having children as their only route to fulfilment. A population decrease does, however, have negative implications for many aspects of society (e.g. declining working age population (especially regarding the relationship with increasing automation and labor market dynamics), economic growth, etc.) that affects both women and men (and perhaps differently), but the impact on women and their welfare and gender identity is usually not part of the evaluation, even though women are fundamental in increasing the population. In addition to this, a population decrease does have positive benefits for both society and the environment, as it decreases the stress on environmental resources (Meadows et al. 1992).

Goal: who is this a desired behavior for? The first step in model design is identifying a system behavior that is undesirable with the goal of finding a solution to attain the desirable system behavior. The goal of increasing the TFR in order to increase the population implies that women will have to have more babies. This means much more than human females increasing the TFR as a response to policy. Having children and becoming mothers is part of the gender identity of women, but it is only *one* part. Women have always been more than child bearers in society. Nevertheless, the gender classification of woman has changed and developed in the direction of what has traditionally been seen as masculine. Having children is not a rational economic choice; it is a social investment (Palme 2009). Women will in many cases bear the brunt of the financial burden of childbearing/rearing and motherhood (citation: anonymous for peer review), which is a result of an increase in the TFR. There is a wage gap between men and women, women have less lifetime accumulated income (and pensions) and female-dominated jobs are less well-paid than male-dominated jobs. All of these examples are either directly or indirectly related to women having babies and raising children. With the goal of increasing the TFR, the direct impact on women is not being fully valued in this conceptualization of the model problem example.

Policy Structure and Policy Implementation: what is it doing and to whom? If gender is not represented in a model, this can lead to the design of some rather ineffective (or at worst harmful) policy model structures. In research from western countries, one of the most recognized social policies that can affect TFR is to increase the amount of state subsidized nursery care for children (Lister 2009; Jensen 2009). However, there are also many examples available that illustrate how policies that increase TFR can be harmful, like the recent call to completely ban abortion in Poland, regardless of whether or not the context of conception was rape, incest or if the mother was a child herself (Lindrea 2016). If the latter example had been approved as policy, one could expect a series of negative consequences for women, e.g. illegal and unsafe abortions compromising women's lives. In the context of feminist engineering ethics, the design of these policies, if they were designed using dynamic modeling, clearly involved unethical decision-making. If the modelers included gender in their model design and knew that women would die from illegal and unsafe abortions for example, then these are unwanted consequences (known but ignored). If they did not include gender in their model design and did not know what consequences the policy would bring, then these are unintended consequences (unknown). The ethical breach in unwanted consequences is clear, but it is more difficult with unintended consequences because of the impossibility of knowing all the consequences of decision-making in model design before decisions are made. This is where feminist engineering ethics can provide valuable guidance for dynamic modelers. By understanding gender and how to incorporate it in model design, this decreases the likelihood of downstream gender issues as a result of decision-making in model design.

Any type of mathematical modeling is an abstraction from reality. Models do not need to be perfect representations of reality in order to be useful, but this abstraction does have a cost. When stripping humans of their gender, as we did with women in the TFR example, it is easy to design policies that could hurt gender equality goals. Let us again use the population aging chain as an example. In Figure 1, the total fertility rate is exogenous. It may seem an obvious modeling solution to make the TFR endogenous in order to include gender. Models are nonetheless only as good/useful as the theories they are built upon. For the sake of this example, we make use of a theory used in fertility modeling: the Easterlin Hypothesis (Easterlin 1987). If you model the TFR to reflect the Easterlin Hypothesis, then income and standard of living will be important elements of the endogenous TFR. In this theory, as income increases, so does the number of births, and this again leads to the standard of living decreasing and then births in turn decrease. This balancing loop keeps the TFR stable in the long term but creates larger and smaller age groups in the medium term. 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 and Byun 2005; Jeon and Shields 2005). In addition to using Norwegian (not global) population dynamics as the basis for the modeling example, the Easterlin Hypothesis was used in the modeling example because of its prevalence in population economics and population dynamics literature. A very simple representation of the Easterlin Hypothesis is shown in Figure 4, where we see the interaction of two feedback loops (R1 and B1). The behavior of this model is similar to the model behavior shown in Figure 2 with the TFR stabilizing just above 1.8 (Figure 5). The income is represented as disposable income, which is the ratio of the fertile population/juvenile population. The TFR is a graphical function representing how as disposable income decreases/increases so does the TFR. The ratio between adults and children is used as a proxy, meaning that the more children per adult, the less disposable income a person has. Therefore, as disposable income increases, the TFR increases, which increases the births and juvenile population. As the juvenile population increases, the fertile adult population increases, which further increases disposable income (R1). At the same time, however, when the juvenile population increases, the disposable income decreases (B1). This leads to the stable behavior shown in Figure 5. Figure 6 shows the population behavior from the endogenous TFR compared with the actual population behavior. The comparison shows a reasonable fit between simulation and actual system behavior, contributing to the model's validity. This structure is built completely from the Easterlin Hypothesis, which is a genderless economic rationalization that can be used for an endogenous TFR. This is a simple example of an endogenous TFR used for illustrative purposes and would be built with a more complex structure for actual policy development.

