DYNAMIC ANALYSIS OF PUBLIC HEALTH INSURANCE PROGRAMMES

by

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ABSTRACT

DYNAMIC ANALYSIS OF PUBLIC HEALTH INSURANCE PROGRAMMES

Effectiveness and continuity of public health insurance systems are facing significant threats from structural and demographic challenges such as principle-agent problems and population aging. In this thesis, we construct a multi-sector broad-boundary dynamic simulation model: i) to explore the underlying causal structure surrounding public health insurance systems, and ii) to analyze the operational causality that leads to the development of structural problems for single-payer health insurance models that is financed by employee contributions. The model is simulated under different parameter configurations to analyze the system behavior under different scenarios. We show that the austerity periods carry the danger of overlooking the critical essential demand which would leave collateral damage on population health, lasting long after the first reduction in coverages. Several policy options such as public revenue injections and labor immigration policies are tested to preserve the programme benefits in the long run. We find that greater magnitude interventions generally perform better even with low frequency when the early action is taken. We also show that the effectiveness of some policies are dependent on the scenario conditions. Although highly related, the population health and public programme benefits are found not to share the same exact dynamics and eventual fate. Consequently, the stabilization of programme variables does not necessarily mean a better population health outcome for all cases. As a further research avenue to this study, a multi-payer sector can be added to the model in order to conduct a comparative simulation analysis on the health systems performance of single-payer, multi-payer and hybrid insurance models.

ÖZET

KAMU SAĞLIK SİGORTASI PROGRAMLARININ DİNAMİK İNCELENMESİ

Kamu sağlık sigortası sistemlerinin etkinliği ve sürekliliği, asil-vekil problemleri ve yaşlanan nüfus gibi yapısal ve demografik zorluklardan kaynaklanan önemli tehditlerle karşı karşıyadır. Bu tezde, kamu sağlık sigortası programlarını çevreleyen sistem yapısını ve çalışan katkı payları ile finanse edilen sağlık sigortası modellerinde yapısal sorunların gelişmesine yol açan işleyişsel nedenselliği incelemek için; çok sektörlü ve geniş sınırlı dinamik bir simülasyon modeli kurulmuştur. Kurulan simülasyon modeli, farklı senaryolarda sistem davranışını analiz etmek için farklı parametre değerleriyle çalıştırılmıştır. Kemer sıkma dönemlerinin nüfus sağlığına ikincil zararlar bırakacak temel talebi göz ardı etme tehlikesini taşıdığı gösterilmiştir. Yaptığımız politika analizinde kamu geliri aktarımları ve işgücü göçü politikaları gibi çeşitli politika seçenekleri, programı uzun vadede sürdürmek için test edilmiştir ve daha büyük ölçekli müdahalelerin erken harekete geçmenin yararından dolayı düşük sıklıkta bile daha iyi performans gösterdiği bulunmuştur. Buna ek olarak bazı politikaların etkinliğinin senaryo koşulları- na bağlı olarak farklılık gösterdiği de gösterilmiştir. Büyük ölçüde ilişkili olmasına rağmen, nüfus sağlığı ve kamusal sigorta programının sürdürülebilirliğinin aynı dinamikleri ve nihai kaderi paylaşmadığı, program değişkenlerinin istikrarının tüm durumlar için mutlaka daha iyi bir nüfus sağlığıyla sonuçlanmayacağı sonucuna varılmıştır. Bu tezin üzerine gelecek çalışma olarak, modele çok ödemeli dinamikleri kapsayan bir sektör eklenip; tek ödemeli, çok ödemeli ve hibrit sigorta modellerinin sağlık sistemleri performansı üzerine karşılaştırmalı bir simülasyon analizi yapılabilir.

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LIST OF ACRONYMS/ABBREVIATIONS

CBR	Crude Birth Rate
CDR	Crude Death Rate
CE	Covered Elderly
CF	Contribution Fraction
CiD	Condition in Delay
CL	Coverage Level
CS	Cost-sharing Level
DC	Demand Coefficient
FER	Formal Employment Rate
FEW	Formally Employed Workforce
GC	Government Contributions
HF	Healthcare Fund
HI	Household Income
IER	Informal Employment Rate
IEW	Informally Employed Workforce
ILO	International Labor Organization
LFPR	Labor Force Participation Rate
PEss	Percentage of Essential Elastic Demand
PHS	Population Health Status
PS	Public Scheme
SDGs	Sustainable Development Goals
UE	Uncovered Elderly
UNDP	United Nations Development Programme
UR	Unemployment Rate
UVC	Unit Visit Cost
UW	Unemployed Workforce
YoW	Years of Work

1. INTRODUCTION

Societies have greater expectations of healthcare systems compared to other public services like education or employment, due to health being the central factor in the quality of life [1]. Similar to social determinants such as poverty and inequality; heterogeneity in access to healthcare services results in great inequalities in human life. The resulting discrepancy in health outcomes can be observed across or within countries, as evidenced by a nearly 50-year gap in life expectancy between Sierra Leone and Japan, and a 20-year gap between the most and least advantaged populations in the United States [2].

Access to quality healthcare has been described as a basic human right [3]. In this regard, the global effort toward removing financial barriers to healthcare is a major topic of discussion in the 21st century. Between 2000 and 2015, United Nations Millennium Development Goals (MDGs) have led to a significant progress in maternal and infant mortality reduction, the fight against malaria, and the decrease of HIV spread in developing countries [4]. The following globally endorsed agenda, Sustainable Development Goals (SDGs) of 2015, have a wider objective of increasing and sustaining health services in both developed and developing countries. The corresponding SDG, Goal 3: Good Health and Well-Being, calls for all member states to achieve Universal Health Coverage (UHC) by 2030. The path toward UHC is naturally challenging in middle- and low-income countries, due to the lack of resources, personnel, and funding [1]. However, changes in demographics and expansion of disease definitions threaten the sustainability of health services and national health insurance programmes in high-income countries as well [1–3].

Many industrialized countries achieved UHC in the 20th century, provided either by public health services or health insurance systems which improved the living conditions of their people tremendously [5]. It is crucial to stress that the healthcare systems of these countries vary greatly and there is no “gold standard” model that would work for every country. Each country establishes its health system based on

its socio-economic structure and socio-political paradigm, as well as its available resources [3]. That being said, there are some umbrella models which can be used to classify health systems based on their funding and service provision characteristics, such as the state-operated models of Bismarck and Beveridge [6, 7]. Both of these models provide UHC for their whole population with their funding respectively coming from employee contributions and public tax revenues. But some alarming factors threaten the effective continuity of these systems, such as the aging of the population, increased chronic disease prevalence, more expensive medicine and treatments, and endogenous principle-agent problems like moral hazard and adverse selection [1, 8].

With an aging population, the share of the revenue-generating portion in a population monotonically decreases. The direct consequence of this condition is a decrease in funding for public services since the working people are usually the source of funding. The Statutory Health Insurance (SHI) model of the Bismarck system, in particular, is more vulnerable to this condition as the funding comes directly from workers' salaries as a payroll deduction. Also, with an aging population, the prevalence of chronic diseases and the need for overall healthcare and care-giving services increases. The developments in medical technology work in favor of improving health outcomes, but also result in more expensive treatment procedures, medications, and vaccines.

Another significant risk of UHC is moral hazard. When services are available to every individual, people are inclined to over-utilize provided services. Thus, service might be based on demand and not on need, increasing costs even further [3, 5]. However, since the essential and inessential demand cannot be fully distinguished, effective demand targeting is usually not an option. Declining the essential demand allows them to develop into more serious conditions that will cost more in the future [8]. The presence of all these factors indicates a serious risk for the financial sustainability of UHC services in the mid-and long-term, with lower funding and higher costs.

In this thesis, our objective is to structurally analyze the statutory (or national, social) health insurance models using a multi-sector broad-boundary System Dynamics (SD) model to understand the interplay of the endogenous causal mechanisms that

create the scene for inefficiencies in such models. The simulation model is constructed for a population with a single centralized healthcare fund financed by payroll taxation. The healthcare demand is modeled as a function of public programme, varying for programme benefits, while the healthcare service affects the public programme through varying service rates and expenditure. We endogenize demographic and economic developments to account for the feedback between healthcare services and socio-economic gradient. We examine the dynamics in public programme benefits and their effect on population health under various scenarios such as rising or decreasing healthcare costs and increasing or decreasing birth rate.

Alternative policy measures are tested to sustain the system financially and increase its resilience against possible disturbances. In this regard, we analyze several options such as labor immigration and public revenue injection policies in terms of their dynamic impacts on the overall system.

The thesis is organized as follows: In chapter 2, we provide a brief background of health insurance in social policy parlance and clarify our objectives in chapter 3. Chapter 4 briefly explains the System Dynamics (SD) methodology and justifies the method selection of this thesis. In chapter 5, we introduce our causal loop diagrams and stock-flow simulation model architecture for each sector. We discuss the parametrization process and test the model credibility in chapter 6. Scenario analysis and policy analysis chapters follow in chapters 7 and 8. Chapter 9 concludes the thesis with a future road map and other potential avenues to visit in further research.

2. BACKGROUND

Public responsibility for health has a long history going back to the ancient city-states of Greece where doctors are employed to serve the poor [3]. Following the industrial developments in the modern age of the 18th and 19th centuries, state-operated public health systems are constructed as part of their welfare regimes to combat communicable diseases among workers [5]. There are several explanations behind the motivation of this endeavor. Navarro argues that these systems were constructed to ensure the well-being of laborers, who are important parts of capitalist production [9]. In an alternative explanation, Foucault suggests that the public coverages were constructed to allow states to hold important leverage of governmental "power" over the lives of the population [10]. The explanation of Navarro is especially important to understand the foundations of Bismarckian welfare regimes in which the workers play a central role. But before delving into specific models, it is important to understand the characteristics of a healthcare system with formal typologies.

In the domain of social policy, comparative research of welfare regimes heavily relies on the Weberian sense of ideal and real types [11]. In his seminal work "The Three Worlds of Welfare Capitalism", Esping-Andersen defines three ideal types of welfare regimes: social democratic, conservative, and liberal [12]. Following this framework, Wendt et al. [13] distinguish three dimensions to differentiate ideal healthcare system types: financing, service provision, and regulation (governance). Their classification is based on the actors responsible for these dimensions, in line with Esping-Andersen's three worlds: state, non-governmental (societal) actors, and the market. Respective to the previously described actors, dimensions of healthcare may each have different forms: financing through taxation, social insurance contributions, or private sources; provision through state-owned facilities, non-profit societal based facilities, or for-profit private actors; and regulation through state regulation, non-governmental regulation, or market mechanisms. A system is defined to be of ideal type if only one actor is responsible for each of these three dimensions, and of mixed type, if not [13].

Over the last century, healthcare systems of the modern age have become increasingly complex and divergent from the Weberian ideal types, due to the cultural and social characteristics of each population as well as the political atmosphere and agenda of their country [14]. Even though there are differences in their implementation by governing bodies, 4 general models prevail in real-life healthcare systems: Bismarck Model (ideal type: Societal Healthcare System), Beveridge Model (ideal type: State Healthcare System), National Health Insurance (NHI) Model (State-based Mixed Type) and Private Insurance Model (ideal type: Private Healthcare System). Typologies in brackets indicate the corresponding types of these models in the Wendt et. al framework, and the differences between models can be explained by the holders of previously described dimensions. Bismarck and Beveridge models are the centerpieces of this study. We model a public health insurance system that is financed Bismarckian with a Beveridgean way of risk pooling to fully capture the bilateral feedback relationship between the public programme benefits and the population's formal employment dynamics.

The Bismarck model is the predecessor of other public health systems. In the 19th century Germany, industrialization was at its peak and the country was on a path towards having a dominantly working-class population. In order to avoid a labor-centric societal drift towards socialism, German Chancellor Otto von Bismarck established Europe's first welfare state that provided national health insurance and pension systems for the workers and their families [8, 13]. The Bismarck regime required all workers to be registered to a social insurance fund which was financed via payroll deduction from workers' salaries, paid jointly by employees and employers. The money was pooled in multiple non-governmental non-profit sickness funds (Krankenkassen) that paid for the privately provided health services. It should be noted that in this original form of Bismarckian health, public responsibility was only directed at the working class with employment-based social insurance.

In the following decades, national health insurance models were widely adopted by other countries including the United Kingdom. After many hospitals in the UK faced risks of bankruptcy and relied on government support during the Second World War, economist William Beveridge was commissioned to prepare a postwar social recon-

struction program. His report Social Insurance and Health Services placed healthcare as a general social policy for the whole population and healthcare came to be considered a basic citizenship right [3,5]. Beveridge model of National Health Service (NHS) was established in 1948 as a tax-based financed UHC system that provides the whole population with healthcare through state-owned facilities. Spain and Italy are among the other countries that adopted the Beveridgean welfare regime in the following years.

Following the post-war developments and the change of discourses as in the UK, other welfare states, including Bismarckian France and Germany, expanded their healthcare services available to all. In modern Bismarck, all individuals are mandated to register for private non-profit health insurance, with those unable to pay to have limited essential coverage. Germany, France, Belgium, Netherlands, Japan, Switzerland, and Israel are some of the states with institutionalized Bismarck systems, though each has its own distinct characteristics. A similar picture is present in Turkey, where a single-payer state-run public health insurance programme that is financed by payroll taxation (GSS) covers the whole population [5].

These state-run insurance models provide their population with UHC, and their state holds a significant power of cost-control. An important issue with UHC is that more care does not always mean better health and financial outcomes due to increased rates of over-treatment and over-diagnosis in industrialized countries [8,15]. Moreover, health economists generally view that a UHC system is doomed to suffer from moral hazard, and for state-run health insurance the problem is even worse because of the lack of incentives and competition [5].

In public programmes, overutilization of healthcare can lead to longer waiting times, increased costs, and decreased efficiency. All these make the extent of public coverage open to debate in many Bismarckian countries [6,8]., and several policy actions such as coverage reductions and copayments were taken to prevent such problems. In Germany and France, complementary and supplementary private health insurances are available for services that are not included in the public coverage, such as dental and eye care [6].

An even bigger problem arises in the form of a gradual demographic challenge: the aging population. As the working/retired ratio decreases, financing healthcare becomes harder of a problem, since the sickness funds have to feed on employee payrolls. As the chronic disease prevalence increases with and without relating to the aging population (without; visibility itself can impose changes in understanding and definition of diseases), medical treatments and drugs get more expensive with technological advancements, and health expectations of the population increase; financial sustainability of such systems will be in danger [1, 2, 6]. The most direct consequences on the horizon are reductions in coverage levels and increases in tax burden. With private supplementary insurances in the market, the extent of this reduction bears the risks of privatization of health insurance systems or even a complete convergence to the private insurance model, fulfilling the prophecies of the commodification of healthcare [5].

However, as with all rights, a once granted right, especially in healthcare, is difficult to take back without a dreadful decline in population satisfaction, which influences elected governments via concerns over their public popularity [16]. Alternative modes of financing should be sought to prepare for demographic challenges, which may include allocation of public revenues for healthcare, labor immigration policies to promote incoming workers, or even a transformation of healthcare provision structure from curative to preventive and palliative care.

3. RESEARCH OBJECTIVES

Public health insurance programmes have various effects on the daily lives of the population both in health in wealth. The systemic complexity brought by the involvement of various aspects and actors makes the sustainability issue of public programmes more than just a financial problem, but rather a complex societal issue. In this thesis, our main research objective is to analyze the sustainability of public health insurance programmes against demographical and financial challenges while also accounting for the public scheme's effects on population health and socio-economic gradient.

The particular healthcare system structure we focus on in this thesis involves a state-run healthcare fund with a single plan. The whole population benefits from the public programme but the funding source is only the contributions by the formally employed workforce (payroll taxation). We aim to analyze the endogenous causal mechanisms that constitutes this system and explore the causal processes that lead to the development of structural problems and ways to alleviate such problems via hypothetical policies. Instead of focusing on a single region or a country, we model and simulate a hypothetical population with limited external disturbance to analyze the endogenous dynamics essentially inherent to the single-payer public health insurance programmes.

Our scenario analysis in chapter 7 aims to understand under which conditions the effects of demographical and financial challenges would be more destructive and under which conditions these adverse effects can be offset in a causally descriptive manner. Followingly in our policy analysis chapter, we analyze how policies perform in alleviating the problematic behavior in predefined scenario configurations. Policies included in our analysis are government contribution (public revenue injection), labor force immigration (unemployed and formally employed), and healthcare capacity building.

In addition to a causal description and policy testing, we also aim to further this study by providing a single-payer (Beveridgean), multi-payer (Bismarckian), and hybrid model (State-based mixed) performance comparison in terms of financial and health outcomes. How these different models comparatively perform against demographic challenges, economic challenges (like a recession), or health crises (like COVID-19) is another path we aim to follow in this research.

4. RESEARCH METHODOLOGY

The system we aim to analyze in this thesis consists of various distinct elements with interrelated constituents. For example, the benefit package of the public programme affects the population health and is in turn affected by it due to the dynamic revenue generation capability and hence employee contributions. These effects are not immediate as there usually exists a time delay for the effect to manifest as a result of the cause. The presence of many causally interlinked elements, inherent delays, and nonlinearities increases the complexity of the system and makes it hard to trace its dynamics over time using only qualitative methods. Similarly, empirical research in this domain proves to be both time-consuming and hard to evade blocking factors without limiting the model boundary to a very modest extent. In this regard, employing a dynamic simulation approach with formal quantitative fundamentals like System Dynamics (SD) is promising in: i) accounting for the complexity of the underlying feedback structure with a quantitative simulation model, and ii) tracing the sequence of cause and effects with a qualitative feedback map [17, 18].

In systems thinking, a system is defined as a collection of interrelated constituents enclosed in a meaningful setting, where a systemic problem is a problem emerging from the system in the context of its constituents [19]. The systems approach would take the systemic problem as a whole and analyze it by accounting for the interrelations between its building blocks over time, in a wider frame and broad boundary. In other words, the analysis of constituents is only meaningful when examined with each other. The related school of thought, System Dynamics, introduces formal modeling procedures and quantitative policy analysis techniques from a systems perspective. There are two main and common tools in system dynamics research methodology: the qualitative Causal Loop Diagram (CLD) and the generally quantitative Stock-Flow Diagram (SFD).

Causal Loop Diagrams are utilized to map the causal structure of the system from a qualitative lens, produced either by mental models, literature search, or stakeholder engagement [17, 19]. Elements of the CLD are linked with each other by causal links

which may have positive or negative polarity. If there exists a positive link from variable A to variable B, this means that A and B change in the same direction other things being equal (ceteris paribus principle). An increase (decrease) in A will impose an increase (decrease) on B. Similarly, if there exists a negative link from variable A to variable B, this means that A and B change in the opposite direction, other things being equal. An increase (decrease) in B will impose a decrease (increase) on A.

If causal linkages form a cycle (a route starting and ending on the same vertex), it creates a feedback loop, which is a crucial element in the analysis of complex systems. If the product of all causal link polarities of a cycle is negative, then the feedback loop is called a balancing (negative) loop. Balancing loops are controlling loops that operate to balance out the disturbances on their constituents with the aim of carrying the system state to a certain level. If the product is positive, then the feedback loop is a reinforcing (positive) loop. Reinforcing loops are vicious cycles that absorb the disturbance and amplify it through the cycle. Reinforcing loops are widely considered to be more dangerous than balancing loops because of their ability to cause tremendous systemic shifts.

Another important property of CLD is the consideration for temporal lags. A causal influence from one variable to another rarely reaches immediately. Instead, there usually exists a time delay for causal influence to reach from the source to the sink. A causal link with a time delay is denoted with a link scratched with two small bars.

An exemplary CLD of an SI (Susceptible-Infected) epidemic model is given in Figure 4.1. An increase in the Infected Population increases the contact between susceptible and infected populations. As a result of increased contacts, Infection Rate goes up, and increases the Infected Population, hereby closing a reinforcing (positive) feedback loop named “Contagion”. Also, with an increased Infection Rate, the Susceptible Population decreases, which in turn decreases the Contacts; hereby closing a balancing (negative) feedback loop named “Depletion”.

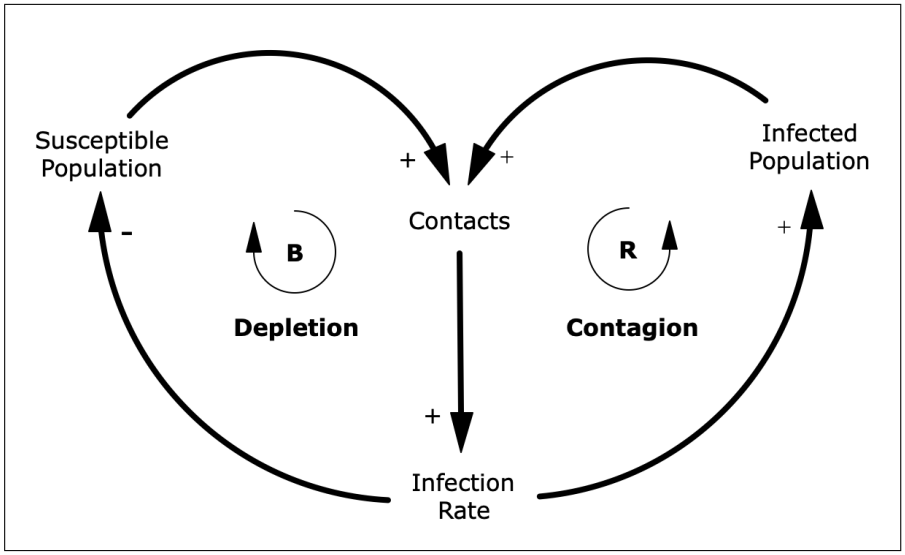


Figure 4.1. An exemplary causal loop diagram.

System Dynamics methodology is built on the principle that dynamic behavior is caused by the process of accumulation and depletion [20–22]. Its main quantitative modeling tool Stock-Flow Diagram operates on this principle. Three main types of variables exist in an SFD: stocks, flows, and auxiliaries. Stocks (also called levels) represent variables that can be identified as accumulations or memories, having inertia. Flows (also called rate) represent the variables that impose changes on stock variables with respect to time. A common way to understand whether a variable should be modeled as a stock or a flow is to freeze time; a flow would equate to zero while a stock retains its value. Auxiliaries represent variables that may or may not be dynamic, having lower importance in their dynamic behavior to be considered as stocks [19].

Stock-flow diagram of the previously shown SI model is presented in Figure 4.2. The diagram includes two stock variables (Susceptible Population and Infected Population) shown as rectangular boxes, two flow variables (Infection Rate and Recovery Rate) shown as valves, and four auxiliary variables shown as circles. The links denote a causal or equational relation from the source variable to the sink, akin to a CLD.

In the exemplary SI model, Infection Rate is determined by a fraction (Contact Fraction) of all possible Contacts between Susceptible and Infected populations de-

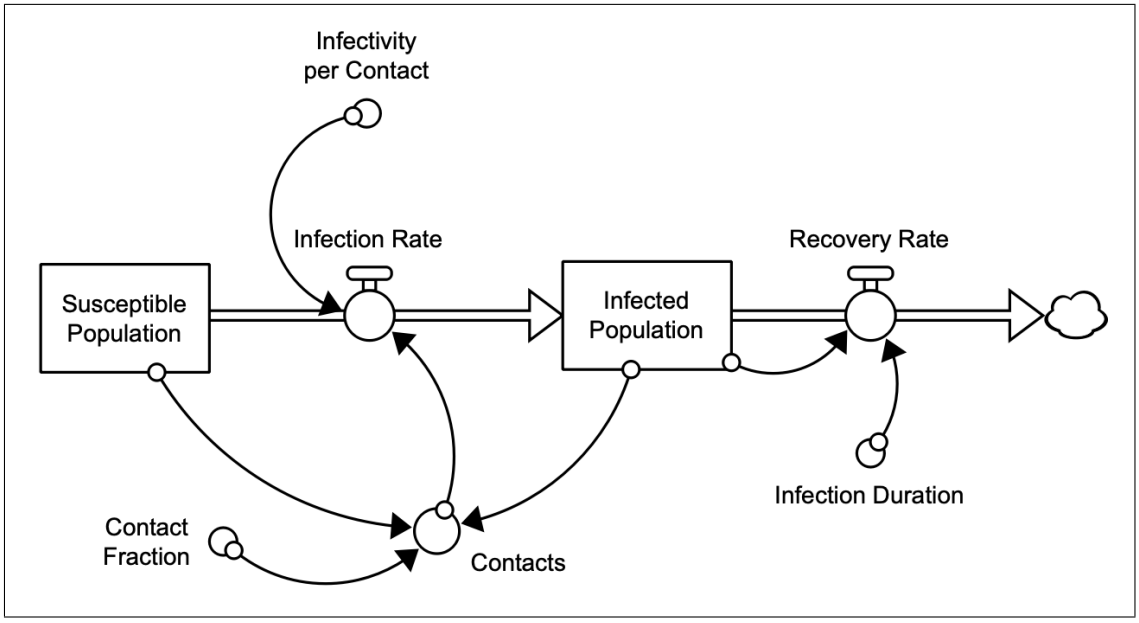


Figure 4.2. An exemplary stock-flow diagram.

pending on the disease Infectivity. Newly infected individuals flow from Susceptible to Infected stocks via Infection Rate. Infected individuals spend Infection Duration amount of time on average at Infected stock before they recover and leave the system via an outflow to a cloud (outside the model boundary). Equations corresponding to this stock-flow structure are

$$\frac{d(Susceptible\ Population)}{dt} = -Infection\ Rate \tag{4.1}$$

$$\frac{d(Infected\ Population)}{dt} = Infection\ Rate - Recovery\ Rate \tag{4.2}$$

$$Infection\ Rate = Contacts \times Infectivity\ per\ Contact \tag{4.3}$$

$$Recovery\ Rate = \frac{Infected\ Population}{Infection\ Duration} \tag{4.4}$$

$$Contacts = Susceptible\,Population \times Infected\,Population \times Contact\,Fraction \quad (4.5)$$

where the types and units of the model variables are presented in Table 4.1.

Table 4.1. Variables of the exemplary model.

Variable	**Type**	**Unit**
Susceptible Population	Stock	$People$
Infected Population	Stock	$People$
Infection Rate	Flow	$People/Days$
Recovery Rate	Flow	$People/Days$
Contacts	Auxiliary	$People^2/Days$
Contact Fraction	Auxiliary	$1/Days$
Infectivity per Contact	Auxiliary	$1/People$
Infection Duration	Auxiliary	$Days$

System dynamics is commonly employed for simulation-aided dynamic analysis of socio-economic problems [19]. After the formation of the dynamic hypothesis and construction of the simulation model, the model can be used for: i) projection of system behavior over time under given assumptions, ii) scenario analysis to explore the system behavior under different conditions and iii) policy analysis to evaluate the effectiveness of different policy options in alleviating the dynamic problem. Moreover, ease of trackability and posterior analysis makes it a suitable technique for the causal descriptive analysis of complex system structures.

Considering the delays in health policy implementations, underlying causal relations in the system, as well as the suitability of this method for policy design practices, we employ SD as the methodology of this study. Darabi and Hosseinichimeh [23] provided an extensive systematic literature review on SD research in health, in which they recognized three major categories in applications. The scope and objectives of this thesis fit into the third category, Regional Health Modeling. Among many SD applications in healthcare systems modeling [24–27], closer to our topic and issue was

that of Grösser [28]. In their work, Grösser focuses on the health insurance system of Germany, a Bismarckian multi-payer model, and implemented several policies aiming to balance the sickness fund; but they have not attempted to provide a causally descriptive analysis of the endogenous mechanisms that lead to inefficiencies and funding problems.

5. MODEL DESCRIPTION

5.1. Overview of the Model

We built our model to represent a country with a state-run health insurance program, aka statutory or national health insurance (Public Scheme, PS hereafter), with a single centralized healthcare fund and therefore a single risk pool. Demographic and economic developments are endogenized to account for the feedback between healthcare services and socio-economic gradient.

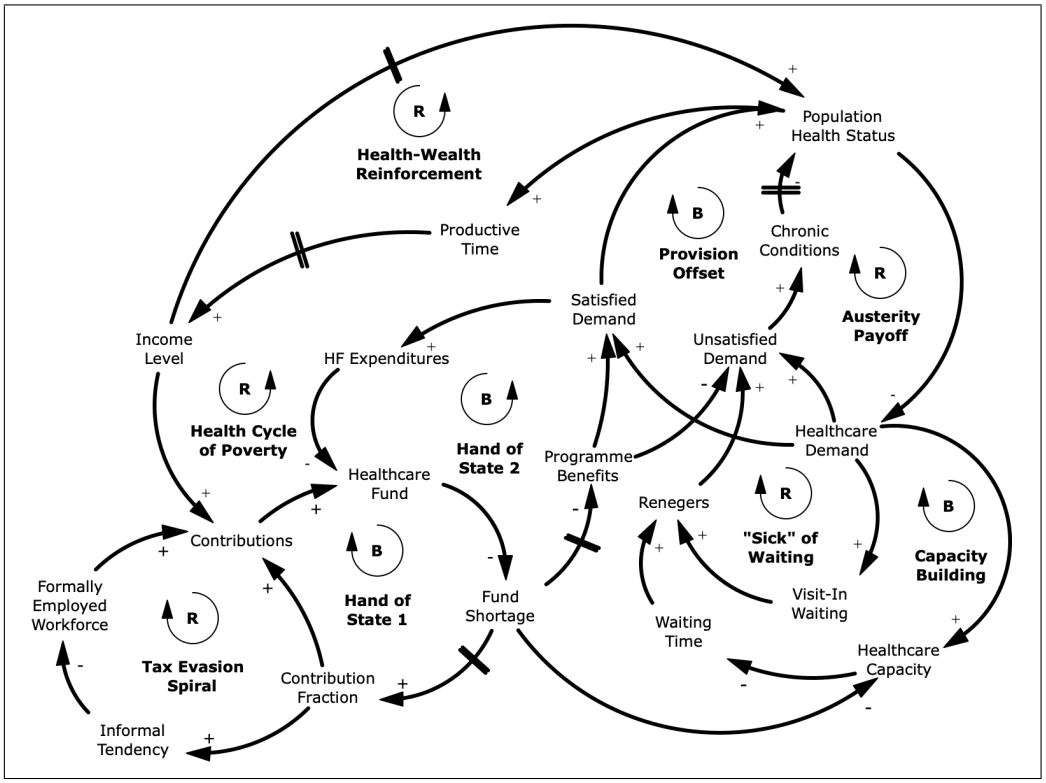


Figure 5.1. Overview causal loop diagram of the model.

A simplified causal loop diagram of the whole model is presented in Figure 5.1. The CLD shows the main model variables and feedback loops. Healthcare Fund is the main stock variable of the public programme, representing the fund reserve allocated for healthcare. A decrease in Healthcare Fund increases Fund Shortage and

puts economic stress on the programme. With increased stress, the state reduces the programme benefits and increases the tax burden (Contribution Fraction) in order to reduce Expenditures and increase Contributions respectively, closing the Hand of State balancing feedback loop on two ends. Increased tax burden (Contribution Fraction), incentivizes the employers to shift to the informal sector which would eventually decrease the Contributions, closing a reinforcing feedback loop named Tax Evasion Spiral.

Unsatisfied healthcare demand results in the accumulation of chronic conditions and consequently reduces Population Health Status. Lowered population health generates more healthcare demand. The satisfied portion of the demand alleviates the condition and increases Population Health Status (hereby Provision Offset balancing loop) while the unsatisfied portion further deteriorates population health (hereby Austerity Payoff reinforcing loop).

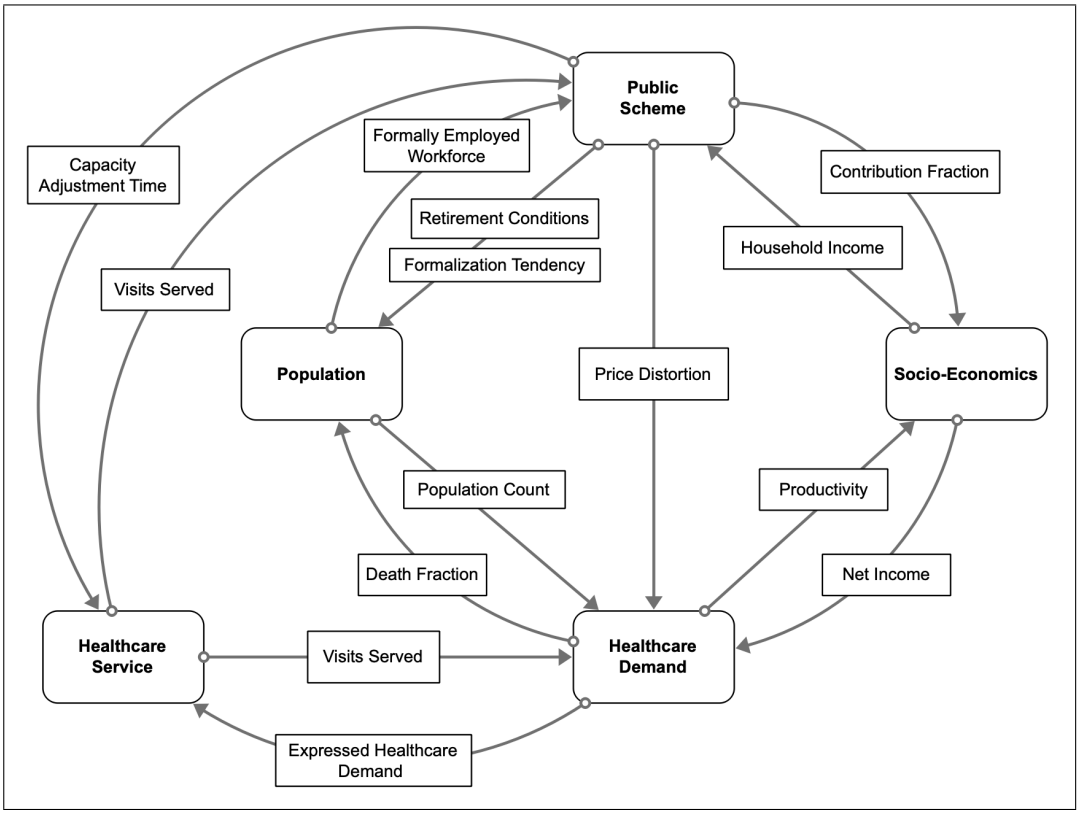


Figure 5.2. Macro-level feedback interactions between model sectors.

Population Health Status positively affects the population's productive time and increases its revenue generation capability. Therefore, increased population health would result in more income, consequently more programme benefits, and eventually more population health. This reinforcing feedback loop is named as Health-Wealth Reinforcement in our overview CLD. As another effect over income level, a decrease in the income level of the population would result in decreased employee contributions and reduced program benefits. A less beneficious insurance programme covers less of the generated healthcare demand and worsens the Population Health Status as a result. This cycle creates a poverty trap, a positive feedback loop we named Health Cycle of Poverty.

The overview causal loop diagram shows several balancing and reinforcing loops together in a complex system structure. During the development of the simulation model, we separate the system into sectors and model them one by one. The SD model consists of 5 sectors distinguished by their conceptual denotation: Public Scheme Sector, Population Sector, Healthcare Demand Sector, Healthcare Service Sector, and Socio-economics Sector. Figure 5.2 shows the feedback interactions between sectors from the top level. The information carried by specific linkages are indicated in the figure and will be explained in detail sector by sector in the following subchapters. The entirety of the model equations and parameters are provided in Appendix A.

5.2. Public Scheme Sector

The Public Scheme sector involves the public health insurance programme benefits that are adjusted by the availability of financial reserves and operate with financial flow information like workforce, serviced healthcare, and income level respectively coming from Population, Healthcare Service, and Socio-economics sectors.

The causal loop diagram of the Public Scheme sector is presented in Figure 5.3. In the presence of a shortage in the Healthcare Fund, Hand of State balancing loop operates by adjusting Contribution Fraction (CF), Cost-Sharing level (CS), Coverage Level (CL), and years of work required for formal retirement (RA) in order to sustain

fund reserves. Cost-Sharing level (CS) and Coverage Level (CL) determine the Price Distortion level which influences the expression of price-elastic demand by inducing the Moral Hazard effect [5, 8].

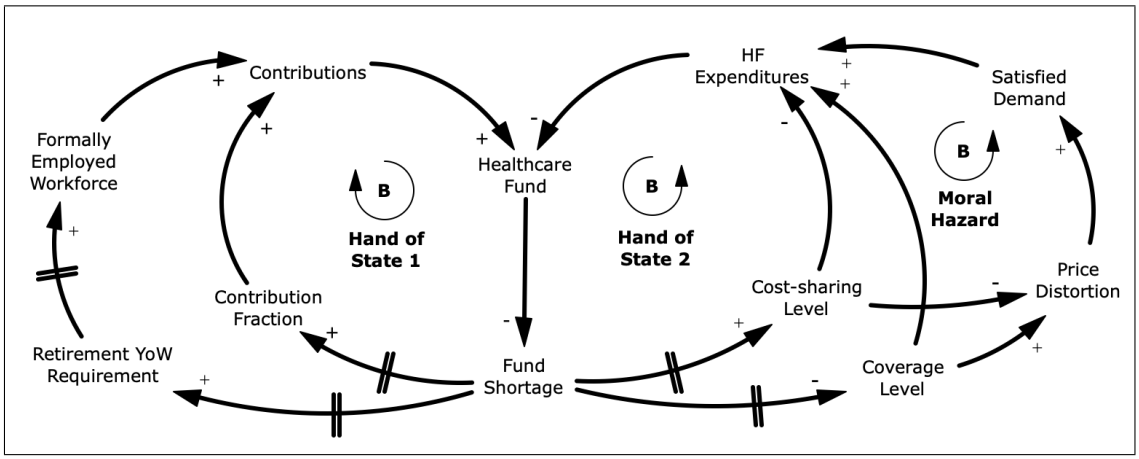


Figure 5.3. Causal loop diagram of the Public Scheme sector.

Healthcare Fund is a stock variable that represents the financial reserve for the PS (Figure 5.4). The fund is financed by its single inflow of Contributions from the Formally Employed Workforce (from the Population sector) by a fraction of their Household Income (from the Socio-economics sector). Healthcare expenditures of PS are simplified to the healthcare visits, omitting other expenditure elements such as medical procedures and prescription drugs covered by public programmes. In this regard, we define a Unit Visit Cost that represents the unit cost of each healthcare visit. The product of Unit Visit Cost and Visits Served yields the Total Visit Cost. The covered portion of the Total Visit Cost is deducted from the fund reserve via Expenditure outflow.

The Public Scheme is modeled to have 4 policy levers endogenously activated by the economic stress depending on the Budget Shortfall and Desired Fund Level. Economic Stress on Public Scheme (ES) is presented in Figure 5.5 as a graphical function of the ratio of Budget Shortfall to Desired Fund Level. When the healthcare fund equals the desired level, the Budget Shortfall becomes zero and the ES equals 1, denot-

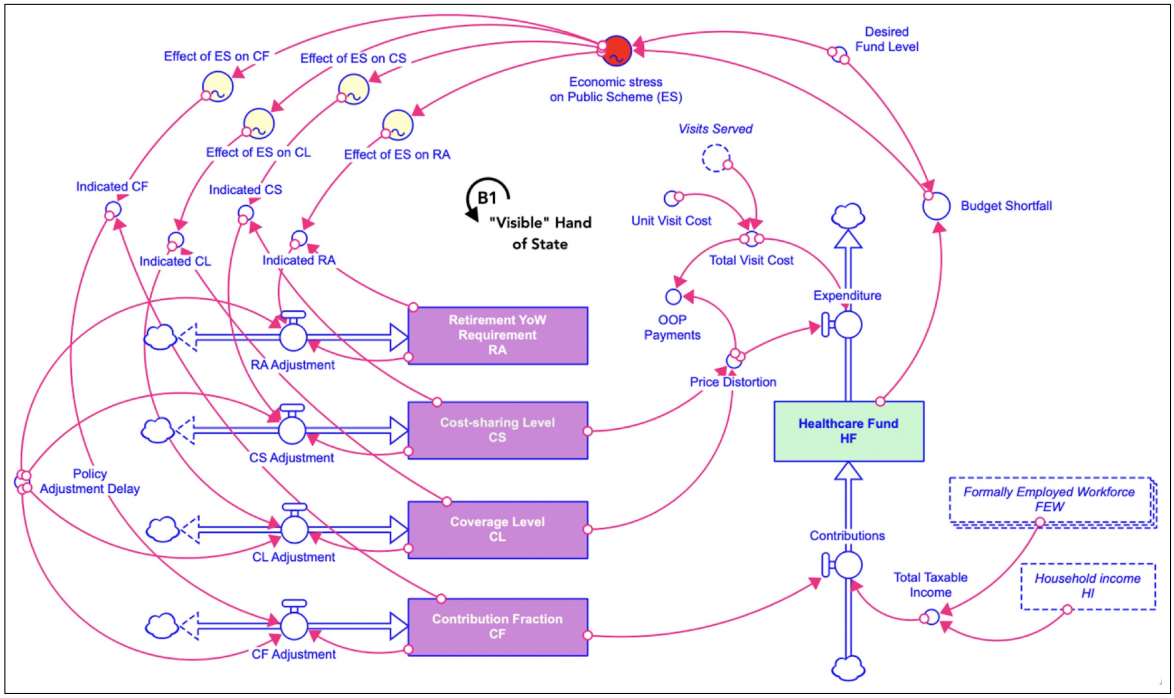


Figure 5.4. Stock-flow diagram of the Public Scheme sector.

ing a financial equilibrium. Lower (higher) fund levels than desired induce a positive (negative) stress on the levers of the PS programme; making the ES greater (lower) than 1 which would operate the Hand of State loop to reduce (enlarge) programme benefits, where the adjustment is formulated (for the Contribution Fraction example) as the following:

$$Indicated\,CF = Coverage\ Level \times Effect\ of\ Economic\ Stress\ on\ CF \tag{5.1}$$

$$CF\ Adjustment = \frac{Indicated\,CF - Coverage\ Level}{Policy\ Adjustment\ Delay}. \tag{5.2}$$

The economic stress drives a balancing feedback loop with 4 routes: In scarce reserves, the state shall; increase the Contribution Fraction (CF) to achieve a higher level of inflow, increase the Cost-Sharing level (CS) to decrease Expenditure, decrease the Coverage Level (CL) to decrease the visits covered, or increase the years of work required for formal retirement (RA) to preserve or enlarge the size of the revenue-generating population, Formally Employed Workforce.

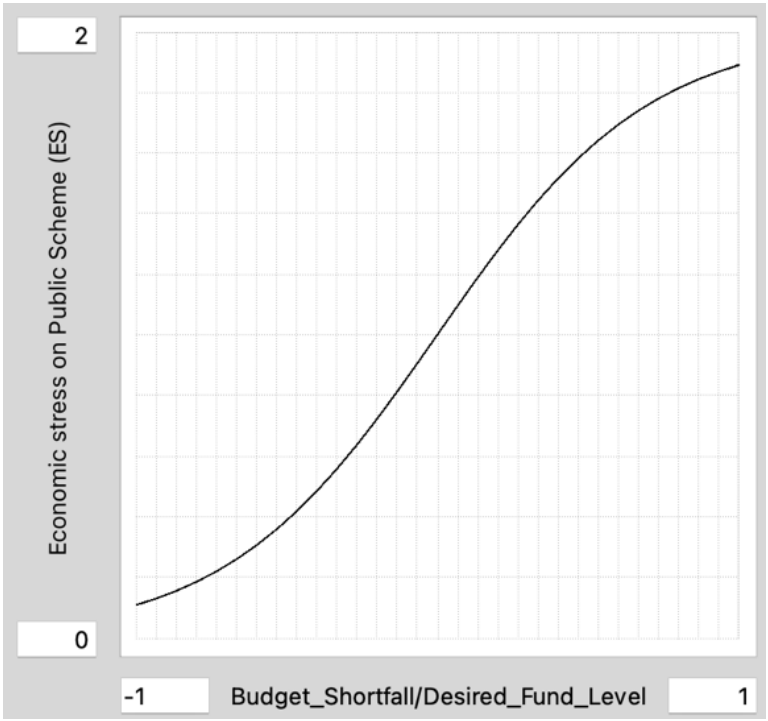


Figure 5.5. Economic Stress on Public Scheme graphical function (dimensionless).