In this model, the gender of women is still not represented, women are instead represented as human females. Among other concepts, the model lacks the concept of motherhood and fatherhood. What happens when you build policy structure on top of this? If the goal is to raise the TFR, then female labor force participation will be built into policy structure along with childcare resources in order to increase income and reduce expenses. This may seem like a great policy idea to both the modeler and the policy decision-maker, but an important question has not been asked: *Do women actually want more babies?* If income is increased and expenditures reduced in this policy structure (where women are treated as resources for social investment), but gender identity has evolved where couples want fewer babies, then the policy structure will have no effect on the behavior.

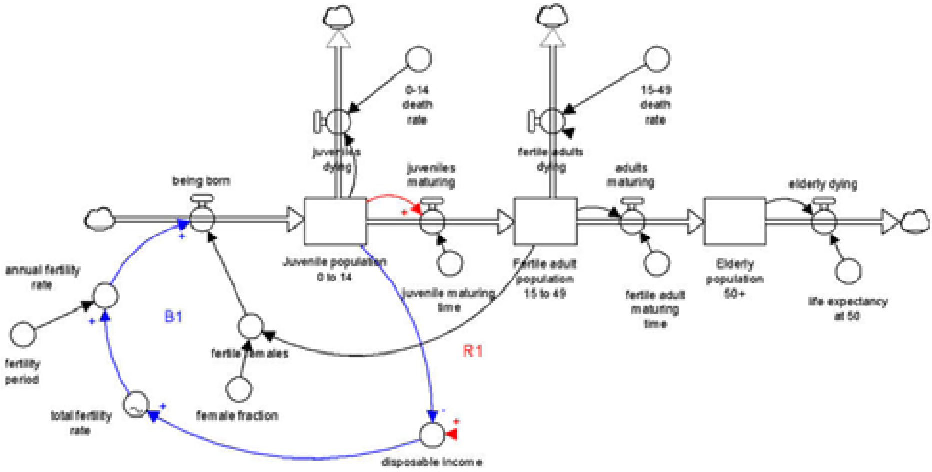


Figure 4: A simple representation of an endogenous TFR with two feedback loops (balancing loop B1 in blue and reinforcing loop R1 shown in red).

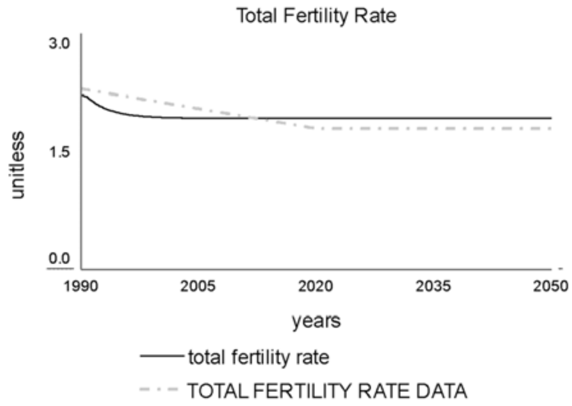


Figure 5: TFR with endogenous structure compared to TFR data

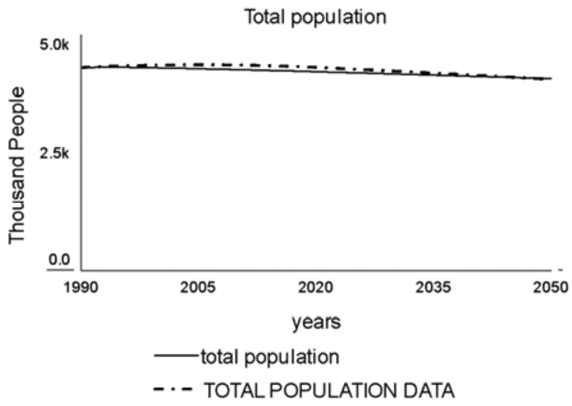


Figure 6: Total population with endogenous TFR compared with total population data (actual system behavior)