Table 5.1. Stock and Flow variables of the Public Scheme sector.

Variable	**Type**	**Unit**
Healthcare Fund	Stock	Unit Currency
Coverage Level	Stock	Dimensionless
Cost-Sharing Level	Stock	Dimensionless
Contribution Fraction	Stock	Dimensionless
Retirement YoW Requirement	Stock	Years
Contributions	Inflow	Unit Currency/Years
Expenditures	Outflow	Unit Currency/Years
CL Adjustment	Biflow	1/Years
CS Adjustment	Biflow	1/Years
CF Adjustment	Biflow	1/Years
RA Adjustment	Biflow	Dimensionless

5.3. Population Sector

The Population sector presents the lifeline of our simulated society that is disaggregated into two dimensions: age and working status. The sector receives feedback from Public Scheme and Healthcare Demand sectors. Retirement and employment conditions are affected by the PS package while age-specific death fractions change by the Population Health Status (of Healthcare Demand sector).

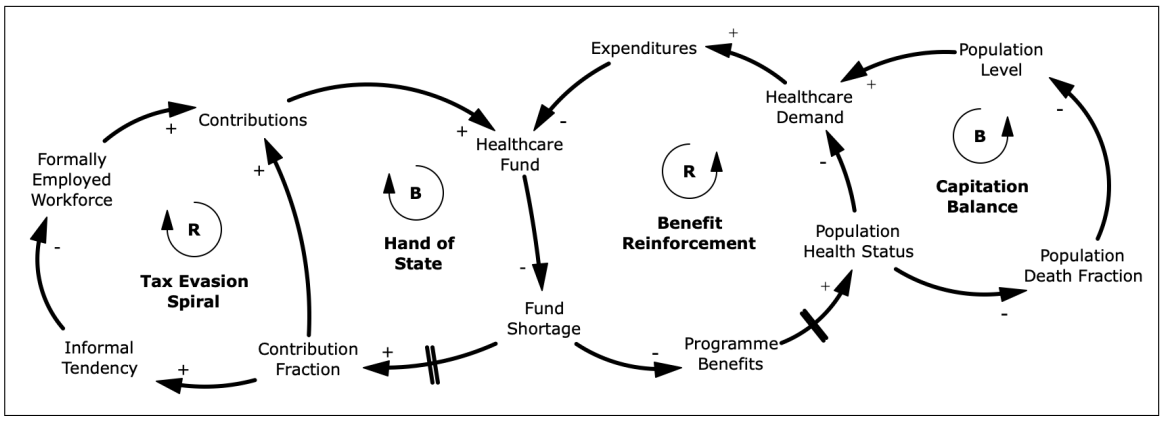


Figure 5.6. Causal loop diagram of the Population sector.

The causal loop diagram of the Population sector is presented in Figure 5.6. Contribution Fraction is modeled with an effect on the exchange between informally employed and formally employed workforce. As CF increases, employers have less incentive to renew employment contracts in order to evade the tax burden that is shared between the employers and employees [5]. This rise in employment informality decreases the Contributions and increases the Economic Stress on Public Scheme, closing a reinforcing feedback loop that is limited by the extent of the informal sector.

Death fractions for each cohort are affected by the Population Health Status from the Healthcare Demand sector. An increase in Population Health Status decreases death rates and increases the population level which generates more healthcare demand. More demand means more expenditure for the healthcare fund, which forces a benefit reduction to the public programme. With lowered benefits, Population Health Status

decreases, closing a balancing feedback loop named Capitation Balance. However, an increase in Population Health Status also decreases the unit healthcare demand of the population which generates the reinforcing feedback loop Benefit Reinforcement.

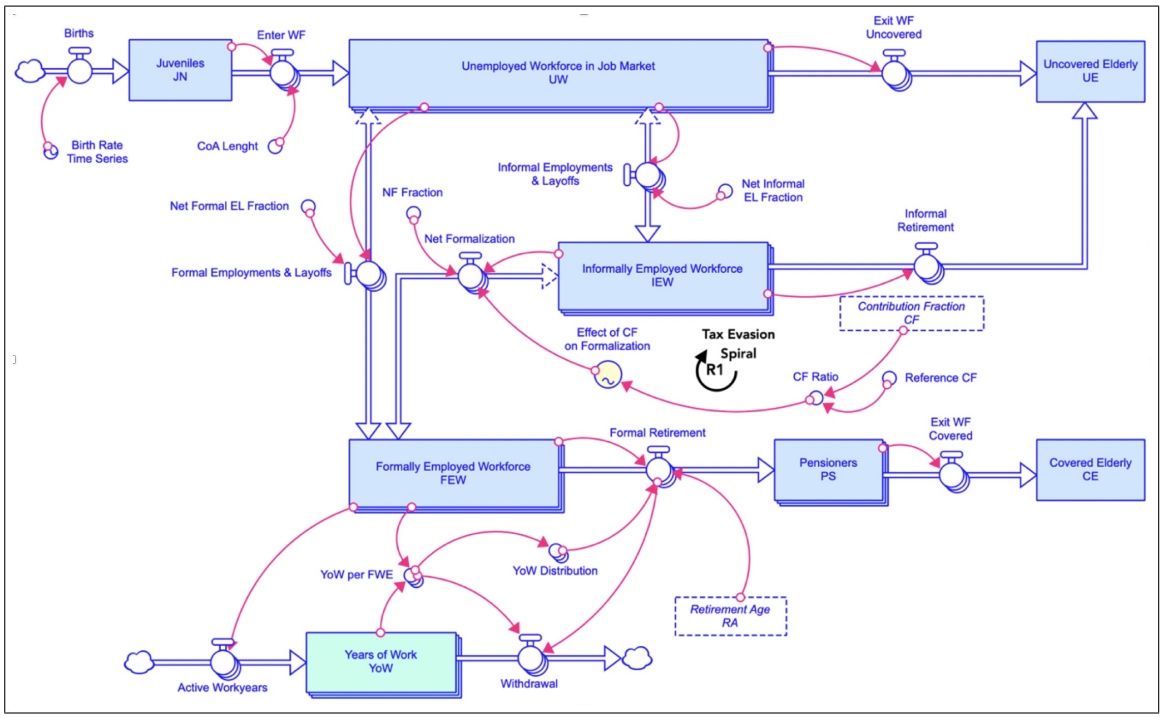


Figure 5.7. Stock-flow diagram of the Population sector.

Stock-flow diagram of the Public Scheme sector is presented in Figure 5.7 which comprises of an aging chain and dynamic employment status. The aging chain has 5 age cohorts: 0-20, 20-35, 35-50, 50-65, and 65+. The first and last cohorts respectively represent the juvenile and elderly population that is not eligible for employment. Births flow to join the Juveniles stock representing the people under the age of 20. After a Coming of Age Delay, Juveniles join the workforce.

The middle three cohorts of the aging chain are the labor force that is either unemployed (UW), formally employed (FEW), informally employed (IEW), or retired (PS). UW, FEW, IEW, and PS stocks are given the three-leveled dimension of WFage (for cohorts 20-35, 35-50, 50-65). Each stock of age and working status go through aging to join the age of the upper cohort and exchange between other working states

with respective rates. Two distinct states are defined for the elderly: covered and uncovered, which represent not the health insurance coverage but their pension status.

Table 5.2. Stock and Flow variables of the Population sector.

Variable	**Type**	**Unit**
Juveniles	Stock	People
Formally Employed Workforce [WFAge]	Stock	People
Informally Employed Workforce [WFAge]	Stock	People
Unemployed Workforce [WFAge]	Stock	People
Pensioners [WFAge]	Stock	People
Covered Elderly	Stock	People
Uncovered Elderly	Stock	People
Years of Work	Stock	Years
Births	Inflow	People/Years
Enter WF	Flow	People/Years
Formal Employments & Layoffs	Biflow	People/Years
Informal Employments & Layoffs	Biflow	People/Years
Formal Retirement	Biflow	People/Years
Informal Retirement	Biflow	People/Years
Net Formalization	Biflow	People/Years
Exit WF Covered	Flow	People/Years
Exit WF Uncovered	Flow	People/Years
Active Workyears	Inflow	Dimensionless
Withdrawal	Outflow	Dimensionless
Deaths	Outflow	People/Years
Aging	Biflow	People/Years
YoW Aging	Biflow	Dimensionless

Work years of each cohort of FEW are stored in the Years of Work coflow. FEW retire depending on the YoW accumulated for their cohort and retirement requirement coming from the Public Scheme sector, formulated as the following:

$$YoW\ per\ FWE = \frac{(Indicated\,CF - Coverage\ Level)}{Policy\ Adjustment\ Delay} \tag{5.3}$$

$$YoW\ Distribution = \frac{Formally\ Employed\,Workforce}{Years\ of\ Work} \tag{5.4}$$

and

$$Formal\ Retirement = \frac{Formally\ Employed\,Workforce \times YoW\ Distribution}{Retirement\ Age\ RA}. \tag{5.5}$$

For each year, current FEW level equivalents of years are added to the YoW stock via Active Workyears inflow, and average years of the retirees are deduced from the stock via Withdrawal outflow.

5.4. Healthcare Demand Sector

The Healthcare demand sector covers the generation and expression of healthcare demand due to the population's need for healthcare and the availability of healthcare services related to price and PS benefits. Population Health Status soft variable is created to indicate the overall health of the population that is determined by the delayed effect of three major factors: severity of chronic conditions, provision of healthcare, and average income level of the population.

PHS level determines the age-specific death fractions via multiplicative effect formulations where

$$\begin{aligned} &Death\ Fraction\,[Age] = \\ &\quad Normal\ Death\ Fraction\,[Age] \times Effect\ of\ PHS\ on\ Death\ Fraction. \end{aligned} \tag{5.6}$$

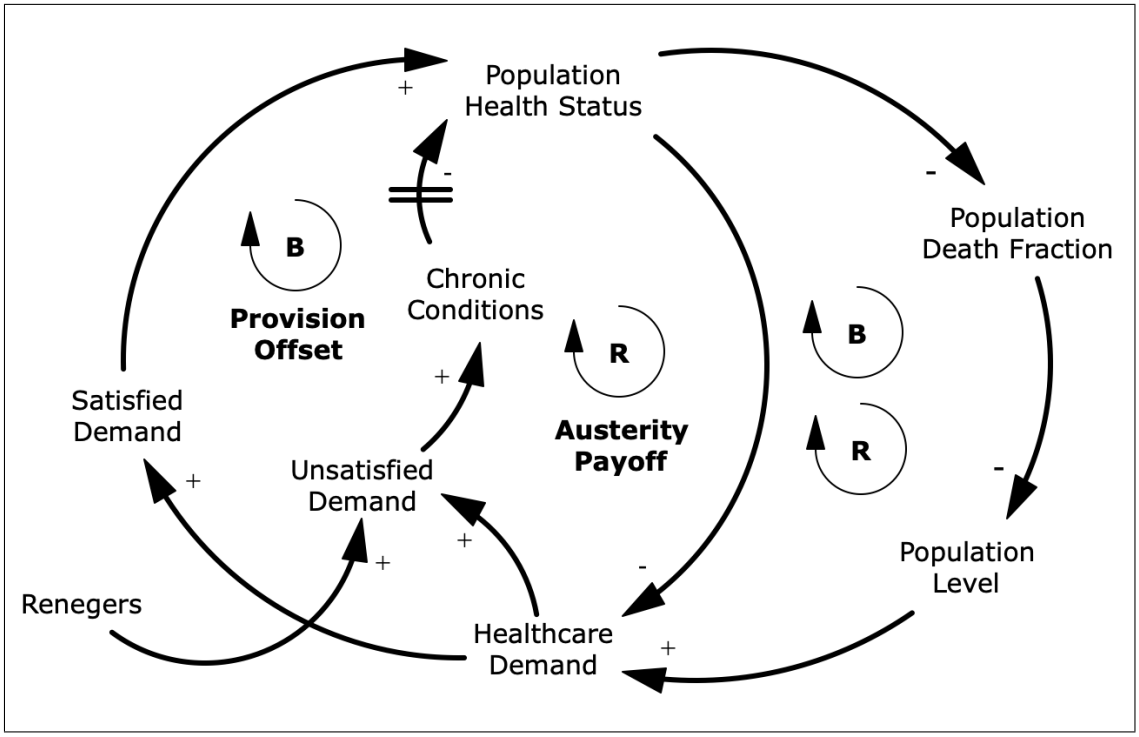


Figure 5.8. Causal loop diagram of the Healthcare Demand sector.

The effect formulation utilizes a graphical effect function that is calibrated via country-specific crude death rate data such that the minimum and maximum PHS levels (0 and 2) represent the countries with the lowest and highest death rates [29].

Two major feedback loops are present in the Healthcare Demand sector: Provision Offset (balancing) and Austerity Payoff (reinforcing) (Figure 5.8). Not all generated healthcare demand is expressed due to price elasticity. Accordingly, we define expressed (generated and to be satisfied) and unexpressed (generated but not to be satisfied) healthcare demand types. Healthcare demand level positively affects both satisfied and unsatisfied healthcare demand levels. An increase in satisfied demand improves the PHS and leads to less demand generation as a result. This mechanism is termed as Provision Offset balancing feedback loop. The unsatisfied demand, on the other hand, leads to the development of more chronic conditions which worsens the population health once matured. This in turn generates more demand and creates the Austerity Payoff reinforcing feedback loop.

Table 5.3. Stock and Flow variables of the Healthcare Demand sector.

Variable	**Type**	**Unit**
Population Health Status	Stock	Dimensionless
Condition in Delay 1	Stock	Visits/Years
Condition in Delay 2	Stock	Visits/Years
PHS-CiD Adjustment	Biflow	1/Years
PHS-Provision Adjustment	Biflow	1/Years
PHS-Wealth Adjustment	Biflow	1/Years
CiD Correct 1	Biflow	Visits/Years/Years
CiD Correct 2	Biflow	Visits/Years/Years

Two additional feedback loops arise through the PHS effect on death fractions, one balancing, and one reinforcing loop. The balancing loop is the Capitation Balance we described in the population sector. The reinforcing loop closes through the same pathway as the Provision Offset from Healthcare Demand to PHS.

There have been multiple pieces of evidence generated by health insurance experiments that suggest a downward sloping demand curve for healthcare with respect to price [8]. Participants' healthcare demand is largely affected by the price of care, though the effect is heavily dependent on the severity of the care need. In this direction, we define two types of demand for healthcare, price elastic (e.g., outpatient care) and price inelastic demands (e.g., inpatient care). By definition, Price Inelastic Demand is robust to price distortion while the expression of Price Elastic Demand is dependent on the levels of healthcare pricing. PHS level is used to estimate the price elastic and price inelastic demand for healthcare for each age cohort of the population: the lower the PHS, the higher the care need. Price Inelastic Demand is sent to the healthcare service sector as orders independent of monetary constraints, while only a fraction of Price Elastic Demand is expressed and treated as an order.

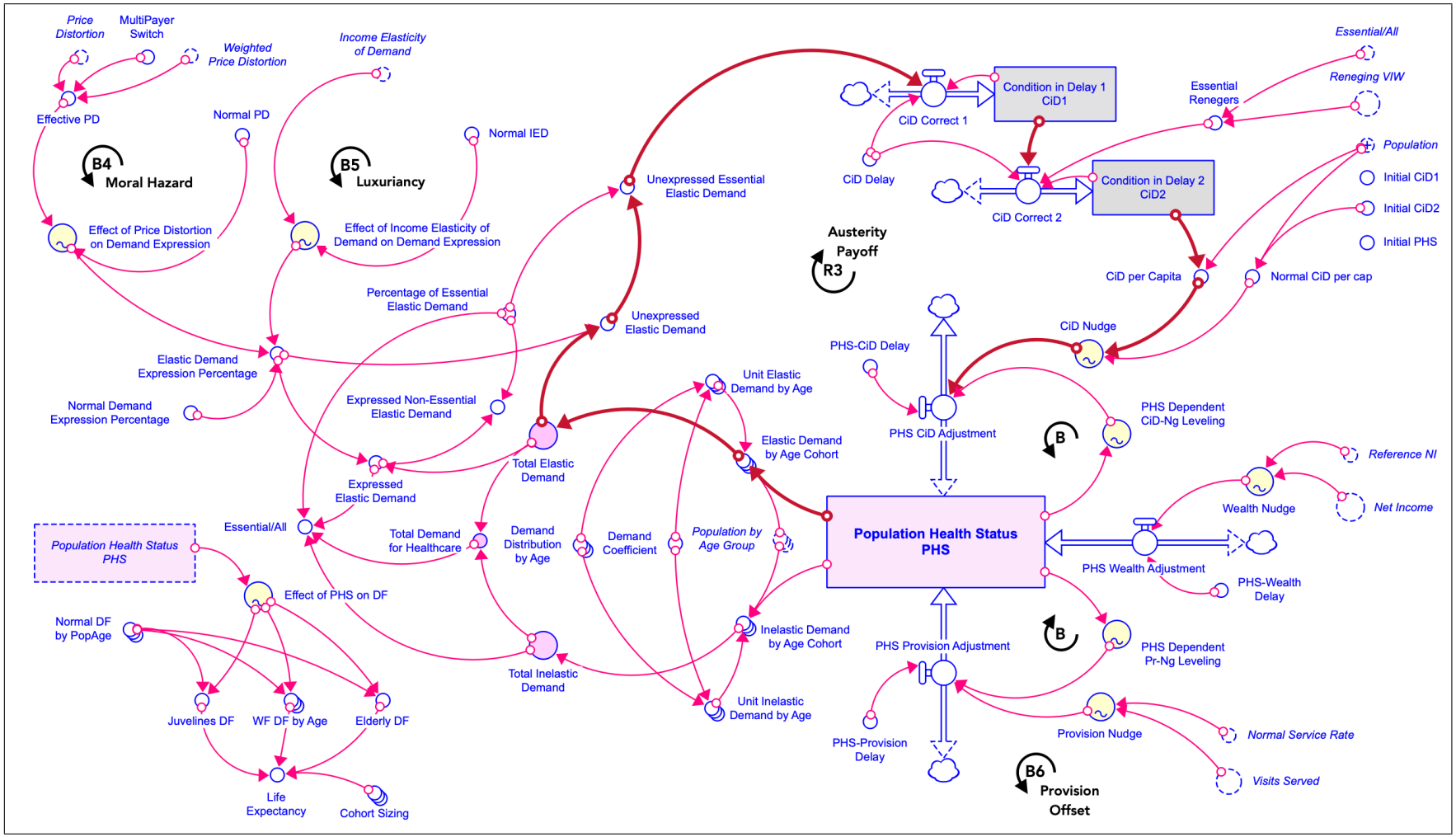


Figure 5.9. Stock-flow diagram of the Healthcare Demand sector.

We formulate two factors that affect the expression for Price Elastic Demand: Price Distortion, and Income Elasticity of Demand. Price Distortion represents the portion of the PS benefits that are covered by the plan, calculated by the

$$Price\ Distortion = (Coverage\ Level) * (1\ -\ Cost - Sharing\ Level) \tag{5.7}$$

for each benefit type. Ceteris paribus, an increase in Price Distortion (i.e., a more beneficial plan) induces more demand expression regardless of the need and necessity, escalating the healthcare expenditure as a result. In contract theory, this problem is termed post-ante moral hazard, shown as a balancing feedback loop in Figure 5.9. The second factor is Income Elasticity of Demand which is under the influence of Household Income. As wages increase, more demand is expressed and PS Expenditures rise, limiting the benefits in the long run, thus closing a balancing feedback loop named Luxuriancy. The two effects determines the Elastic Demand Expression Percentage as:

$$\begin{aligned} &Elastic\ Demand\ Expression\ Percentage = \\ &Eff\ of\ Price\ Distortion\ on\ Demand\ Expression \times Eff\ of\ Income \\ &\qquad\qquad\qquad\qquad\qquad\qquad Elasticity\ on\ Demand\ Expression \end{aligned} \tag{5.8}$$

where

$$Eff\ of\ Price\ Distortion\ on\ Demand\ Expression = f(\frac{Price\ Distortion}{Normal\ PD}) \tag{5.9}$$

and

$$Eff\ of\ Income\ Elasticity\ on\ Demand\ Expression = f(\frac{Income\ Elasticity}{Normal\ IE}). \tag{5.10}$$

It should be noted that some of the Price Elastic Demand is essential, meaning that if not treated now, they will develop chronically into more serious conditions that will cost more in the future [15]. We model such developments with a second-order information delay that eventually reduces the Population Health Status. This formulation is also in line with the common logic of a chronic condition which is defined as a medical condition that spans several years in development and effect [8], though it still stands abstract due to the immeasurable nature of its real-life counterpart. Renegers, having waited a certain amount in the service queue and quitted, directly join the second chronic condition stock, Condition in Delay 2.

5.5. Healthcare Service Sector

A capacity-order formulation is used to model the public healthcare services with feedback coming from Healthcare Demand and Public Scheme sectors. The sector takes the information on generated healthcare demand, processes it through its internal structure, and yields the total serviced healthcare amount.