Models with Gender. If, as discussed above, the lack of gender in modeling is a problem and an ethical concern, how does one represent gender and what happens to the behavior of the model? Figure 7 shows a very simple representation of gender. The model is kept simple for this example to illustrate the complex nature of modeling gender, as there are many influences on TFR related to gender, and this example should not be taken as comprehensive. One gender issue regarding childcare is related to the motherhood/fatherhood burden (Lewis 2001). Women assume the majority of the parental duties and unpaid care work in the home, even if they are working full time jobs. Men retain their historical responsibility of supporting their family financially but do not partake much in the care of children and the affairs of the home. This is referred to as “the double burden” on women (Kostøl 2010; Crompton 1999; Lewis 1992). Though it forms part of their gender identity, women do not define themselves solely in terms of having children and caring for their family. Today, women and men are often dual earners, but they are not 50/50 shared caregivers, and this has led to women having a greater share of the unpaid care work at home once they have families (Esping-Andersen *et al.* 2002). This is simply represented in Figure 7 as the motherhood burden and the fatherhood burden, which influences the TFR. The more disposable income a family has, the greater the double burden because it means that women are working more. We introduced an exogenous policy of “childcare resources” in the model that affects disposable income. This allows for more disposable income, which will increase the TFR in models that do not include gender. Childcare resources have no effect on the motherhood/fatherhood burden because it increases the amount of paid work a woman can have and not the amount of unpaid care work she must do at home. When childcare resources are introduced, one type of work is substituted for another. Women use the childcare resources to go into paid work instead of doing unpaid care work at home. The burden effect then remains the same, although the burden category (paid vs. unpaid work) changes (citation: anonymous due to peer review).

Figure 7 shows a gender adjusted model, where disposable income matters, but so does the burden of motherhood. As disposable income increases, the average number of children per family will also increase. This then increases the motherhood burden, represented as an S-shaped curved graphical function (see Appendix). This graphical function states that as the average number of children increases, the motherhood burden increases at first slowly and then much more so with additional children. The fatherhood burden is 1-motherhood burden, representing that, although mothers take the vast majority of the parental burden, the father assumes the remaining burden. Once accounting for the fatherhood burden, the motherhood burden then affects the TFR, shown in Figure 7 as the "gender adjusted TFR." The TFR without gender (normal TFR) is 2- representing the replacement TFR (although this number varies depending on the country, we assume 2 for simplicity.)

Accounting for gender in model design results in the identification of the feedback loops shown in Figure 4, but with changed properties. B1 (in Figure 3) is no longer a balancing feedback loop, but a reinforcing loop (R2 in Figure 5), and R1 (in Figure 3) is now a balancing feedback loop (B2 in Figure 5). As disposable income increases the average number of children in a family increases, which increases the motherhood burden. This increased burden decreases the TFR, which decreases the number of babies being born and decreases the juvenile population. This then leads to more disposable income, creating a reinforcing feedback loop (R2). However, as the juvenile population decreases, over time, there are fewer fertile adults; leading to a decrease in disposable income. This is the balancing feedback loop (B2) that keeps the TFR stable. When childcare resources (increasing disposable income by 30%) are introduced in 2015 in order to increase the TFR – which would be a reasonable policy decision developed from the model shown in Figure 4- disposable income increases as shown in Figure 8. The population, however, declines at an even faster rate as shown in Figure 9. This is due to the gender adjusted TFR with the childcare resources policy in place, decreasing the TFR to 1.6 (Figure 10), which decreases the total population over time (all else being equal).

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 its concerns as feminist engineering ethics becomes better known in the engineering and scientific community.

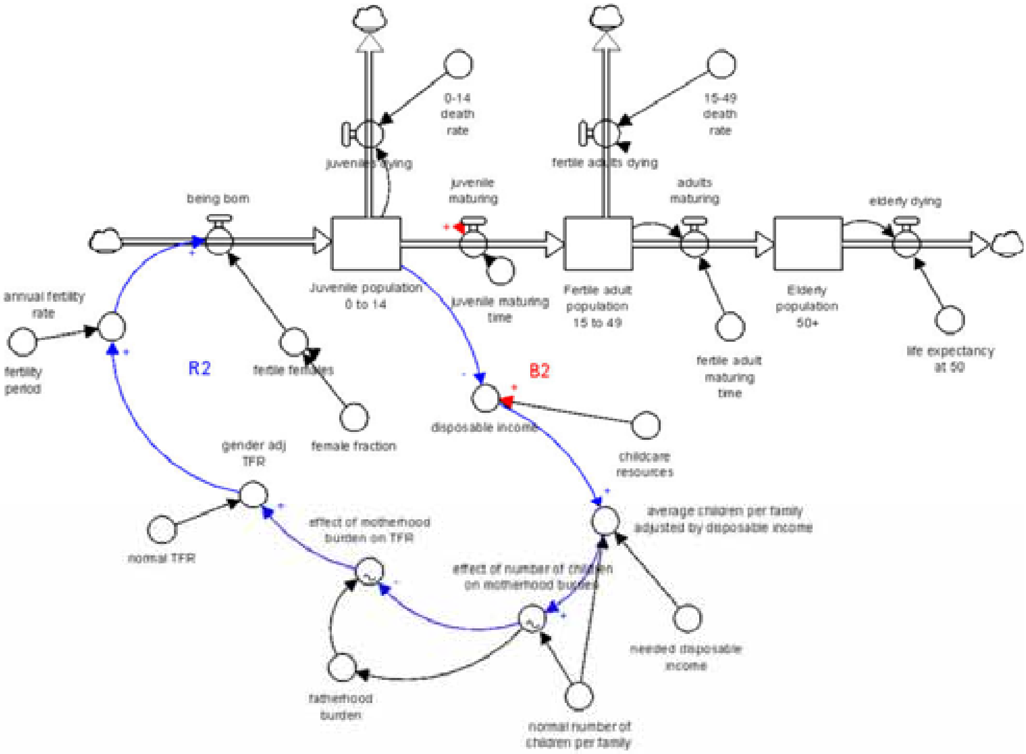


Figure 7: Population aging chain with gender represented

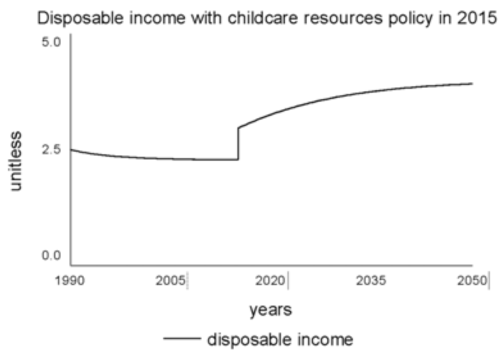


Figure 8: Disposable income decreasing and then increases as childcare resources (increased by 30%) allow for more double earner households and fewer childcare expenses

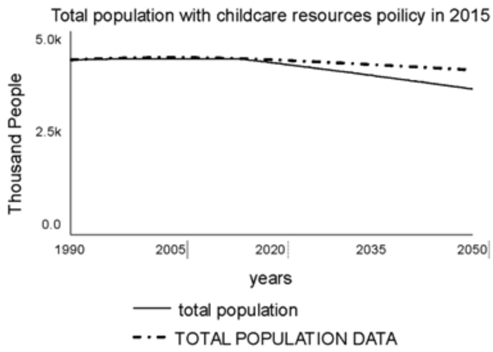


Figure 9: Population decline with a childcare resources policy in place, which was intended to increase/stabilize the total population. This is compared to the total population data which assumes a stable 1.8 TFR after 2015.

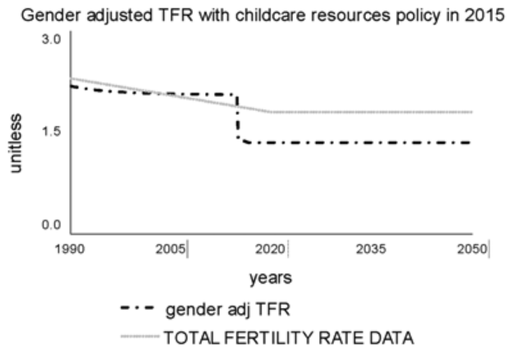


Figure 10: Gender adjusted total fertility rate showing the interaction of R2 and B2. This compared to TFR data, which is assumed to remain stable at 1.8 after 2015.

Concluding remarks

All modelers must concern themselves with gender when it is necessary in their modeling. A concern when discussing gender and modeling is that the genders should be treated identically in the model. Men and women are different, and the gender categories/spectrum have different attributes, which requires different model structures to give an accurate representation of gender. No one gender should be built into the model structure to represent an entire population that includes both men and women.

Another issue in discussing gender and modeling is that it is just a matter of naming variables; for example, changing the variable name of "fraction female" to "fraction women." As shown from the example given in this study, accommodating the concept of gender is not simply a matter of changing language. Nevertheless, words matter and the naming of variables influences decision-makers. At the 2016 System Dynamics Conference, Laura Black discussed the importance of words when naming variables (Black 2016). The level of abstraction, for example, was illustrated through Hayakawa's Abstraction Ladder (Hayakawa 1990). This explains that the further the words are from their actual intended meaning distorts communication. It is important to be specific in naming variables in modeling and describing the model so as not to detach the modeler and the decision-maker too far from reality. To demonstrate this, consider these two statements that describe the same thing:

1. *The female fraction of the fertile adult age group is multiplied by an annual fertility rate that is determined by the total fertility rate divided by the fertility period in order to determine the number of annual births.*

2. *Women have and care for babies both with and without the help of a dedicated partner. The number of babies that women and their partners decide to have is determined by a number of elements: life goals, education timing, professional goals, personal finances, their personal gender identity and more.*

The demonstration above illustrates how language can be a solution for helping modelers think about gender. The first statement does not include gender, and the second statement does. Language shapes our perspective. By using different words (such as in statement 2) and being less abstract, it is easier to understand and appreciate what the model is representing.