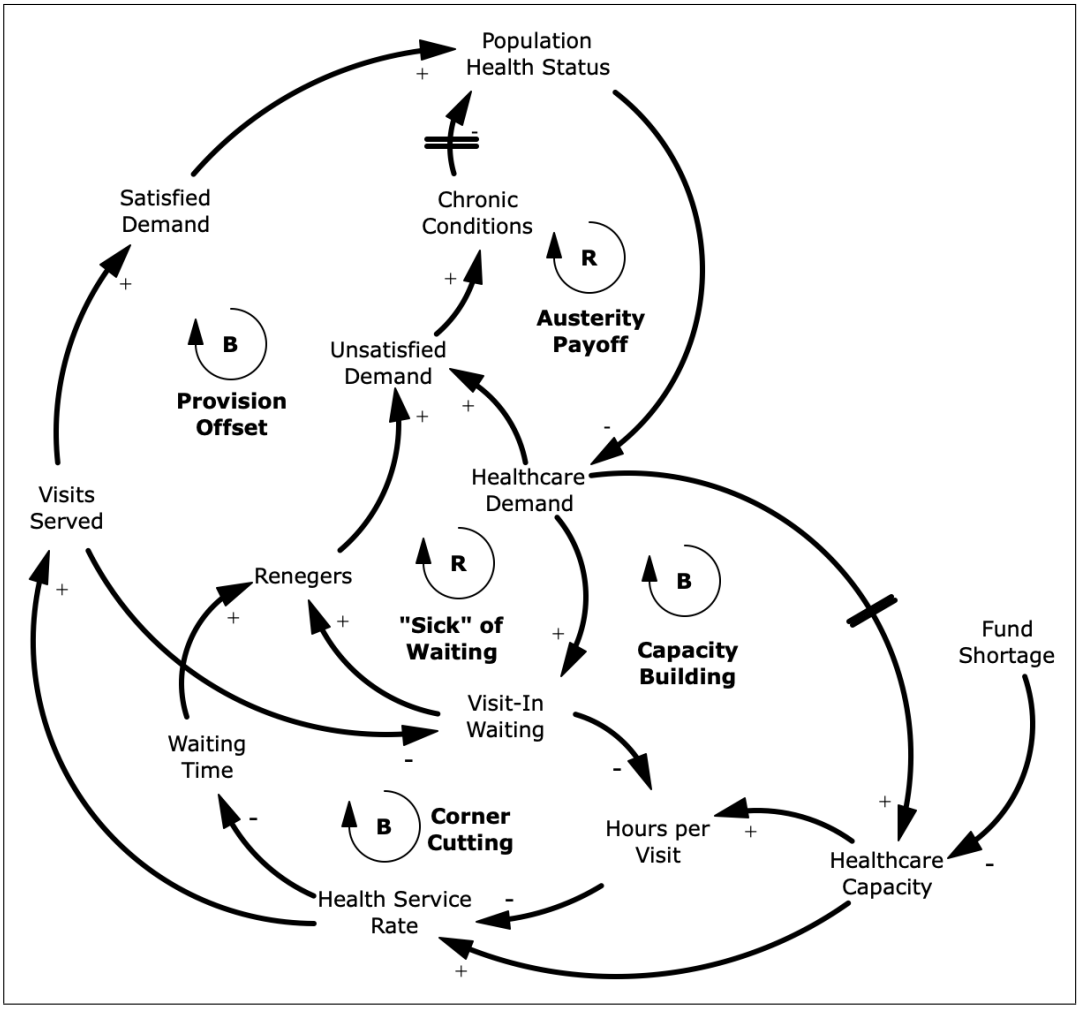


Figure 5.10. Causal loop diagram of the Healthcare Service sector.

The feedback of the Healthcare Service sector operates around the healthcare capacity and expressed healthcare demand as shown in the sector CLD in Figure 5.10. With an increased healthcare demand, visits-in waiting and so does the reneging increase. An increase in reneging results in more chronic conditions which leads to a

deterioration in population health. The resulting amplified healthcare demand closes the reinforcing feedback loop we named "Sick" of Waiting. As a balancing mechanism to this reinforcement, the Capacity Building feedback loop operates to increase the Healthcare Capacity to reduce reneging. Also with increased waiting visits, the system reduces the Hours per Visit to reduce the waiting times via the Corner Cutting strategy as

$$Health\ Service\ Rate = Eff\ of\ Workload\ on\ HSR \times \frac{Healthcare\ Capacity}{Hours\ per\ Visit} \tag{5.11}$$

where

$$Eff\ of\ Workload\ on\ HSR = f(\frac{Hours\ per\ Visit}{Standard\ Hours\ per\ Visit}). \tag{5.12}$$

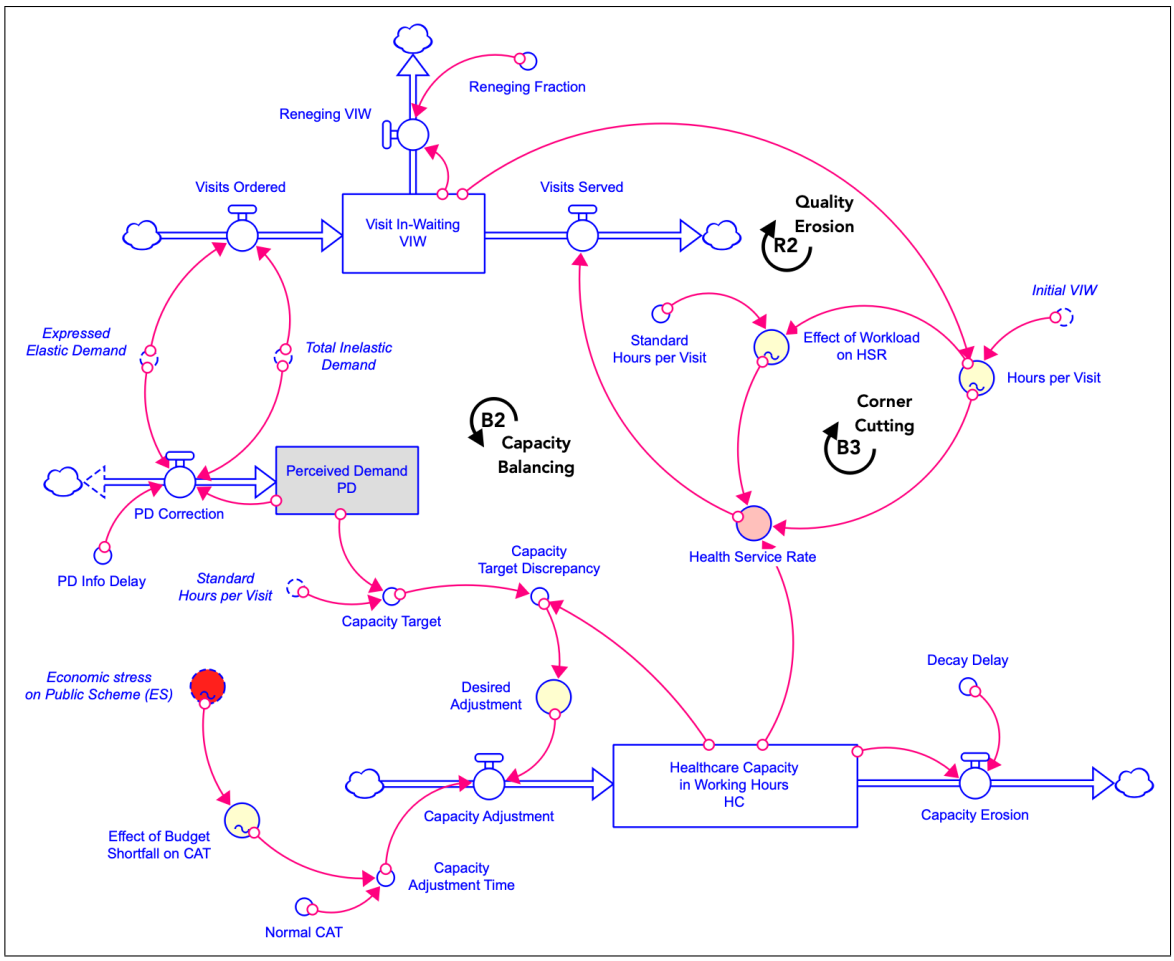


Figure 5.11. Stock-flow diagram of the Healthcare Service sector.

Table 5.4. Stock and Flow variables of the Healthcare Service sector.

Variable	**Type**	**Unit**
Visit In-Waiting	Stock	Visits
Perceived Demand	Stock	Visits/Years
Healthcare Capacity	Stock	Hours/Years
Visits Ordered	Inflow	Visits/Years
Visits Served	Outflow	Visits/Years
Reneging VIW	Outflow	Visits/Years
Capacity Building	Inflow	Hours/Years/Years
Capacity Erosion	Outflow	Hours/Years/Years

Stock-flow diagram of the Healthcare Service sector is shown in Figure 5.11. There are three stock variables in the sector: Visit In-Waiting, Healthcare Capacity in Working Hours, and Perceived Demand. Total healthcare demand from the Healthcare Demand sector joins Visit In-Waiting stock to either be served with the present healthcare service capacity or to go renege for the lengthened waiting times by a certain fraction. State records Perceived Demand for PS services with an information delay as

$$PD\,Correction = \frac{(Expressed\,Demand - Perceived\,Demand)}{PD\,Info\,Delay} \tag{5.13}$$

$$\frac{d(Perceived\,Demand)}{dt} = PD\,Correction \tag{5.14}$$

and sets a Capacity Target for healthcare by

$$Capacity\,Target = Perceived\,Demand \times Standard\,Hours\,per\,Visit. \tag{5.15}$$

Healthcare Capacity in Working Hours is adjusted by this capacity target with a delay positively affected by the economic stress on the public scheme. Capacity decays with a Decay Delay via the outflow Capacity Erosion.

As the outgoing feedback, the Visits Served flow is sent to the Public Scheme sector to be used in the calculation of covered healthcare expenditures by the public programme.

5.6. Socio-Economics Sector

We establish a simple macroeconomic structure to endogenize the relation between healthcare and socio-economic development in the Socio-Economics sector. The sector receives the PHS information from the Healthcare Demand sector and Contributions and OOP payments information from the Public Scheme sector.

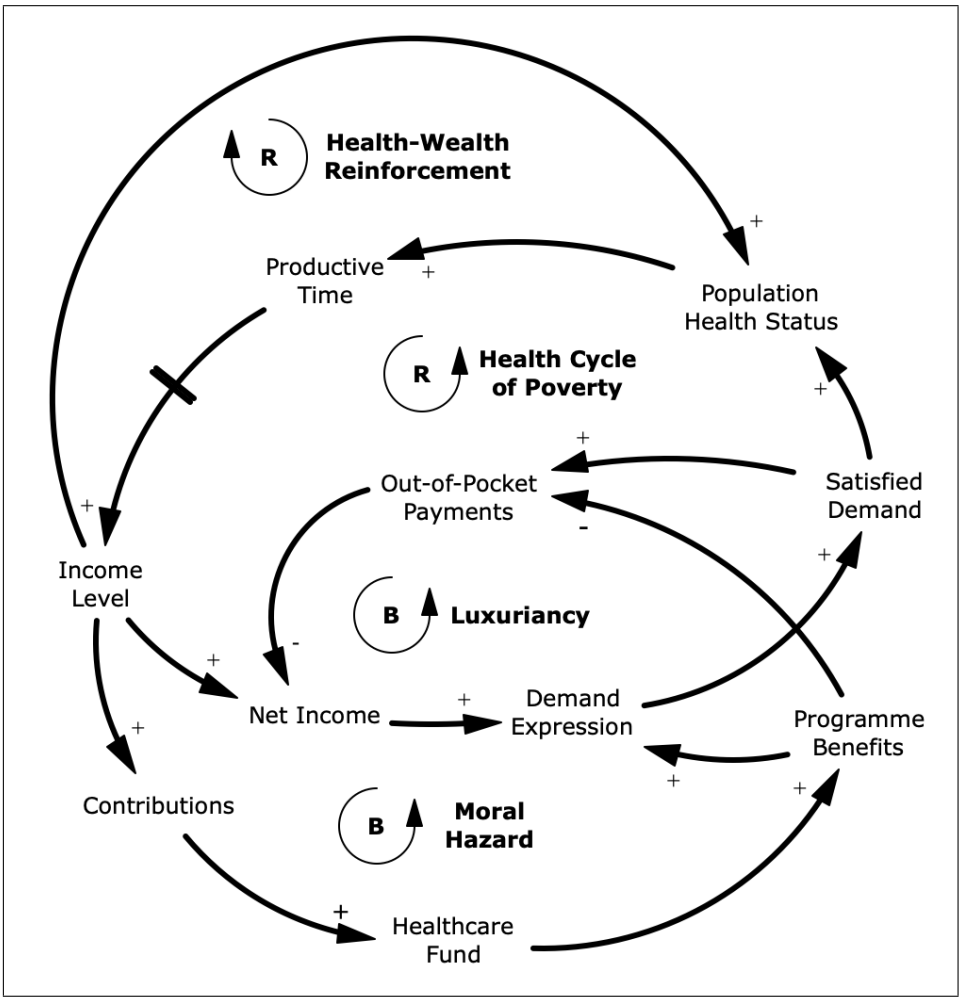


Figure 5.12. Causal loop diagram of the Socio-Economics sector.

Following the fundamentals of the Grossman model of healthcare demand [30], an individual's daily time is divided into two: Productive Time and Sick Time. Productive Time is the time the individual spends to generate income, increase their health, or play (i.e., daily-social activities). Sick Time is the time spent with disease or disabilities, that is effectively wasted. Two reinforcing feedback loops close over Productive Time: Health-Wealth Reinforcement and Health Cycle of Poverty. These two feedback loops represent the Income Level's respectively direct and indirect effects on PHS.

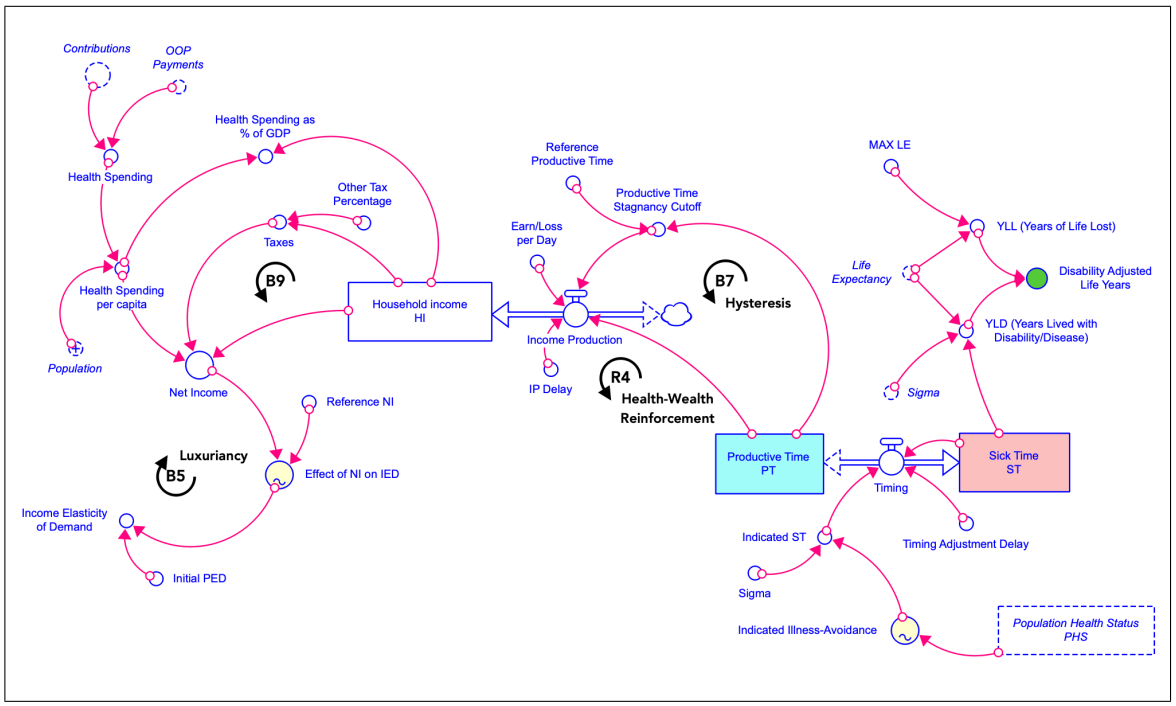


Figure 5.13. Stock-flow diagram of the Socio-Economics sector.

Using this time characterization of the Grossman model also allows us to estimate YLD (Years Lived with Disability or Disease), which is one of the two main elements in the calculation of DALY (Disability-Adjusted Life Years), another health metric of our model. Though it should be noted that there is minimal difference between the novelty of the information carried by DALY and PHS since DALY is partly an indirect function of PHS (through YLD).

The stock-flow structure of the Socio-Economics sector in Figure 5.13 is comprised of three stock variables: Household Income, Productive Time, and Sick Time. Household Income stock represents the income of the average working-class capita, which is the funding source of the Healthcare Fund of PS. Productive Time and Sick Time stocks represent their counterparts in the Grossman model. The productive/sick time separation is dynamic and affected by the PHS. An exponential decaying Illness-Avoidance Function is used to determine Indicated Sick Time using PHS, and then the time allocation is adjusted with a delay by:

$$Indicated\,ST = Illness\,Avoidance\,Function(Population\,Health\,Status) \tag{5.16}$$

$$Timing = \frac{(Indicated\,ST - Sick\,Time)}{Timing\,Adjustment\,Delay}. \tag{5.17}$$

Per the productive time hypothesis of Grossman, increased Productive Time will allow the workforce to generate more income, which will better the PHS and then produce more Productive Time [30]. We formulate the Income Production flow as the following:

$$Income\,Production = \frac{(Productive\,Time - PT\,Stagnancy\,Cutoff) \times Earn/Loss\,per\,Day}{Income\,Production\,Delay}. \tag{5.18}$$

Table 5.5. Stock and Flow variables of the Socio-Economics sector.

Variable	**Type**	**Unit**
Household Income	Stock	Unit Currency/Years/People
Productive Time	Stock	Days/Years
Sick Time	Stock	Days/Years
Timing	Inflow	Days/Years/Years
Income Production	Outflow	Unit Currency/Years/People/Years

This Health-Wealth Reinforcement loop is limited by the Hysteresis loop caused by economic stagnancy. Moreover, Net Income (after health spending and taxes) determines the demand expression level through Income Elasticity of Demand, creating the balancing loop of Luxuriancy.

6. PARAMETRIZATION AND STRUCTURAL VALIDITY

In this section, we describe the parametrization process to produce the equilibrium run, test the structural validity of the model, and analyze the model sensitivity to several central model parameters.

6.1. Parametrization

The model parameters are taken from the literature upon availability for generic levels, and some parameters (e.g., Unit Visit Cost, Crude Birth Rate) are treated as inputs for scenario purposes. Additionally, we estimate the default level of Unit Visit Cost on the principle of collective annual equivalence [15], equating annual Contributions to Expenditures for the base case scenario which creates an initial dynamic equilibrium in the Healthcare Fund stock.

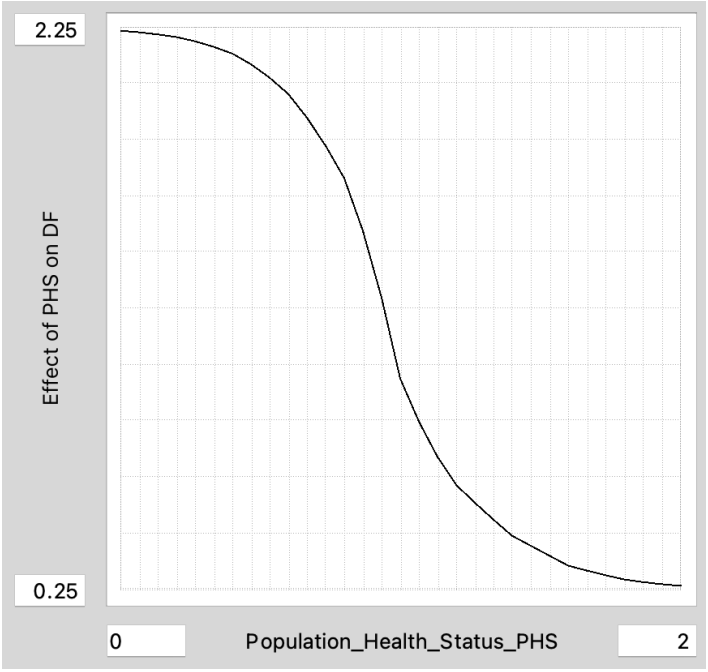


Figure 6.1. Graphical effect: Effect of Population Health Status on Death Fraction (dimensionless).

The effect formulations are formulated mainly by sigmoidal graphical effect functions that are calibrated either by empirical data, and most of the time by qualitative scaling. To exemplify, the Effect of Population Health Status on Death Fraction (Figure 6.1) is calibrated via country-specific crude death rate data [29] such that the maximum and minimum PHS levels (2 and 0) analogize the countries with the highest and lowest death rates.

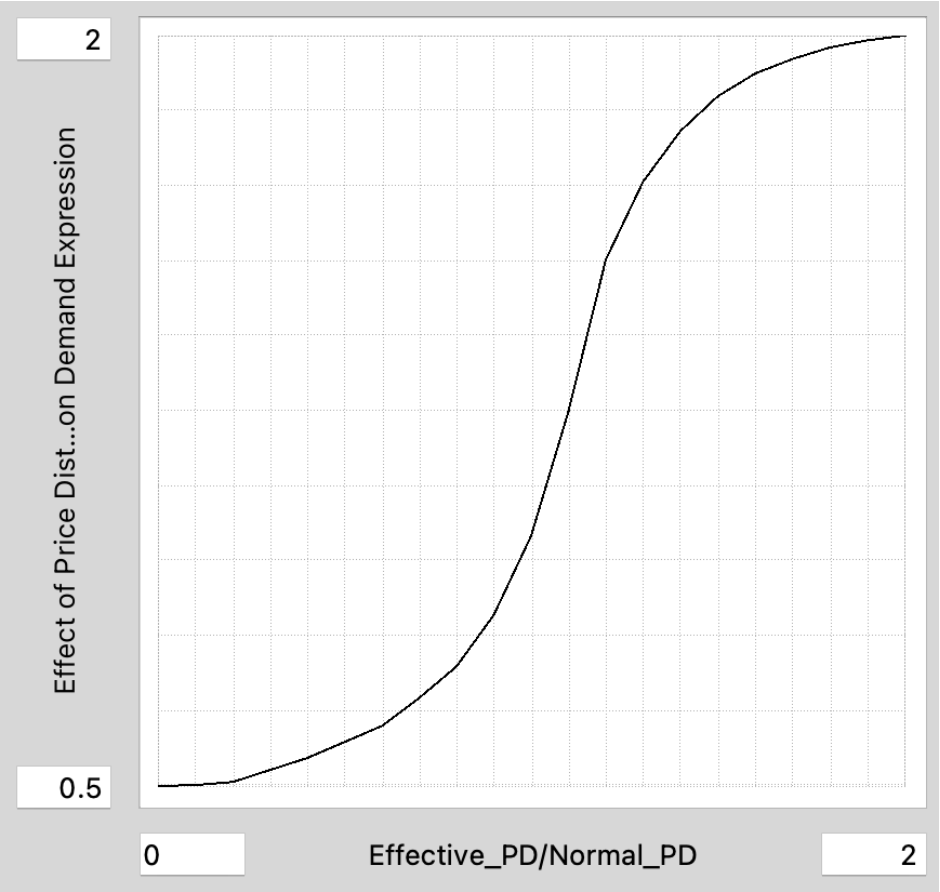


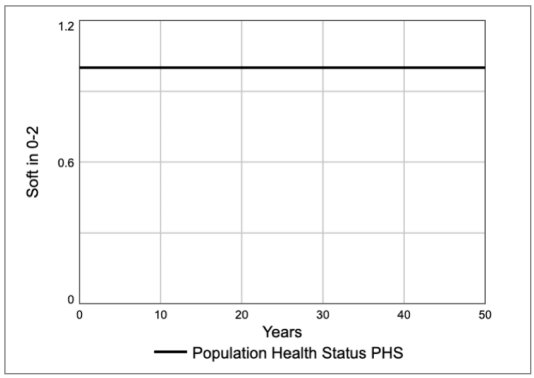
Figure 6.2. Graphical effect: Effect of Price Distortion on Demand Expression (dimensionless).