Works Cited

Black, L. (2016). From Situated Action to Model Abstraction—and Back Again. Plenary Presentation. *Proceedings of the 2016 International Conference of the System Dynamics Society.* Delft, NL, System Dynamics Society.

Bleijenbergh, I., Blonk, E., Schulte, L. and van Engen, M. (2008). Explaining Women's Careers at a Dutch university: Model building as a method for knowledge elicitation in gender analysis. In *Proceedings of the 2008 International Conference of the System Dynamics Society*. Athens, Greece, System Dynamics Society.

Bleijenbergh, I. and Van Engen, M. (2015). Participatory modeling to support gender equality: The importance of including stakeholders. *Equality, Diversity and Inclusion: An International Journal*, 34(5), 422-438.

Brown, L., Callahan, M., Strega, S., Walmsley, C. and Dominelli, L. (2009). Manufacturing ghost fathers: the paradox of father presence and absence in child welfare. *Child & Family Social Work*, 14, 25–34.

Cass, B. and Brennan, D. (2003). Taxing Women: The Politics of Gender in the tax/transfer System. St. Louis: Federal Reserve Bank of St Louis. http://search.proquest.com/docview/1698963367?accountid=8579. Accessed 14 Nov 2016.

Celis, K., Kantola, J., Waylen, G. and Weldon, S.L. (2013). Introduction: Gender and Politics: A Gendered World, a Gendered Discipline. *The Oxford Handbook of Gender and Politics*. Eds. Waylen, G., Celis, K., Kantola, J. and Weldon, S.L. Oxford (UK): Oxford University Press.

Crompton, R. (1999). *Restructuring gender relations and employment: The decline of the male breadwinner*. Oxford: Oxford University Press.

Easterlin, R. A. (1987). "Easterlin Hypothesis", in: Eatwell J., Murray M. & Newman P. (ed): The New Palgrave, A Dictionary of Economics 2, Stockton Press, New York, pp. 1-4

Esping-Andersen, G., Gallie, D., Hemerijck, A. and Myles, J. (2002). Why We Need a New Welfare State. Oxford (UK): Oxford University Press.

European Union. (2016). European Institute for Gender Equality (EIGE). http://europa.eu/european-union/about-eu/agencies/eige_en. Accessed 11 Nov 2016.

Fausto-Sterling, A. (2000). *Sexing the body: Gender politics and the construction of sexuality*. Basic Books.

Ferrant, G., Pesando, L.M. and Nowacka, K. (2014). Unpaid Care Work: The missing link in the analysis of gender gaps in labour outcomes, Issues paper, Issy-les-Moulineaux: OECD Development Centre. http://www.oecd.org/dev/development-gender/Unpaid_care_work.pdf. Accessed 10 May 10, 2017.

Getgen, Jocelyn E. (2008). Reproductive Injustice: An Analysis of Nicaragua's Complete Abortion Ban. *Cornell International Law Journal*, 41(1), 143-176.

Hayakawa, S. I. (1990). *Language in Thought and Action* (Fifth Edition). New York: Harcourt Brace & Company.

Heikkila, M., Hvinden, B. and Kautto, M. (2002). *Nordic Social Policy: Changing Welfare States*. London, US: Routledge.

Herkert, J. R. (2000). Engineering ethics education in the USA: Content, pedagogy and curriculum. *European Journal of Engineering Education*, 25(4), 303-313.

Jeanes, E., Knights, D. and Martin, P.Y. (2012). *Handbook of gender, work and organization.* London: John Wiley & Sons.

Jejeebhoy, Shireen J. (1995). Women's education, autonomy, and reproductive behaviour: Experience from developing countries. *OUP Catalogue*.

Jenson J. (2009). Lost in Translation: The Social Investment Perspective and Gender Equality. *Social Politics: International Studies in Gender, State & Society*, 16(4), 446–83.

Jeon, Y. and Shields M. P. (2005). The Easterlin hypothesis in the recent experience of higher-income OECD countries: A panel-data approach. *Journal of Population Economics*, 18(1), 1-13.

Kostøl, A. R. (2010). Kunnskapsoppsummering av samfunnsvitenskapelig litteratur om årsaker til sykefravær og utstøting. Kunnskapsoppsummering til Almlid-utvalget: Statistisk sentralbyrå.

Lewis, J. (1992). Gender and the Development of Welfare Regimes. *Journal of European Social Policy,* 2(3), 159 – 173.

Lewis, J. (2001). The decline of the male breadwinner model: implications for work and care. *Social Politics: International Studies in Gender, State & Society,* 8(2), 152-169.

Lindrea, V. (2016). Poland's parliament withdraws proposed abortion ban. *CNN*. http://edition.cnn.com/2016/10/06/europe/poland-abortion-ban-rejected/. Accessed 13 Oct 2016.

Lister, R. (2009). A Nordic nirvana? Gender, citizenship, and social justice in the Nordic welfare states. *Social Politics: International Studies in Gender, State & Society*, 16(2), 242-278.

Macunovich, D. (2011). Re-visiting the Easterlin Hypothesis: U.S. Fertility 1968-2010, IZA DP#5885.

Meadows, D., Meadows, D. and Randers, J. (1992). *Beyond the limits*. Post Mills, VT: Chelsea Green Publishing.

OECD. (2016). Gender Equality. *Organisation for Economic Co-operation and Development.* https://www.oecd.org/gender/. Accessed 11 Nov 2016.

Olaya C. (2012). Models that include cows: the significance of operational thinking. In *Proceedings of the 2012 International Conference of the System Dynamics Society*. St. Gallen, Switzerland, System Dynamics Society.

Olaya, C. (2014). The Scientist Personality of System Dynamics. In *Proceedings of the 32nd International Conference of the System Dynamics Society.* Delft, The Netherlands, System Dynamics Society.

Palme, J. (2009). The Quest for Sustainable Social Policies in the EU: The Crisis and Beyond. In: *What Future for Social Investment?* Eds: Nathalie Morel, Bruno Palier och Joakim Palme, Stockholm: Institutet för framtidsstudier, 177-193.

Pop-Eleches, C. (2006). The Impact of an Abortion Ban on Socioeconomic Outcomes of Children: Evidence from Romania. *Journal of Political Economy*, 114(4), 744-773.

Richmond, B. (1993). Systems thinking: critical thinking skills for the 1990s and beyond. *System Dynamics Review*, 9(2), 113-133.

Riley, D. (2013). Hidden in plain view: Feminists doing engineering ethics, engineers doing feminist ethics. *Science and Engineering Ethics*, 19(1), 189-206.

Stapleton, M. (1999). The Unnecessary Tragedy of Fatherless Children: Welfare Reform's Opportunities for Reversing Public Policies that Drove Low-Income Fathers Out of Their Children's Lives. *Clearinghouse Review*, 32(9 – 10), 492-502.

Stotsky, J. G. (1996). Gender Bias in Tax Systems. *IMF Working Paper*. https://ssrn.com/abstract=882995. Accessed 12 Nov 2016.

UN. (1948). General Assembly, Universal Declaration of Human Rights, *United Nations.* 10 December, 217 A (III). http://www.refworld.org/docid/3ae6b3712c.html. Accessed 13 Oct 2016.

Wade, L. and Ferree, M. M. (2015). *Gender: Ideas, interactions, institutions.* New York: W. W. Norton & Company.

Waldorf, B. and Byun, P. (2005). Meta-analysis of the impact of age structure on fertility. *Journal of Population Economics*, 18(1), 15-40.

West, C. and Zimmerman, D. (1987). Doing gender. *Gender & Society* 1(2), 125-151.

White House. (2016). Women in STEM. https://www.whitehouse.gov/administration/eop/ostp/women. Accessed 11 Nov 2016.

World Bank. (2016a). Gender. http://www.worldbank.org/en/topic/gender. Accessed 11 Nov 2016.

World Bank. (2016b). Girls Education. http://www.worldbank.org/en/topic/girlseducation/overview#1. Accessed 13 Oct 2016.

Appendix

All models were built using Stella Architect 1.0. There are three separate models, which correspond to the three models presented in this paper (structures shown in Figures 1, 4, 7). Below is the documentation for all variable in each model:

1. Population aging chain with exogenous total fertility rate (Figure 1 in text, Table 1 below)
2. Population aging chain with endogenous total fertility rate (Figure 4 in text, Table 2 below)
3. Population aging chain with endogenous total fertility rate including gender (Figure 7 in text, Table 3 below)

Table 1: Model Variables-Population aging chain with exogenous total fertility rate

Variable Name	**Variable Type**	**Units**	**Equation**
Juvenile population 0 to 14	Stock	Thousand People	800
Fertile adult population	Stock	Thousand People	2000

15 to 49			
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate
fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008
life expectancy at 50	Variable	Years	27
Juvenile maturing Time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
total fertility rate	Variable	Unitless	Data (Stable at 1.8 after 2018)

			total fertility rate 1990 2.3 1991 2.3 1992 2.3 1993 2.3 1994 2.2 1995 2.2 1996 2.2 1997 2.2 1998 2.2 1999 2.2 2000 2.1 2001 2.1 2002 2.1 2003 2.1 2004 2.1 2005 2.0 2006 2.0 2007 2.0 2008 2.0 2009 2.0 2010 2.0 2011 2.0 2012 1.9 2013 1.9 2014 1.9 2015 1.9 2016 1.9 2017 1.9 2018 1.8
annual fertility rate	Variable	Unitless	Total fertility rate / fertility period
fertility period	Variable	Per year	35
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+