In a similar manner, in order to calibrate the Effect of Price Distortion on Healthcare Demand, we used the outputs of a health insurance experiment in China that explores the participant behavior against changing cost-sharing levels and care pricing [31]. All graphical effect functions we use in our model are normalized and pass through (1, 1) point, meaning that the function would equal unity when the input

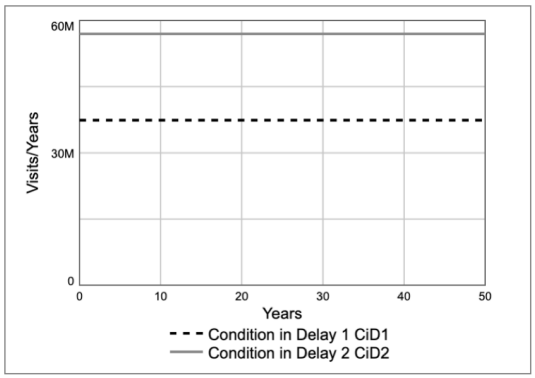
variable is in its reference or normal level. Population and Employment variables are shown in Table 6.1, while the remaining parameter values and graphical effect functions are provided in Appendices A and B, respectively.

Table 6.1. Population and employment parameters.

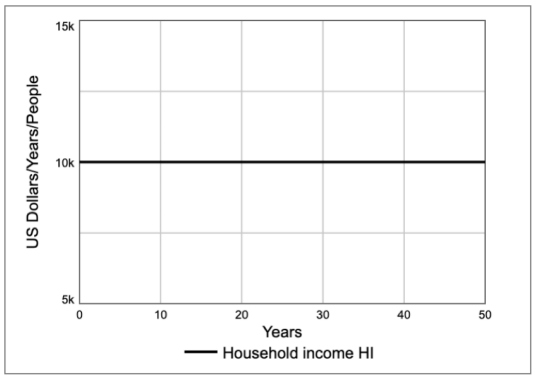
Parameter	Value	Unit	Reference
Population Aging Parameters			
Crude Birth Rate	17	per 1000 people	[32]
Age Specific Death Rate			
Age[0-20]	0.005169508	per year	[33]
Age[20-35]	0.001511475	per year	[33]
Age[35-50]	0.005517304	per year	[33]
Age[50-65]	0.011816029	per year	[33]
Age[65+]	0.079618579	per year	[33]
Initial Age Distribution			
Age[0-20]	0.288272	% of population	Calibrated*
Age[20-35]	0.211446	% of population	Calibrated*
Age[35-50]	0.195332	% of population	Calibrated*
Age[50-65]	0.165957	% of population	Calibrated*
Age[65+]	0.139	% of population	Calibrated*
Employment Parameters			
Unemployment Rate (UR)	5.9	% of workforce	[34]
Labour Force Participation Rate	59.3	% of population	[34]
Employment Rate (FER)	55.8	% of workforce	[34]
Formal Employment Fraction	0.21	employments/year	Calibrated**
Informal Employment Fraction	0.21	employments/year	Calibrated**
Net Formalization Fraction	0.023	employments/year	Calibrated**
* Using WHO data for dynamic equilibrium			
** Using ILO data			



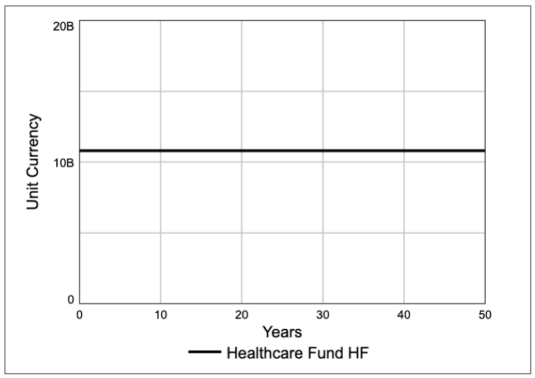
(a) Population Health Status



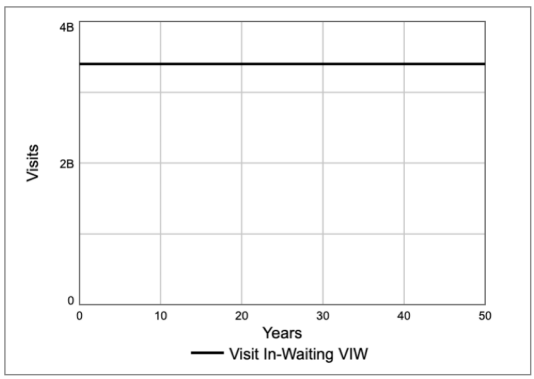
(b) Chronic Conditions



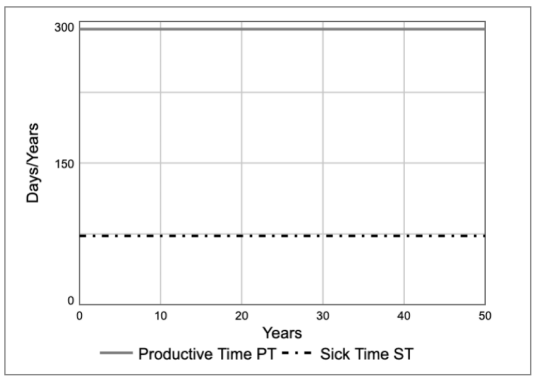
(c) Household Income



(d) Healthcare Fund



(e) Visits In Waiting



(f) Time

Figure 6.3. Selected variables in equilibrium run

6.2. Equilibrium Run

Model behavior in equilibrium run is presented in Figure 6.3. All material stock variables are in a dynamic equilibrium with their inflows and outflows being equal,

while all the information stocks have their adjustment flow equal to 0. The equilibrium run assumes a system where the public programme is in a stable relationship with the population's health, employment, and socioeconomic characteristics. The current benefit package the public programme provides just enough coverage and benefits for this specific population age distribution and income level, making all of the causal effects and feedback loops balancing each other in a dynamic equilibrium.

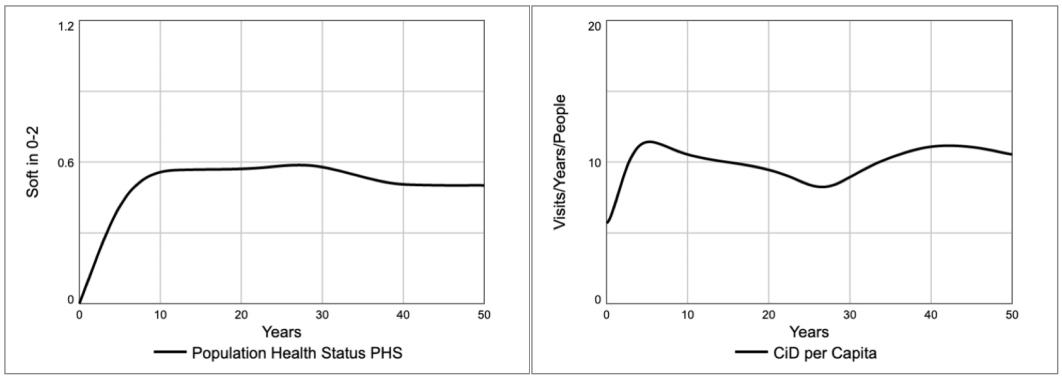
6.3. Structure-oriented Validation Testing

Partial simulation runs are conducted to observe the individual behaviors of sectors in isolation. For a constant birth rate, we observed stable (dynamic equilibrium) behaviors in each sector with the outside feedback suspended. In order to build confidence in the structural validity of our model, we conducted structure-oriented behavior tests (extreme condition tests in particular) to analyze model behavior under extreme conditions [35].

6.3.1. Test 1: Minimal Health

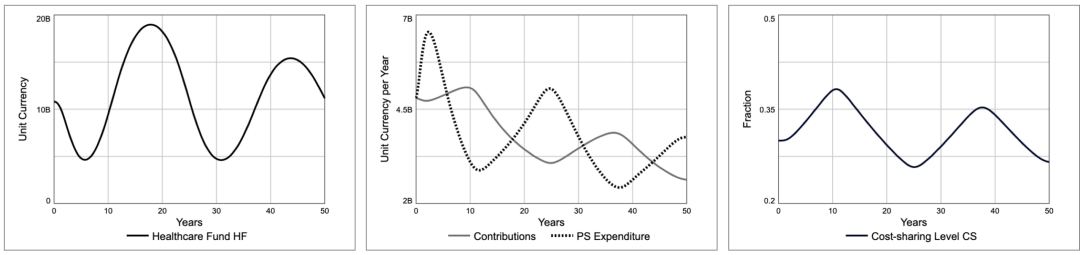
As the first extreme condition test, we simulated the model for an initially minimal health level. In this regard, Population Health Status -which is defined as a soft variable between 0 and 2- is set to zero while all other variables are kept at default. This test represents an initially very unhealthy population with default levels of chronic conditions, public programme benefits, and income level.

PHS level is shown to initiate at zero and continue with an increasing behavior in Figure 6.4a. The improvement in population health lasts for 10 years after which the PHS level saturates at a level well below the default level of 1. CiD per Capita are shown to have a more rapid initial increase in Figure 6.4b. This behavior is the result of the increased healthcare demand generated by the low population health. As more demand is generated, more demand is left unsatisfied, leading to the accumulation of chronic conditions in CiD stocks. The accumulation in the CiD stocks contributes to the saturating behavior of PHS, disabling it to replenish to the default level of 1.

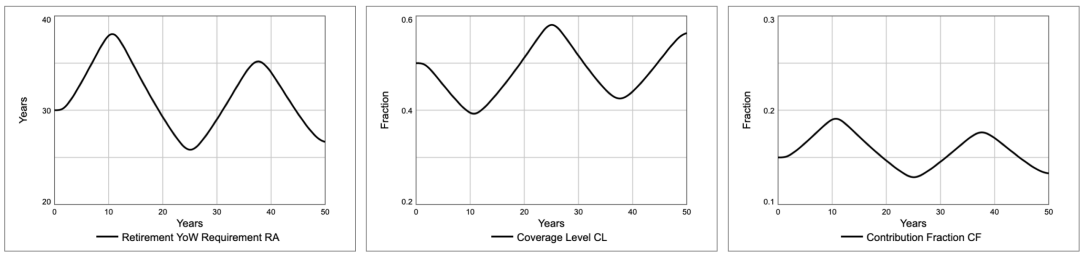


(a) Population Health Status (b) Chronic Conditions

Figure 6.4. Population Health Status and CiD per Capita in minimal health test.



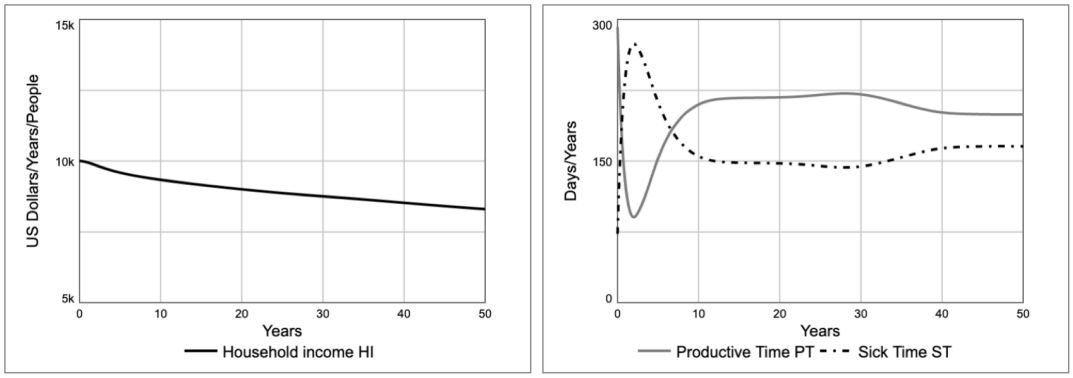
(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level



(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 6.5. Public Scheme sector behavior in minimal health test.

An increase in healthcare demand forces the Healthcare Fund to rapidly deplete in Figure 6.5a. The economic stress reacts by reducing the programme benefits significantly. Once the PHS level ascends to a more reasonable level in the first 10 years, the system finds itself in a state where the benefits are already reduced, and the tax level is heightened. This in turn results in overshoot and oscillation behavior in Healthcare Fund and other programme variables.



(a) Household Income (b) Time

Figure 6.6. Socio-Economics sector behavior in minimal health test.

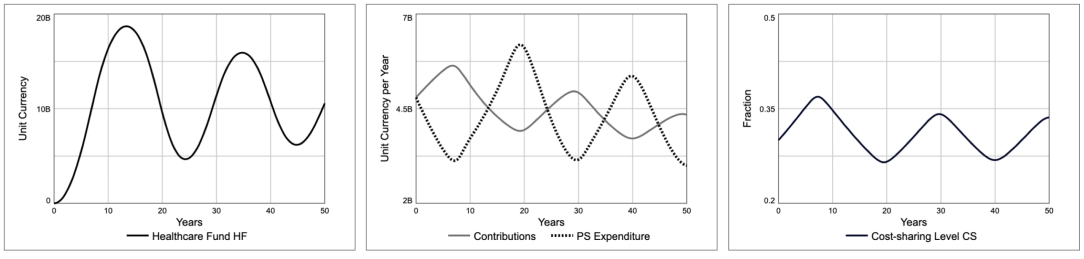
The minimal health also decreases the revenue-generating capability of the population by reducing the Productive Time as shown in Figure 6.6b. The time allocation between productive and sick times is adjusted with a delay, therefore the drop in Productive Time is not immediate but rather an exponential decay behavior. Since the PHS level can recover during the Productive Time‘s descent, the behavior shifts from downward exponential decay to upward exponential decay at year 3. This overall drop in productivity causes the Household Income to decay significantly even after the PHS level replenishes itself to 0.5.

Overall, the system is observed to improve the initial minimal health by a certain extent due to available program benefits and income level at time zero. However, this improvement cannot fully replenish the population health to its default level. We conclude that the model behavior aligns with the expected dynamic behavior of the system for Test 1.

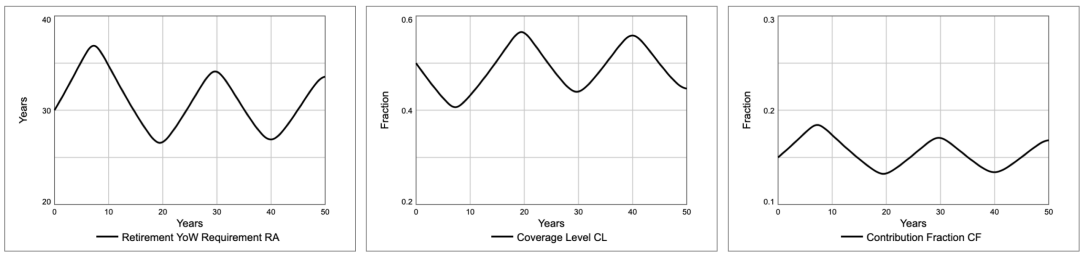
6.3.2. Test 2: Zero Initial Fund Level

In the second extreme condition test, the initial level of the Healthcare Fund is defined as zero. The huge level of initial budget shortfall activates the economic stress to reduce the benefits and increase the tax burden. The drastic measures taken by this initial high shortfall cause the healthcare fund to increase swiftly, overshooting

the desirable level in Figure 6.7a. The following behaviors of the Healthcare Fund and public programme variables are shown to be oscillatory with diminishing amplitudes.



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

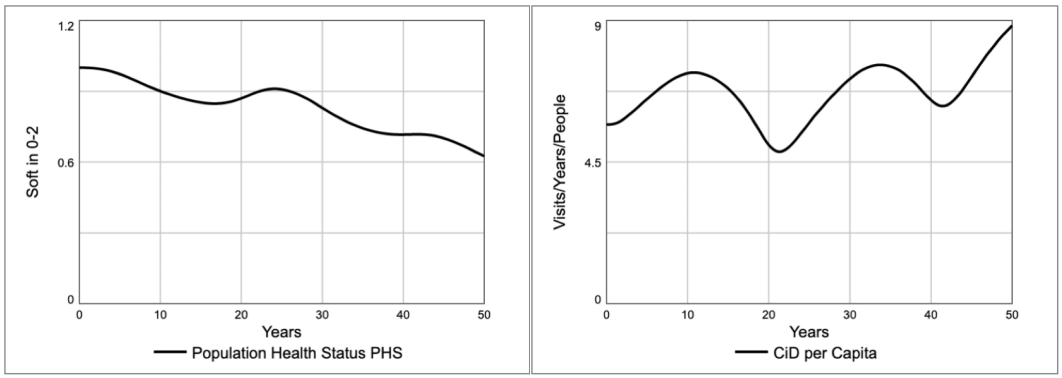


(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 6.7. Public Scheme sector behavior in zero fund test.

The swift initial reduction in benefits allows the chronic conditions to build up in the first 10 years of Figure 6.8b. This increased chronic disease burden shows itself as a decrease in PHS after a delay in Figure 6.8a. The period healthcare fund spends in overshoot allows the programme benefits to enlarge between years 7 and 20. This period decreases the chronic conditions to a significant extent with a time lag (between years 10 and 23 in Figure 6.8b). As a result, PHS is alleviated momentarily to achieve a local peak before the system enters another benefit reduction period in an oscillatory manner.

When the model is initiated with no funds in HF stock, the balancing structure of economic stress (B1 - Hand of State) operates to replenish the fund to its desired level as would occur in a real-life case. However, the delays in policy adjustment leads to overshooting behaviors in model variables, which causes the oscillations. We conclude that the model behavior in Test 2 is expected and valid



(a) Population Health Status (b) Chronic Conditions

Figure 6.8. Population Health Status and CiD per Capita in minimal health test.

6.3.3. Test 3: No Births

The third extreme condition test simulates the model for no birth occurrence. Crude Birth Rate is defined to be zero, thus equating the Births inflow to Juveniles stock to zero.

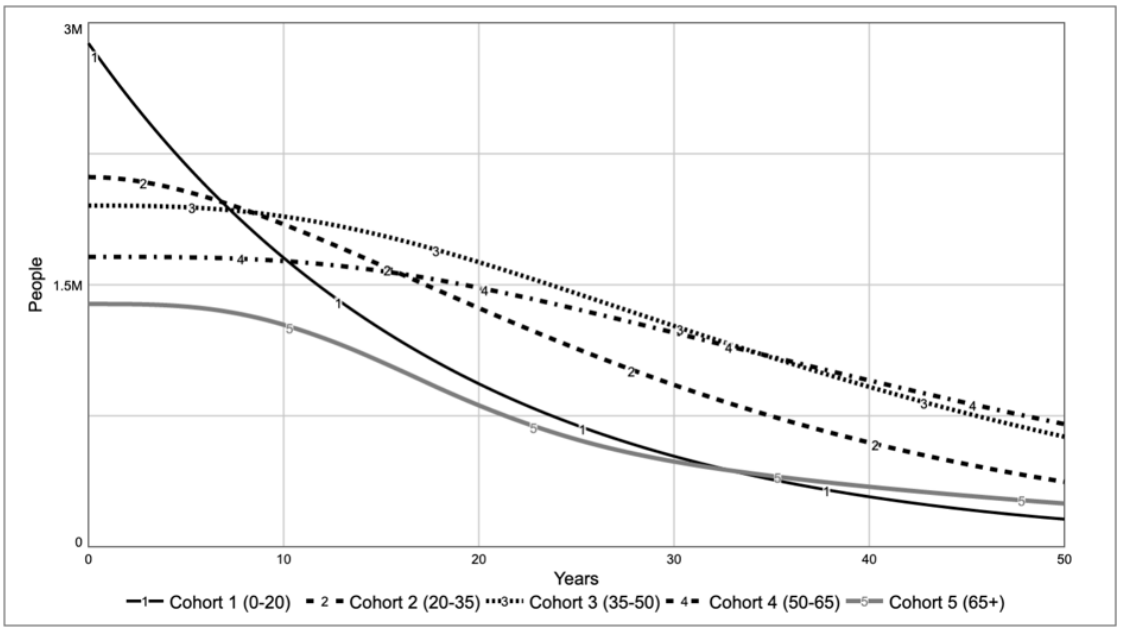
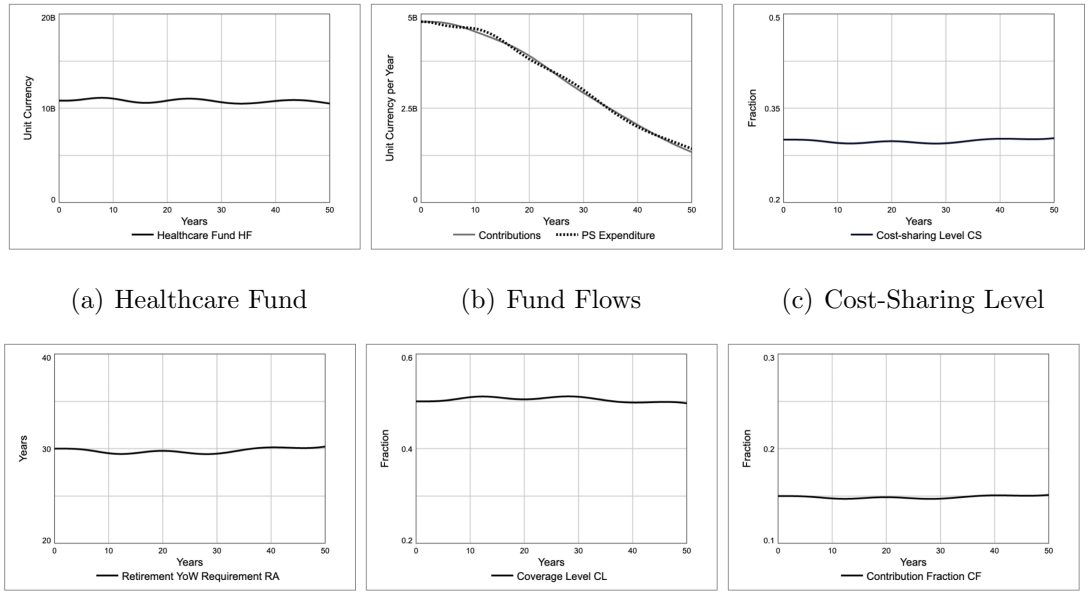


Figure 6.9. Population age distribution in no births test.