Table 2: Model Variables-Population aging chain with endogenous total fertility rate

Variable Name	**Variable Type**	**Units**	**Equation**
Juvenile population	Stock	Thousand People	800

0 to 14			
Fertile adult population 15 to 49	Stock	Thousand People	2000
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate
fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008
life expectancy at 50	Variable	Years	27
Juvenile maturing time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
total fertility rate	Variable	Unitless	Disposable income

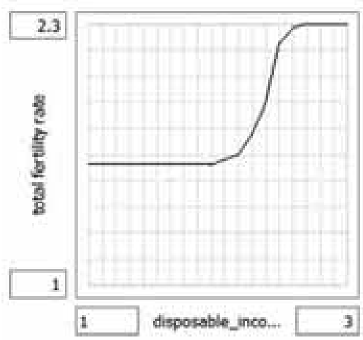
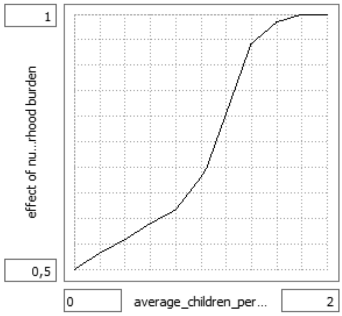
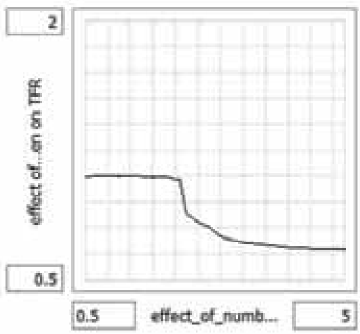
			
annual fertility rate	Variable	Unitless	Total fertility rate / fertility period
Fertility period	Variable	Per year	35
disposable income	Variable	Unitless	Fertile adult population 15 to 49 / Juvenile population 0 to 14
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+

Table 3: Model variables- Population aging chain with endogenous total fertility rate including gender

Variable Name	Variable Type	Units	Equation
Juvenile population 0 to 14	Stock	Thousand People	800
Fertile adult population 15 to 49	Stock	Thousand People	2000
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate

fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008
life expectancy at 50	Variable	Years	27
Juvenile maturing time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
normal TFR	Variable	Unitless	2
annual fertility rate	Variable	Unitless	Gender adjusted TFR / fertility period
fertility period	Variable	Per year	35
disposable income	Variable	Unitless	(Fertile adult population 15 to 49) / (Juvenile population 0 to 14) * childcare resources
gender adj TFR	Variable	Unitless	Normal TFR * effect of motherhood burden on TFR
childcare resources	Variable	Unitless	IF TIME > 2015 THEN 1.3 ELSE 1
average children per family adjusted by disposable income	Variable	Children	(disposable income / needed disposable income) * normal number of children per family
needed disposable income	Variable	Unitless	2.5
normal number of children per family	Variable	Children	2
effect of number of children on motherhood burden	Variable	Unitless	Average children per family adjusted by disposable income / normal number of children per family

			
fatherhood burden	Variable	Unitless	1 - effect of number of children on motherhood burden
effect of motherhood burden on TFR	Variable	Unitless	Effect of number of children on motherhood burden / fatherhood burden 
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+

Appendix

All models were built using Stella Architect 1.0. There are three separate models, which correspond to the three models presented in this paper (structures shown in Figures 1, 4, 7). Below is the documentation for all variable in each model:

1. Population aging chain with exogenous total fertility rate (Figure 1 in text, Table 1 below)
2. Population aging chain with endogenous total fertility rate (Figure 4 in text, Table 2 below)
3. Population aging chain with endogenous total fertility rate including gender (Figure 7 in text, Table 3 below)

Table 1: Model Variables-Population aging chain with exogenous total fertility rate

Variable Name	Variable Type	Units	Equation
Juvenile population 0 to 14	Stock	Thousand People	800
Fertile adult population 15 to 49	Stock	Thousand People	2000
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate
fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008
life expectancy at 50	Variable	Years	27
Juvenile maturing Time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
total fertility rate	Variable	Unitless	Data (Stable at 1.8 after 2018)

			total fertility rate 1990 2.3 1991 2.3 1992 2.3 1993 2.3 1994 2.2 1995 2.2 1996 2.2 1997 2.2 1998 2.2 1999 2.2 2000 2.1 2001 2.1 2002 2.1 2003 2.1 2004 2.1 2005 2.0 2006 2.0 2007 2.0 2008 2.0 2009 2.0 2010 2.0 2011 2.0 2012 1.9 2013 1.9 2014 1.9 2015 1.9 2016 1.9 2017 1.9 2018 1.8
annual fertility rate	Variable	Unitless	Total fertility rate / fertility period
fertility period	Variable	Per year	35
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+