The Juveniles population (Cohort 1) decays exponentially followed by the delayed sub-exponential decays of other cohorts in Figure 6.9a. Even though there are no births occurring, The Juveniles stock does not reach zero over its decaying behavior over 50 years which is due to the decaying nature of the Juveniles behavior. In the end, we observe a highly aged population of around 2.11 million people against the initial level of 10 million.

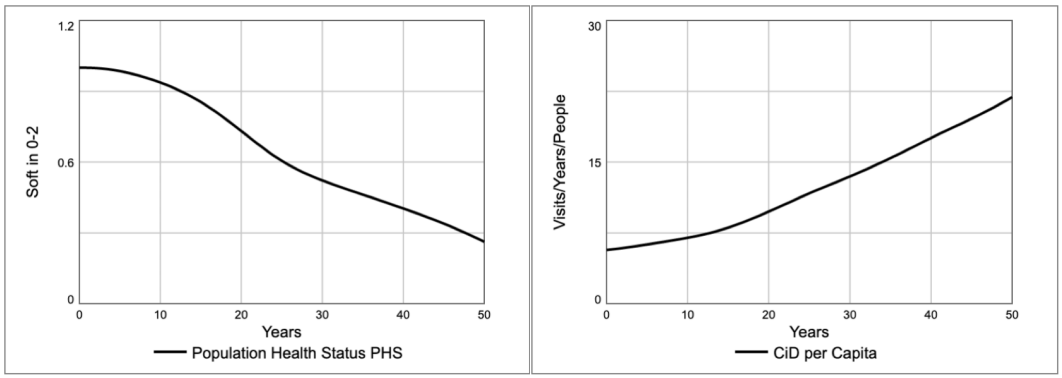


(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 6.10. Public Scheme sector behavior in no births test.

The public programme is shown to be sustained in the no births test in Figure 6.10. With no births present, the formal employment rate can be preserved or even increased in the mid-term, until the population completely ages and therefore becomes unable to work. The only significant shift is apparent in fund flows of Figure 6.10b which is observed because of the heavy drop in population level from 10 million to 2.11 million (and therefore total Expenditure and Contributions decrease). Nonetheless, generated healthcare demand increases (which is modeled to increase by age) with such a shift in population structure. The public programme can cover only a portion of these increased demands while the demand left uncovered leads to the development of more chronic conditions as in Figure 6.11b. Through the operation of the R3 – Austerity Payoff loop, the PHS level deteriorates due to increased CiD.



(a) Population Health Status (b) Chronic Conditions

Figure 6.11. Population Health Status and CiD per Capita in no births test.

The expected model behavior under no births would be an increase in mean population age and an eventual depletion. Also, increase in mean population age would lead to more chronic conditions and worsened population health. In this regard, the model behavior is found to be valid in Test 3 as well.

6.3.4. Test 4: No Formal Employment

The fourth test simulates the model for no initial formal employment. The Informal Employment Rate is kept the same as the default, while Formal Employed Workforce for each workforce age cohort is shifted to the unemployed stock, making the initial Formal Employment Rate zero.

The unemployed workforce shows a swift decline due to the overload caused by the initial high level in Figure 6.12. The workforce leaving the unemployed status joins the informally and formally employed status as shown by the increasing behavior of Informal Employment Rate and Formal Employment Rate. Formal Employment Rate initiates at zero and slowly replenishes, saturating around 33% at year 7 before it starts increasing again at year 25 and saturating around 50% at year 37.

PS sector behavior in Figure 6.13 can explain these behavior shifts. Since no formal employment is present at year zero, employee Contributions is zero (Figure

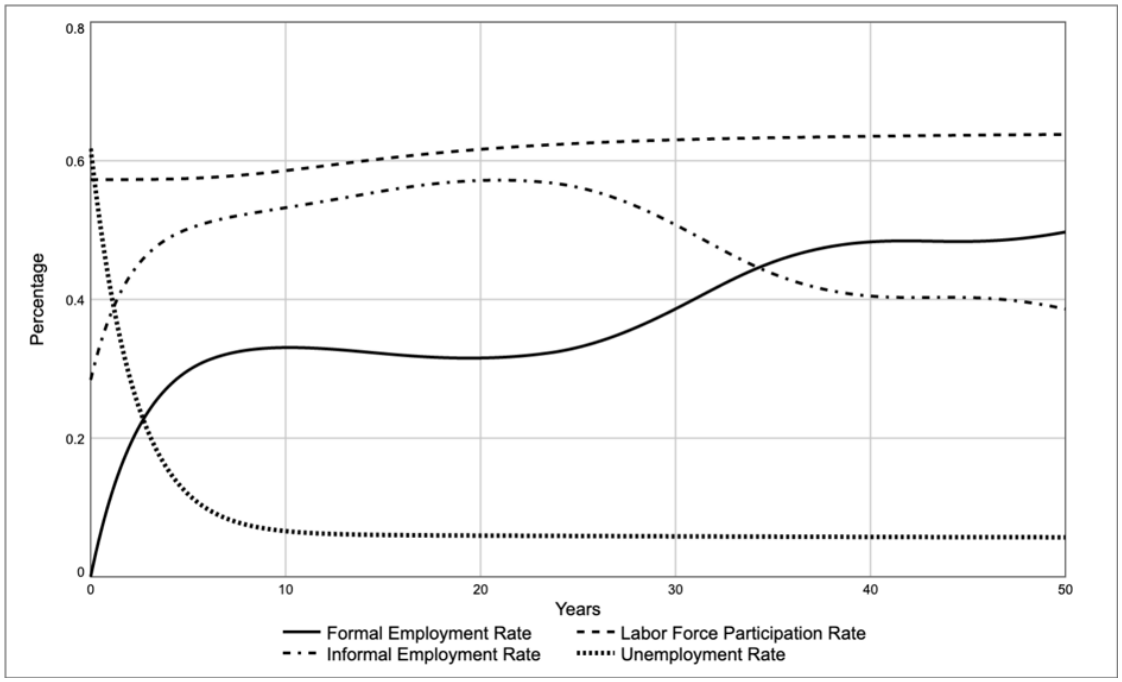
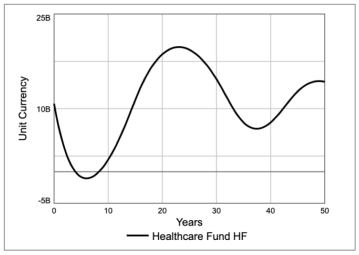
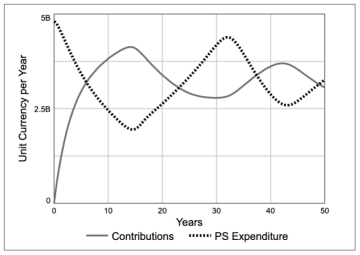


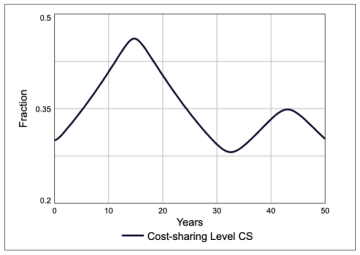
Figure 6.12. Employment variables in no formal employment test.



(a) Healthcare Fund

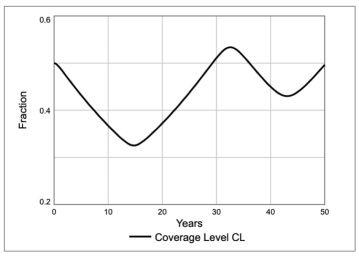


(b) Fund Flows

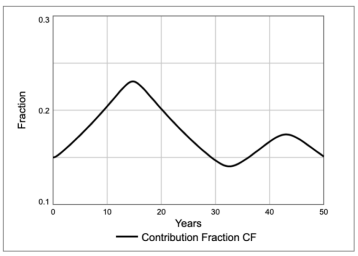


(c) Cost-Sharing Level

(d) Retirement Requirement



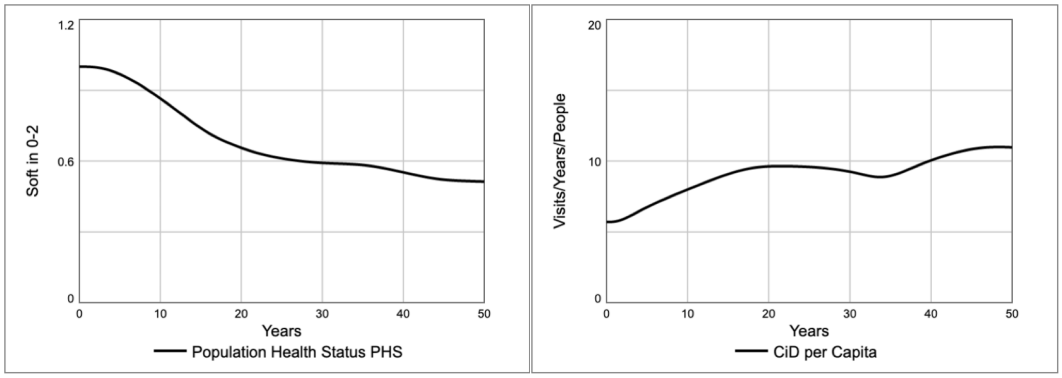
(e) Coverage Level



(f) Contribution Fraction

Figure 6.13. Public Scheme sector behavior in no formal employment test.

6.13b) and Healthcare Fund receives no inflow. This causes HF to plummet sharply, reaching a negative global maximum at year 7. The resulting economic stress acts by limiting the coverages and increasing the Contribution Fraction to stabilize the HF. HF expectedly overshoots and then the economic stress operates in the opposite direction, enlarging the coverages and decreasing the Contribution Fraction. Decreased tax burden operates the R1 – Tax Evasion Spiral in the favor of formal employment, increasing the Formal Employment Rate until year 33.



(a) Population Health Status (b) Chronic Conditions

Figure 6.14. Population Health Status and CiD per Capita in no formal employment test.

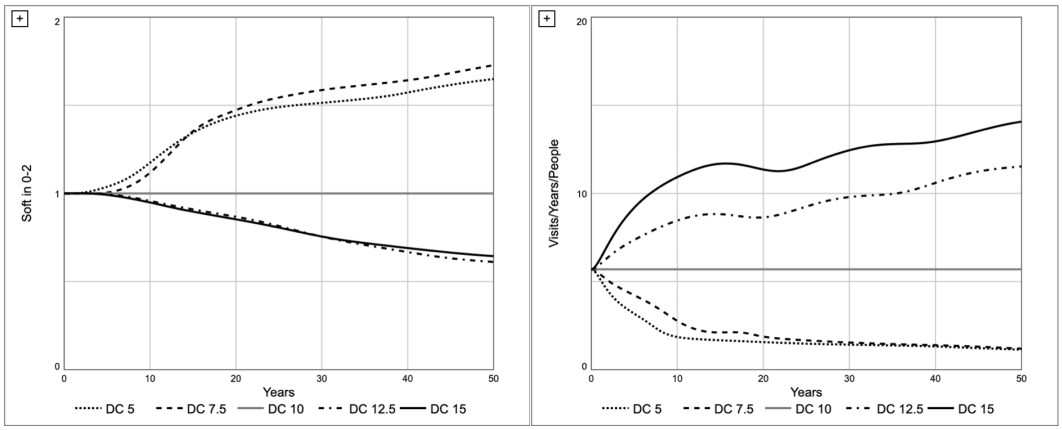
The decreased coverages caused by the initial budget shortage allow for the chronic conditions to build up and deteriorate the PHS in Figure 6.14. We also observe that HF overshoot and consequent enlarged benefits show a slight improvement in CiD per Capita between years 25 and 33 but it fails to compensate for the initial health deterioration.

The model behavior under each extreme condition met with the expected dynamic behavior given the model assumptions for the real-life system behavior, and the behavior itself can be explained by the model's causal structure. We conclude that the model behaves structurally valid. However, the qualitative estimation we utilized in some model variables (e.g., Percentage of Essential Elastic Demand, Normal Demand Expression Percentage) necessitated sensitivity analysis to build further confidence in

model behavior. For each estimated variable with a central role in model behavior, we simulate their respective sector and full model within a sensible but large parameter range.

6.4. Sensitivity to Model Parameters

In order to test the model sensitivity to parameter levels, we have selected several central variables and conducted sensitivity analysis while taking the equilibrium run as the benchmark. In this section, we present the results of the sensitivity testing on Demand Coefficient, Unit Visit Cost, and Percentage of Elastic Demand.

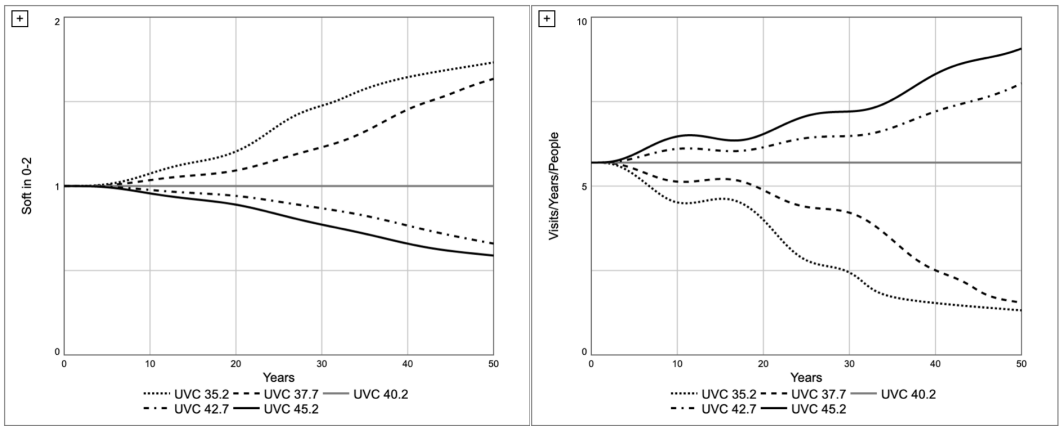


(a) Population Health Status (b) Chronic Conditions

Figure 6.15. Population Health Status and CiD per Capita for Demand Coefficient levels of (5, 7.5, 10, 12.5, 15).

Figure 6.15 presents the sensitivity testing conducted on the Demand Coefficient, the coefficient for unit demand generated per person. The model is simulated for 5 Demand Coefficient levels around the default level of 10: (5, 7.5, 10, 12.5, 15). A change in the unit demand is shown to disturb the initial equilibrium and have intuitive impacts on two of the central model variables: Population Health Status and CiD per Capita worsens for higher DC levels and improves for the lower. However, the relationship is not direction-wise fully linear for the changes in the same direction, DC=7.5 is better than DC=5, implying a trade-off.

The behavior can be explained by the causal structure of Figure 5.8, as less demand is generated, even though Condition in Delay accumulation is minimized, regeneration of Population Health Status by Provision Offset also decreases, making DC=7.5 moderately better off than DC=5. Similarly, DC=15 performs slightly better than DC=12.5 for the same reasoning.



(a) Population Health Status (b) Chronic Conditions

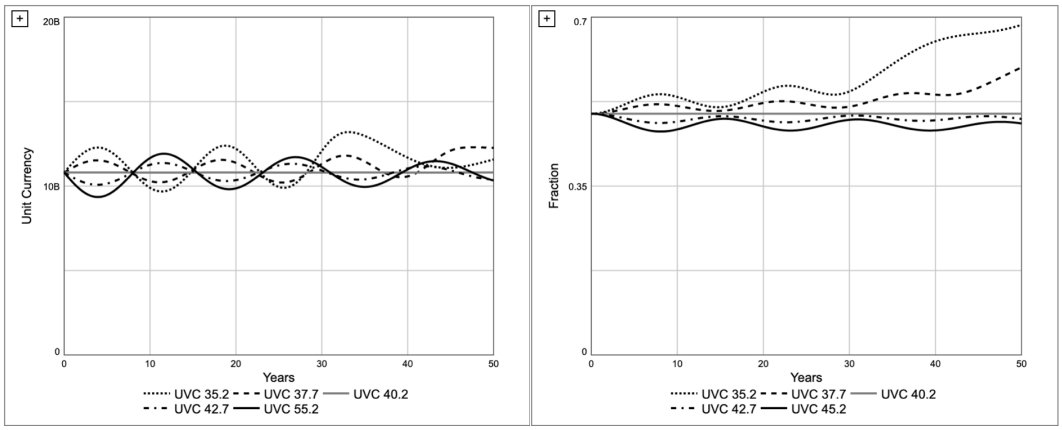
Figure 6.16. Population Health Status and CiD per Capita for Unit Visit Cost levels of (35.2, 37.7, 40.2, 42.7, 45.2).

The second sensitivity parameter we have selected is Unit Visit Cost, representing the unit healthcare cost of the public programme. The model is simulated for 5 Unit Visit Cost levels around the default level of 40.2: (35.2, 37.7, 40.2, 42.7, 45.2). Generated model outputs are presented in Figure 6.16 and Figure 6.17.

Similar to the DC case, the parameter deviation in UVC breaks the equilibrium and carries the system either better-off or worse-off for optimistic (cheap healthcare) and pessimistic (expensive) parameter values respectively. The relationship is observed to be linear, as costs go up, chronic conditions build up and population health eventually worsens.

UVC parameter directly affects the Healthcare Fund by determining its outflow Expenditures. Therefore, the deviation in UVC has a more direct effect on public

programme variables as shown in Figure 6.17. The HF is observed to oscillate for deviations in UVC. For higher than default UVC levels (42.7 and 45.2), the initial HF direction is downwards, while it is upwards for the lower than default UVC levels (35.2 and 37.7). The amplitude of the oscillations has a positive relationship with the parametric difference of the UVC level with the default.



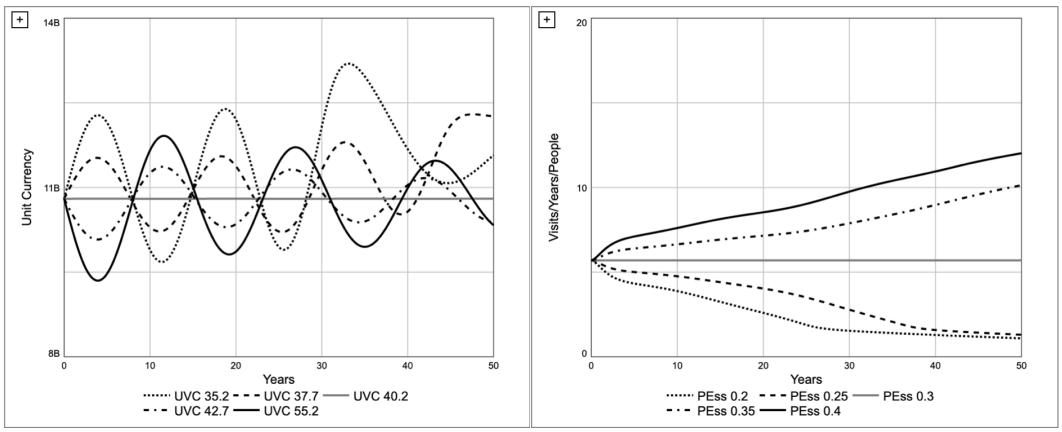
(a) Healthcare Fund (b) Coverage Level

Figure 6.17. Healthcare Fund and Coverage Level for Unit Visit Cost levels of (35.2, 37.7, 40.2, 42.7, 45.2).

The initial HF direction determines the characteristic of the initial oscillation period. A downward initial HF behavior puts economic stress on the public programme and reduces the programme benefits until the HF is restored to the desired level. The resulting Coverage Level behavior is presented in Figure 6.17b. For higher than default UVC levels, the initial CL direction is downwards, a reduction in coverages. This is what makes the difference in terms of the dynamics of population health variables in Figure 6.16 across different UVC settings. Since the initial period sees a reduction in coverages, it allows for the chronic conditions to build up. The balancing mechanisms react later, but they fail to replenish the PHS and CiD back to their initial level.

As the third sensitivity parameter, we analyzed the Percentage of Essential Elastic Demand (PEss). PEss defined to be the fraction of elastic demand that is assumed to be essential and would result in chronic condition accumulation if left untreated. The

default level of PEss is defined to be 0.3 and the model is simulated for 5 PEss levels around the default level: (0.2, 0.25, 0.3, 0.35, 0.4).



(a) Population Health Status (b) Chronic Conditions

Figure 6.18. Population Health Status and CiD per Capita for Percentage of Essential Elastic Demand levels of (0.2, 0.25, 0.3, 0.35, 0.4).

Change in PEss is shown to disturb the equilibrium in Figure 6.18 similar to the DC and UVC. If more than the default percentage of the essential demand is essential, more of the unsatisfied demand becomes essential which leads the chronic conditions to further accumulate. If the percentage is less, then the unsatisfied portion of the essential demand gets smaller, reducing the inflow to chronic condition stocks.

The stability of the initial dynamic equilibrium is shown to be sensitive to parameter changes that disturb the dynamic equational relations. Parameter changes carry the system to new stable equilibrium levels that can be defined by better and worse health and chronic condition levels. After our sensitivity analysis, we conclude that the model behaves logically against deviations in parameters and the behavior changes can be explained by the underlying causal structure.

7. SCENARIO ANALYSIS

In this section, we define several scenarios as settings where the principle of collective equivalence is not present. In this regard, we treat several parameters as inputs to disturb the initial equilibrium and script the scenarios by manipulating their directions from default. The three input parameters we have selected are Crude Birth Rate trend (increasing, decreasing), Unit Visit Cost initial value (high, low), and Unit Visit Cost trend (increasing, decreasing).

Table 7.1. Parameter configurations in scenario analysis.

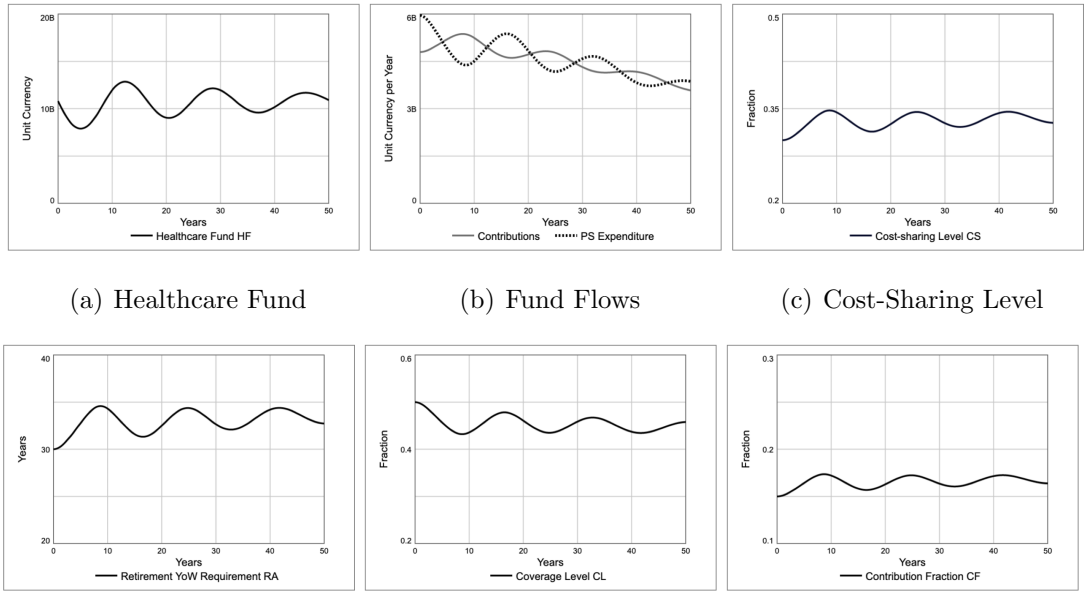
Scenario #	**UVC Level**	**UVC Trend**	**CBR Trend**
Scenario 1 (Base)	High	-	-
Scenario 2	-	Increasing	-
Scenario 3	-	Decreasing	-
Scenario 4	-	-	Decreasing
Scenario 5	-	-	Increasing
Scenario 6	Low	-	-
Scenario 7	High	Decreasing	-
Scenario 8	Low	Increasing	-
Scenario 9	-	Increasing	Increasing
Scenario 10	Low	-	Decreasing
Scenario 11	Low	Increasing	Decreasing

We first analyze the system behavior for one at a time changes of input parameters levels. Then we analyze the scenarios for the several selected combinations of the pessimistic and optimistic (in terms of public programme sustainability and population health) leveling of input parameters. The scenario configurations we have analyzed in this section are presented in Table 7.1. The remaining scenario configurations are left out because of their intuitive or resembling behaviors to other scenarios.

7.1. Scenario 1: High Healthcare Cost Scenario (Base Scenario)

In this scenario, the Unit Visit Cost is set to a moderately higher (50 unit currency) level than its default level (40.2 unit currency) and all the other parameters are kept at their default levels. This scenario represents an SHI system where the annual healthcare fund expenditure is larger than annual employee contributions and therefore a fund shortage persists throughout the simulation horizon. In this section, we analyze how the dynamics of Healthcare Fund affect the population health for the worse through different mechanisms in the base case scenario.

The first aspects to analyze are the financials and benefits of the public programme. Figure 7.1 presents the PS policy variable and fund behavior in the base case scenario. PS benefits are observed to fluctuate with a small but visible decreasing trend. We can examine the development of this behavior by tracing back to the initial triggers and the following sequence of events.



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

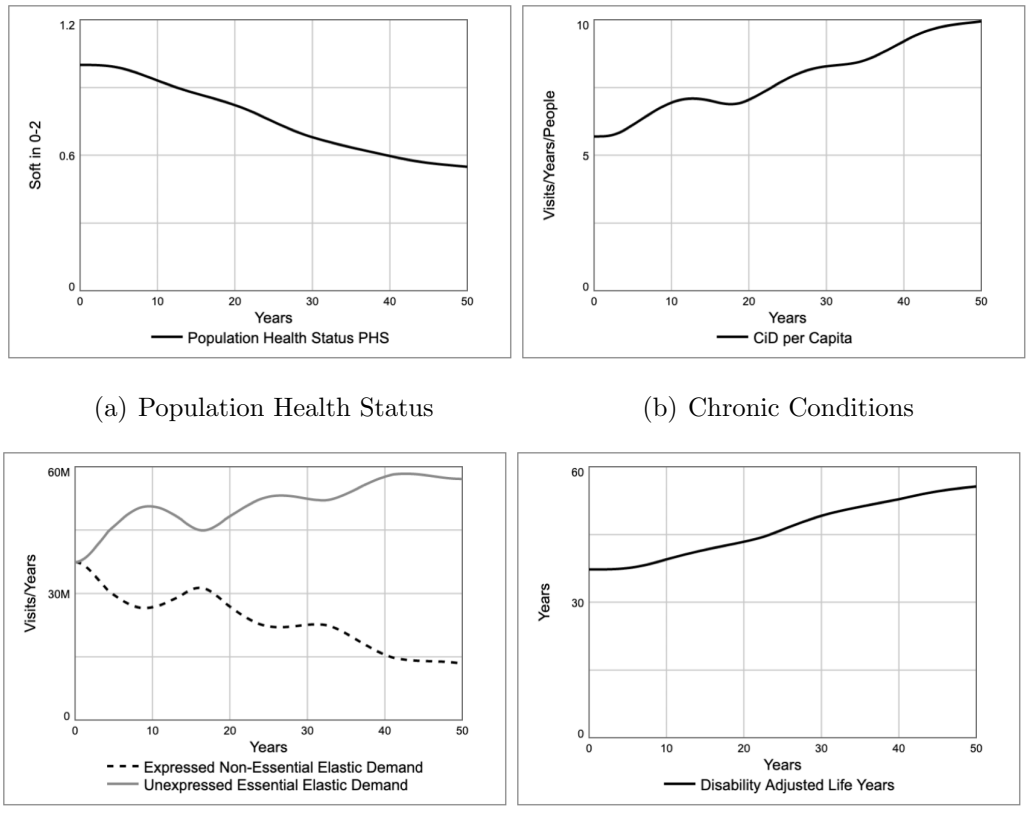
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.1. Public Scheme sector behavior in Scenario 1.

At first, due to the initial higher than default unit cost level, Healthcare Fund shows a decreasing behavior in Figure 7.1a. This decrease triggers the Economic Stress

(ES) in order to adjust the policy variables to a less beneficial level, starting an austerity period. Consequently, the system starts to increase the Contribution Fraction (CF), Cost-Sharing level (CS), and increased required working years for retirement (RA) while decreasing Coverage Level (CL) after a Policy Adjustment Delay, as seen in Figure 7.1.

This ES-induced benefit reductions and taxation increase manage to carry HF Contributions to a larger value than HF Expenditures around year 5 and by year 7, the HF level is restored to its desired level. As the HF level reaches its desired level, Economic Stress becomes 0. However, since the Contributions at that time still stands significantly larger than the Expenditures, the HF level continues increasing and overshoots its desired level. The Economic Stress then takes a negative sign, increasing the PS benefits by starting a generosity period.



(a) Population Health Status

(b) Chronic Conditions

(c) Unnecessary vs Necessary

(d) DALY

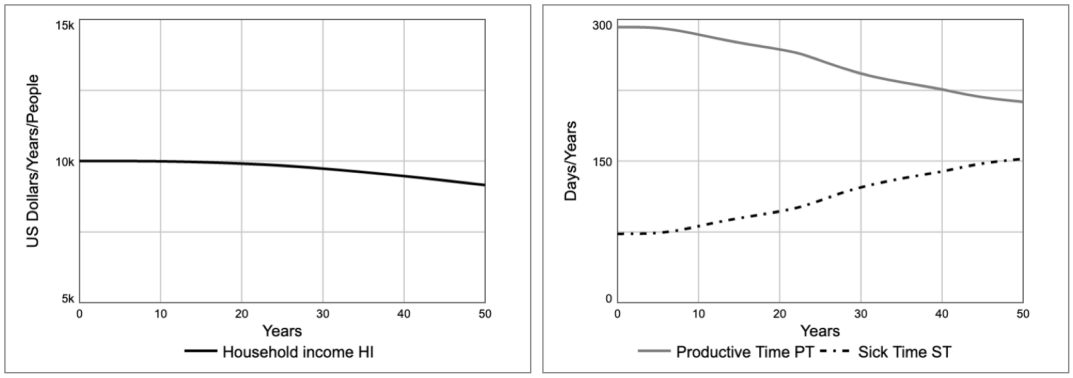
Figure 7.2. Healthcare Demand sector behavior in Scenario 1.

The system shows a very similar behavior but in opposite directions during the generosity and austerity periods. This dual balancing dynamic is the result of the operation of the B1 – Hand of State loop aiming to keep the healthcare fund at the desired level in the face of escalating expenditures. In other words, the state either compromises the PS benefits to sustain the fund reserves or increases the PS benefits when the fund reserves are above the needed level by using the 4 policy levers. Sequential overshoot and declines caused by the policy adjustment delay in this process cause the HF Fund and PS benefits to oscillate for a period of 16 years. But the dynamics in the PS sector do not causally describe the decreasing trend in policy variables. The balancing loop B1 seems like it would operate smoothly to bring the system to a stable or borderline stable equilibrium, to a PS package with more modest benefits, but the steady downward trend in policy variables persists even after the initial austerity period. This hints that the operation of the B1 loop should have some other effects on population health.

Population-level health outcomes of the base scenario are presented in Figure 7.2 using the central variables of the Healthcare Demand Sector. The initial "period of austerity" does not seem to have a swift impact on Population Health Status (PHS) in Figure 7.2.a and we also see that the policy has not immediately affected the DALY metric in Figure 7.2.d as well. However, Figure 7.2.b shows that this austerity era allowed the chronic conditions to build up well enough to deteriorate PHS once matured.

We can trace back to the stock-flow structure in Figure 5.9 to understand this development of events. As more demand is generated due to the worsening population health and moral hazard effect during generosity periods, B1 decreases the PS benefits to alleviate the moral hazard problem and promote austerity. With a less generous plan in effect, the elastic demand expression percentage reduces, leaving more of the essential healthcare demand unexpressed as shown in Figure 7.2.c, activating the R3 – Austerity Payoff loop. This unexpressed-unanswered demand accumulates in Condition in Delay and eventually hits PHS stock with a heavier magnitude. B6 – Provision Offset fails to compensate for the damage caused by R3 and PHS deteriorates.

Each of those austerity periods (declines in Figure 7.1.a) similarly activates R3 -and even though the overall trend in the PS variables isn't very high- the nadirs of the PS oscillations are enough to worsen the population health. It should also be noted that PHS also affects the productive time of the population which is accounted for in the DALY metric. Since Household Income is a major determinant of HF financials an analysis of the Socio-Economics sector may also explain the decreasing trend in PS benefits.



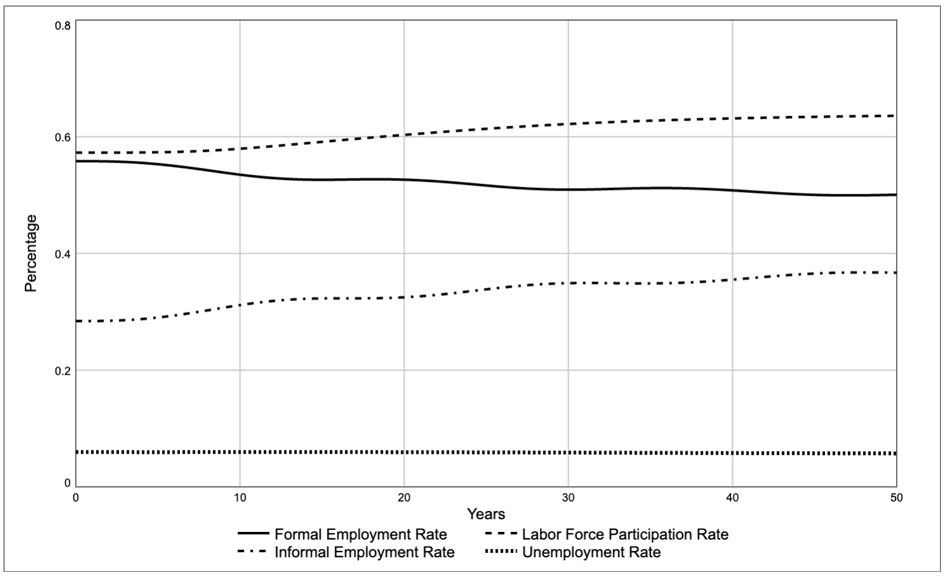
(a) Household Income (b) Time

Figure 7.3. Socio-Economics Sector behavior in Scenario 1.

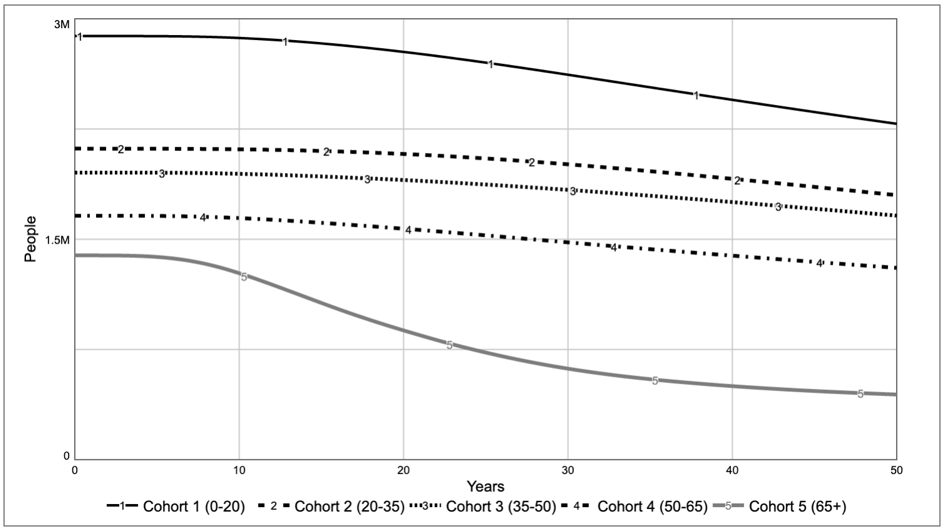
The Socio-Economics sector's behavior in scenario 1 is shown in Figure 7.3. Formulated as a function of PHS, Productive Time shows a nearly identical behavior to the PHS. More time is spent sick as population health worsens, eventually diminishing the revenue generation capability of the population. Its effect on Household Income is only significant after the end of the time horizon due to the decade-long delay in income adjustment. In the end, worsening of the population health and escalation of expenses results in a worsening of the socio-economic status as well.

Along with the Contribution Fraction and Formally Employed Workforce levels, Household Income is one of the three multipliers of the HF Contributions flow. Since the significance of the HI decline is only observed late in the time frame, we can deduce that household income does not contribute to the benefit reduction dynamics we have analyzed earlier, but the significant decline observed at the end of the time horizon

indicates that the public programme will face great fund shortages beyond the time frame as well.



(a) Employment Variables



(b) Population by Age Cohorts

Figure 7.4. Population sector behavior in Scenario 1.

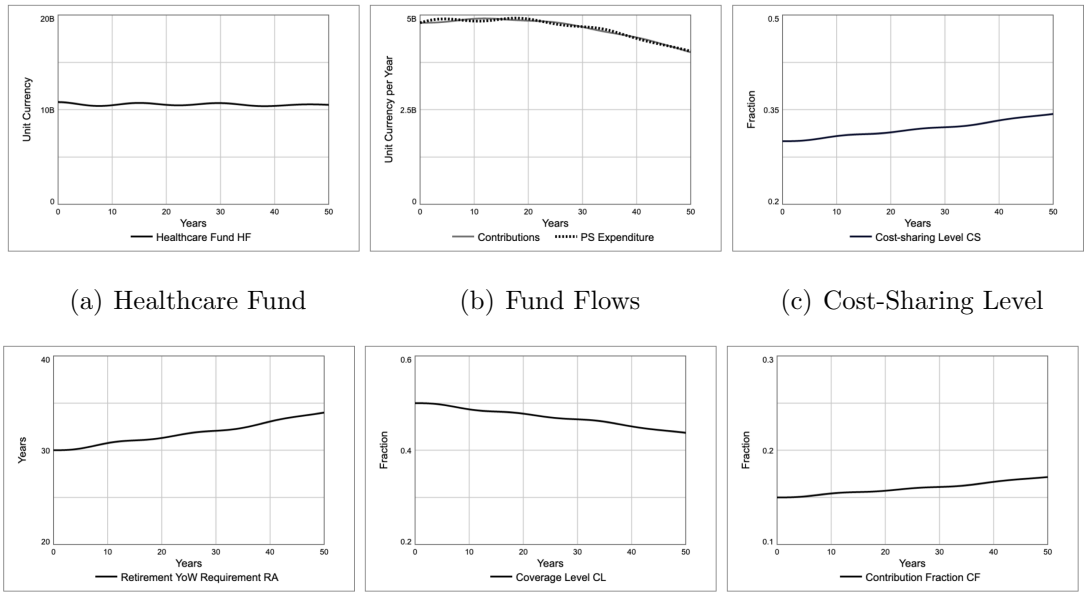
The last element to analyze is the population employment dynamics, mainly the dynamics of the Formally Employed Workforce level. Population goes through significant changes in terms of age distribution and employment leveling in scenario 1 as shown in Figure 7.4. In scenario 1, we kept the crude birth rate at 15.9 (per 1000

persons) which equals the Crude Death Rate in equilibrium. The direct effect of PHS on age-specific death fractions reflects itself in Figure 7.4.b. The initial 5 years show only minor changes in population due to PHS itself being unchanged during that time period. After the gradual decline of PHS begins, death fractions increase, and the population level shows a decreasing trend. Since the rate of increase in death fractions also increase as we go up the age cohorts (death fraction of elderly increasing more), the age distribution also changes. The system carries itself to a new state where the population is younger compared to the initial configuration with a higher Labor Force Participation Rate. This creates a balancing mechanism that generates more workforce as a percentage of the population.

Another causal mechanism that further contributes to the healthcare budget shortage and consequently to the worsening of the population health is the R1 - Tax Evasion Spiral (Figure 5.6) of employment dynamics. Starting from the first period of austerity, as the Contribution Fraction increases, more of the employment shifts from the formal to the informal sector, leading to a steady decline in the Formal Employment Rate (Figure 7.4.a). Even though the Labor Force Participation Rate increases due to the shift in population age structure, it could only slow down the decline of the Formal Employment Rate, dimming the otherwise expected oscillations. Ultimately in the base case scenario, the population is left with low overall health, rising chronic conditions, reduced public programme benefits an enlarged informal sector, and a low-income level, all resulted from a high initial unit cost input.

7.2. Scenario 2: Rising Healthcare Cost Scenario

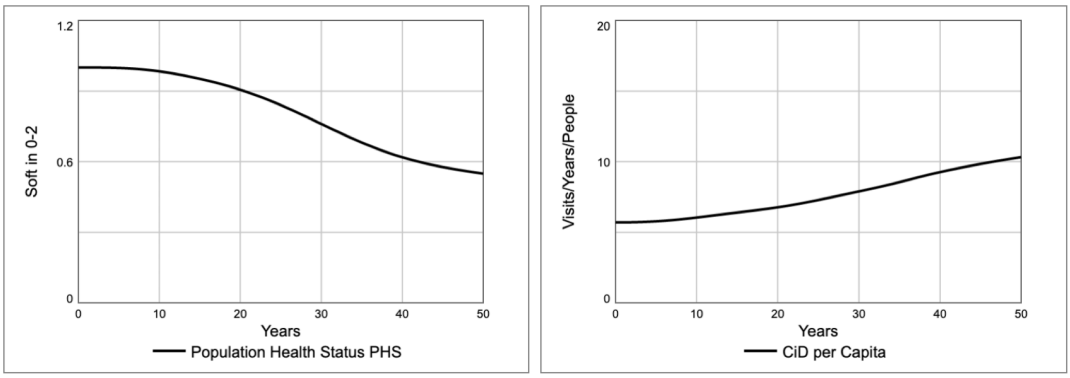
We model the rising healthcare costs scenario by formulating the Unit Visit Cost with a time-dependent trend of [+TIME/3] (annual 1/3 unit currency increase). All other parameter values are kept at their default levels. It should also be noted that since the UVC input trend is a function of time, at time 0, the model is initialized at the default dynamic equilibrium parameter configuration. As time progresses, UVC rises continuously and the system further deviates from equilibrium.



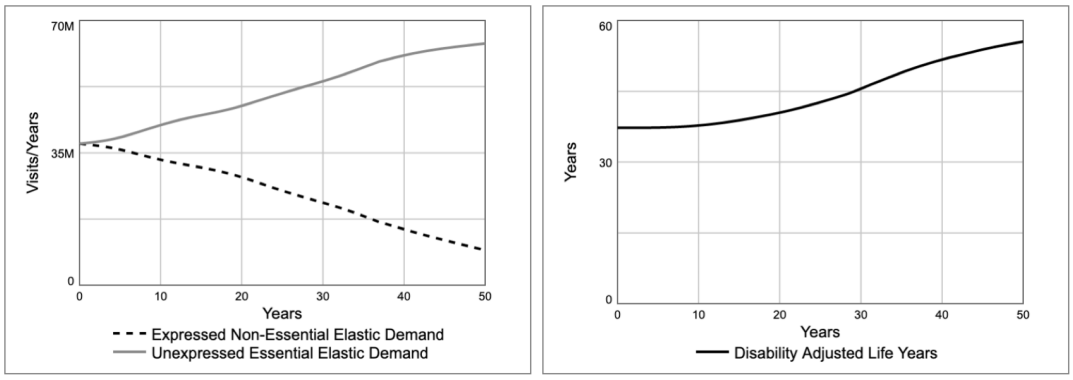
(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.5. Public Scheme sector behavior in Scenario 2.