Table 2: Model Variables: Population aging chain with endogenous total fertility rate

Variable Name	Variable Type	Units	Equation
Juvenile population 0 to 14	Stock	Thousand People	800
Fertile adult population 15 to 49	Stock	Thousand People	2000
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate
fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008
life expectancy at 50	Variable	Years	27
Juvenile maturing time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
total fertility rate	Variable	Unitless	Disposable income

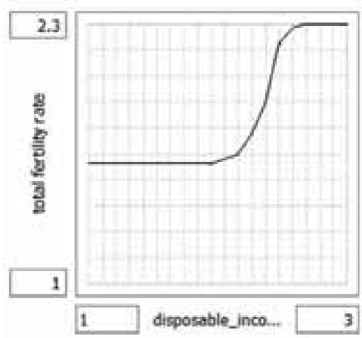
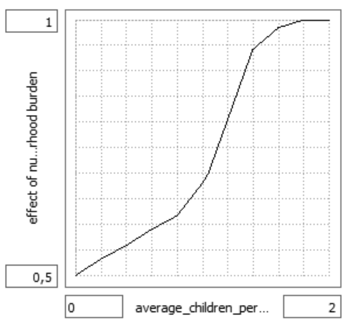
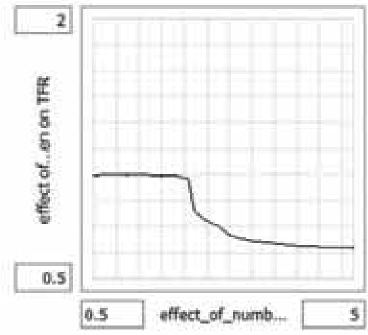
			
annual fertility rate	Variable	Unitless	Total fertility rate / fertility period
Fertility period	Variable	Per year	35
disposable income	Variable	Unitless	Fertile adult population 15 to 49 / Juvenile population 0 to 14
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+

Table 3: Model variables Population aging chain with endogenous total fertility rate including gender

Variable Name	**Variable Type**	**Units**	**Equation**
Juvenile population 0 to 14	Stock	Thousand People	800
Fertile adult population 15 to 49	Stock	Thousand People	2000
Elderly population 50+	Stock	Thousand People	1500
being born	Flow	Thousand People/year	Annual fertility rate * fertile females
juvenile maturing	Flow	Thousand People/year	Juvenile population 0 to 14 / juvenile maturing time
adults maturing	Flow	Thousand People/year	Fertile adult population 15 to 49 / fertile adult maturing time
elderly dying	Flow	Thousand People/year	Elderly population 50+ / life expectancy at 50
juveniles dying	Flow	Thousand People/year	Juvenile population 0 to 14 * 0-14 death rate
fertile adults dying	Flow	Thousand People/year	Fertile adult population 15 to 49 * 15-49 death rate
0-14 death rate	Variable	Per year	0.0003
15-49 death rate	Variable	Per year	0.0008

life expectancy at 50	Variable	Years	27
Juvenile maturing time	Variable	Years	15
fertile adult maturing time	Variable	Years	35
fertile females	Variable	Thousand People	Female fraction * Fertile adult population 15 to 49
female fraction	Variable	Unitless	0.5
normal TFR	Variable	Unitless	2
annual fertility rate	Variable	Unitless	Gender adjusted TFR / fertility period
fertility period	Variable	Per year	35
disposable income	Variable	Unitless	(Fertile adult population 15 to 49) / (Juvenile population 0 to 14) * childcare resources
gender adj TFR	Variable	Unitless	Normal TFR * effect of motherhood burden on TFR
childcare resources	Variable	Unitless	IF TIME > 2015 THEN 1.3 ELSE 1
average children per family adjusted by disposable income	Variable	Children	(disposable income / needed disposable income) * normal number of children per family
needed disposable income	Variable	Unitless	2.5
normal number of children per family	Variable	Children	2
effect of number of children on motherhood burden	Variable	Unitless	Average children per family adjusted by disposable income / normal number of children per family 
fatherhood burden	Variable	Unitless	1 - effect of number of children on motherhood burden
effect of motherhood	Variable	Unitless	Effect of number of children on motherhood burden / fatherhood burden

burden on TFR			
total population	Variable	Thousand People	Juvenile population 0 to 14 + Fertile adult population 15 to 49 + Elderly population 50+