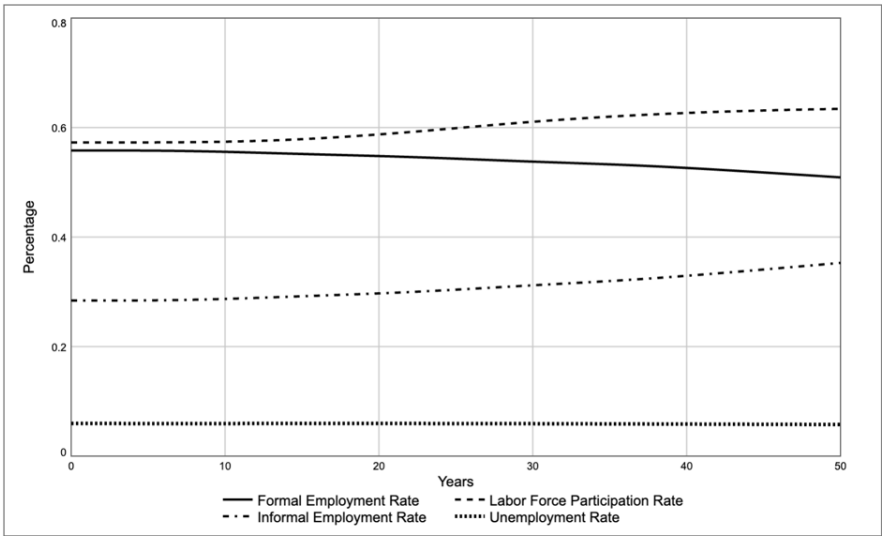
(a) Population Health Status (b) Chronic Conditions



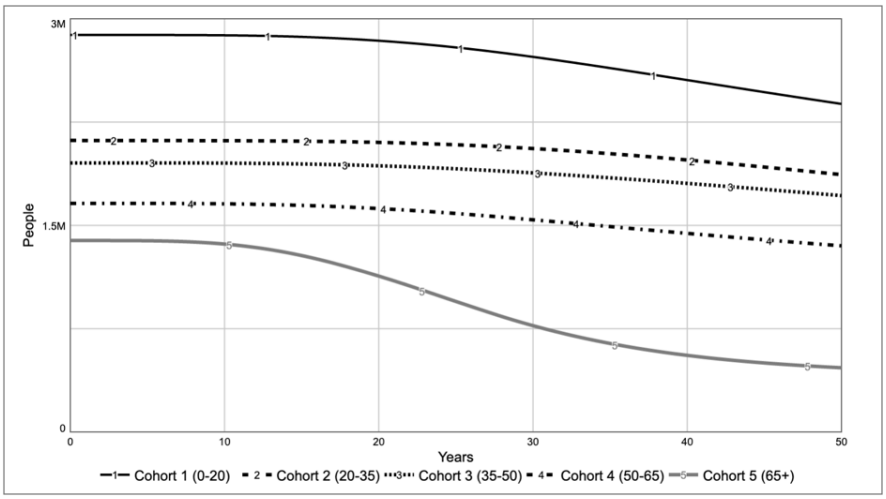
(c) Unnecessary vs Necessary (d) DALY

Figure 7.6. Healthcare Demand sector behavior in Scenario 2.

Public programme benefits show a decreasing trend with very minor oscillatory behavior in Figure 7.5. Similar to scenario 1, oscillatory behavior can be attributed to the effect of the policy adjustment delay. Differing from scenario 1, the low amplitude observed in the oscillations is due to the gradual increase of price rather than disruption of the fund with a sudden increase in prices. This can also be observed in the Healthcare Fund dynamics in Figure 7.5a, where the deviations from the desired fund level are very minimal, which keeps the economic stress formulation within a small interval.



(a) Employment Variables



(b) Population by Age Cohorts

Figure 7.7. Population sector behavior in Scenario 2.

The austerity and generosity periods are still present in this scenario, but since the ES is kept within a small interval, the policy variables do not show as impulsive a behavior as in scenario 1. We can observe smoother behaviors in the other model variables as well.

In contrast to the oscillations of scenario 1, the population health status and accumulation of chronic conditions are shown to have an s-shaped saturating behavior in Figure 7.6. The system is shown to be in the process of carrying itself to a new less healthy and more chronically sick condition. But since the unit healthcare cost is ever-increasing with respect to time, we cannot observe a full saturation at a new equilibrium level.

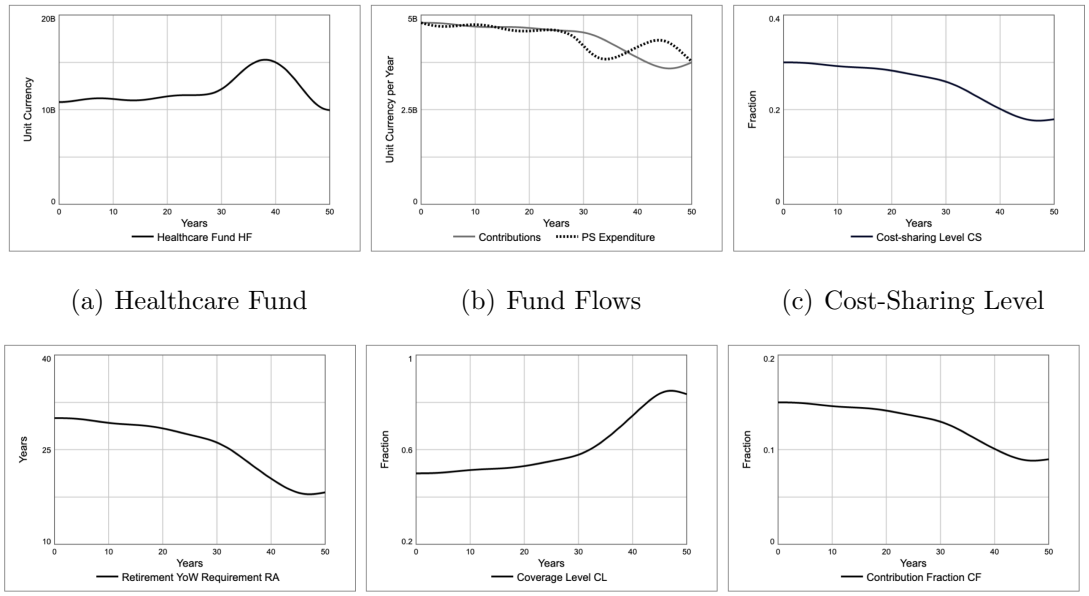
The change in the population age distribution is very similar to scenario 1. Population becomes much younger but with less formal employment due to the operation of the R1 - Tax Evasion Spiral. As a younger population generates less healthcare expenditure, a balancing mechanism is created. However, since the development of this condition resulted in a major decline in population and accumulation of chronic conditions, the worsening persists.

7.3. Scenario 3: Decreasing Healthcare Cost Scenario

The decreasing healthcare costs scenario is formulated by giving the Unit Visit Cost a time-dependent negative trend of [-TIME/3] (annual 1/3 unit currency decrease). All the other parameter values are kept at their default levels. Similar to the increasing healthcare costs scenario of section 7.2, the system starts at the equilibrium at year zero where the time-dependent trend equals 0.

With a decreasing cost input, PS expenditures expectedly decrease with minor oscillations as shown in Figure 7.8b. Although there are several periods where the expenditures exceed contributions in an oscillatory behavior due to policy adjustment and implementation delays, a general fund surplus is observed in the Healthcare Fund. Moreover, aside from the one major peak/pit in the PS sector variables (at year 46

in Figure 7.8.cdef), a significant overall improvement is observed in public programme benefits.



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

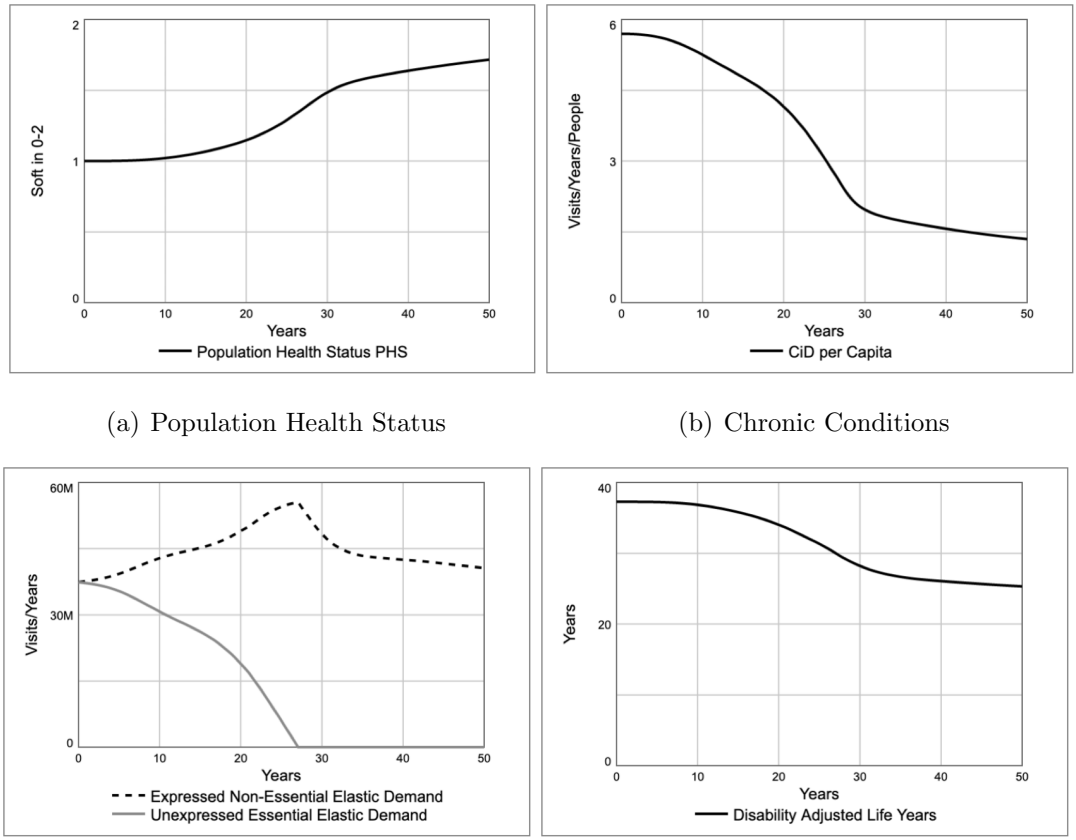
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.8. Public Scheme sector behavior in Scenario 3.

The peak of policy variables around year 45 can be attributed to the Healthcare Fund's more than desired accumulation caused by the scissors-like dynamics of PS Contributions and Expenditures between years 26 and 46. We can observe a widening of the discrepancy between the PS Contributions and Expenditures starting from year 26 in Figure 7.8b. PS Contributions stay above the Expenditures for 11 years until year 37 when the Healthcare Fund peaks and it takes another 9 years for the Healthcare Fund to reduce to its base and desired level.

These 20 years of Healthcare Fund exceeding the desired level causes the economic stress to induce a sharp and steady improvement in policy variables during this time period. The generous policy peak at 46 is an overshoot caused by the Policy Adjustment Delay. Starting from year 46, policy variables show a slightly declining behavior. However, Public Scheme sector behavior alone cannot explain the root cause of the start of this occurrence in year 26.

The starting point of the accumulation in the Healthcare Fund also shows a change of behavior in the Healthcare Demand sector in Figure 7.9. The Population Health Status and Cid per Capita variables switch from exponential growth to exponential decay after the critical time point of year 26.



(a) Population Health Status

(b) Chronic Conditions

(c) Unnecessary vs Necessary

(d) DALY

Figure 7.9. Healthcare Demand sector behavior in Scenario 3.

Unexpressed Essential Elastic Demand behavior in Figure 7.9c helps to causally explain the reason behind this year's significance. Due to the increase in price distortion (caused by increased benefits) and decrease in average unit healthcare demand (caused by population health improvement) up to year 26, demand expression steadily increases to a point where all of the essential demand is expressed and serviced by the public programme. This means that all the essential need for healthcare -that would develop into chronic conditions if left untreated- is expressed and satisfied, deactivating the main source of the chronic conditions. Therefore, during the course of Unexpressed

Essential Elastic Demand's descent to 0, chronic conditions show a downward exponential growth. This decline in chronic conditions operates the R3 – Austerity Payoff loop in the first 26 years in favor of the population health status in Figure 7.9.a. R3 stops its operation when the first chronic condition stock (Condition in Delay 1) reaches 0 at year 26, at which point the CiD per Capita and consequently Population Health Status behavior shifts from exponential growth to exponential decay.

In sum, the programme generosity, which is made possible by the decrease in healthcare costs, provides the population with a more generous healthcare plan that would improve the population health and cut off the main inflow of chronically developing conditions. The critical point we have observed in year 26 is especially significant in explaining the behavior change in these improving healthcare systems. When the price distortion and unit healthcare demand configuration allow all the essential demands to be satisfied, the Austerity Payoff slowly loses dominance, paving the way for a slow but robust increase in population health.

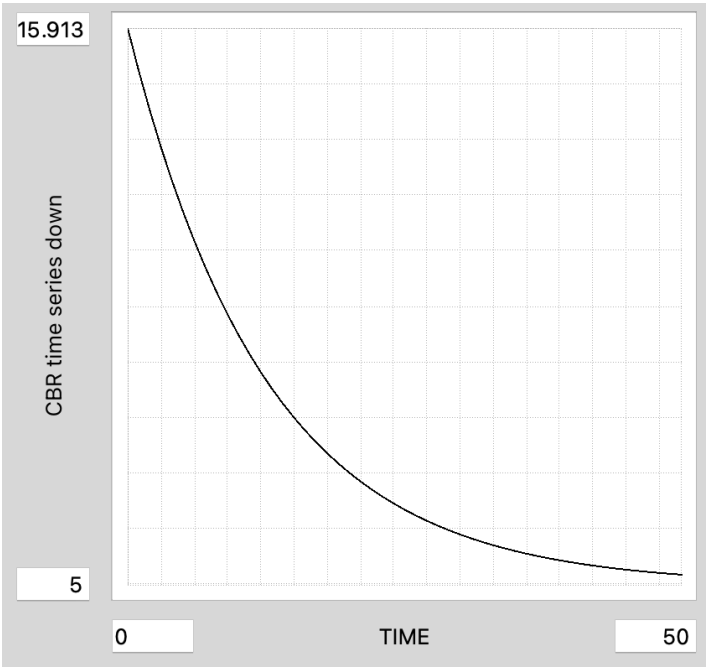
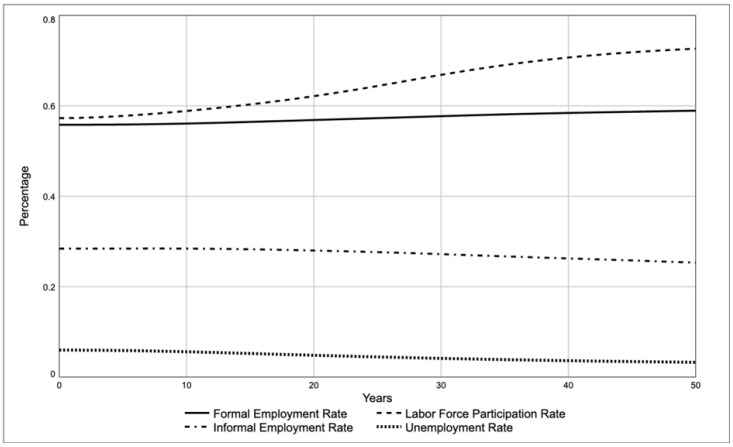


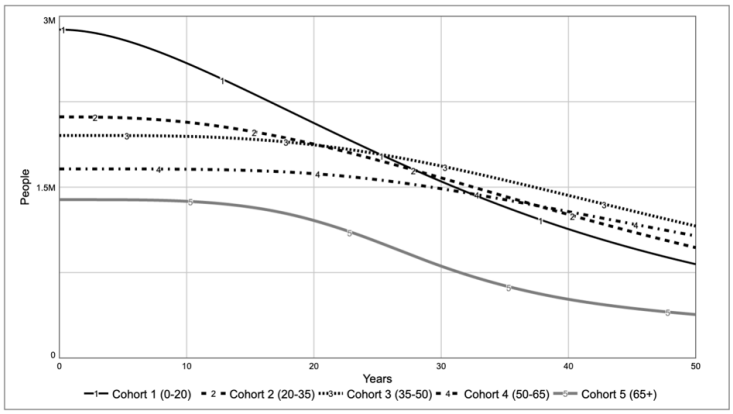
Figure 7.10. Crude Birth Rate time series input function in Scenario 4 (births per 1000 people).

7.4. Scenario 4: Decreasing Birth Rate Scenario

As discussed previously, aging populations are more prone to financial sustainability issues due to decreasing Labor Force Participation Rate. Since the population age distribution is a semi-endogenized element in our model, we can either initialize our simulation run with an aged population distribution or adjust the birth rate in order to achieve an aging population as a result. It should also be noted that since the Population Health Status is highly influential on the birth rates, giving a decreased birth rate input does not necessarily mean that we would have a large number of people in the elderly cohort. Instead, the development of population health determines the aging phenomenon as a result.



(a) Employment Variables

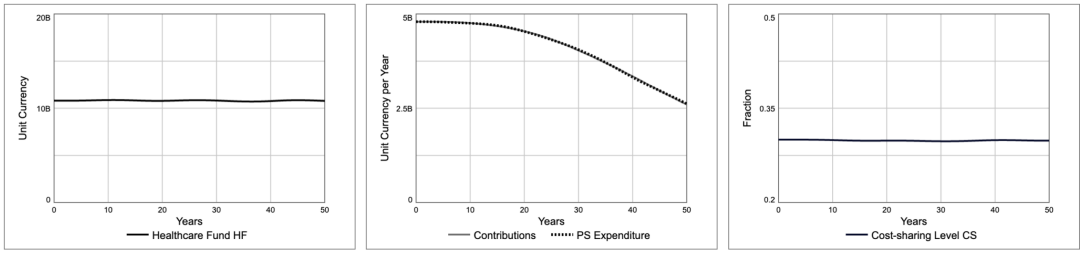


(b) Population by Age Cohorts

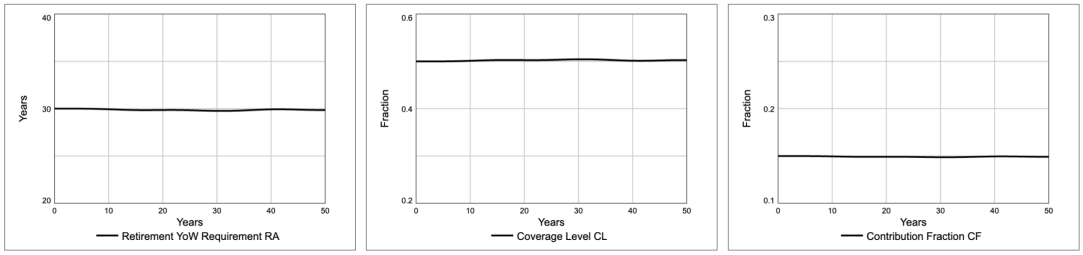
Figure 7.11. Population sector behavior in Scenario 4.

In this scenario, we simulate our model with a time-dependent decreasing Crude Birth Rate. The Crude Birth Rate function we have used in this scenario is an exponentially decaying function as shown in Figure 7.10. The birth rate starts at its equilibrium level of roughly 16 births per 1000 people at time 0 and slowly decays towards 5 births per 1000 people at time 50. Deviating from the normal birth rate by a one-third ratio, the population expectedly shrinks in size in this scenario.

Figure 7.11 presents central population employment and age variables in Decreased Birth Rate Scenario. As a direct effect of decreased birth rates, the juvenile population is shown to decrease significantly in size and share. This decrease in the juvenile population slowly reflects its decreasing effect on older cohorts via impeding their incoming aging flows. Even though the shrinkage in the juvenile cohort initially increases the revenue-generating capability of the population, it also increases the generated average healthcare demand of the population in the mid-run, as the need for care increases with age. On another note, the overall formal employment level is sustained due to the decrease in juvenile and elderly cohorts in the long run.



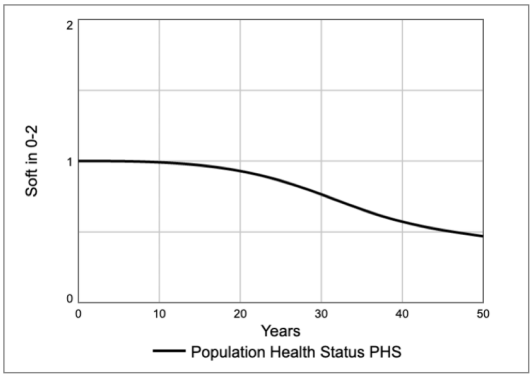
(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level



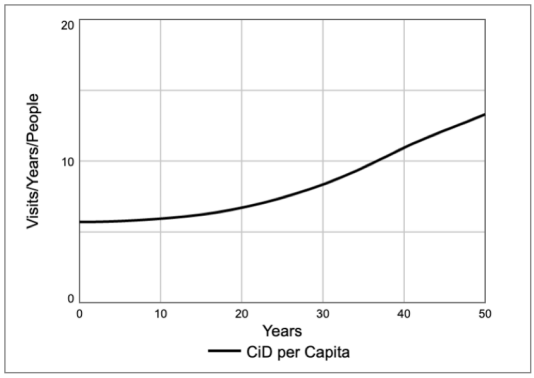
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.12. Public Scheme sector behavior in Scenario 4.

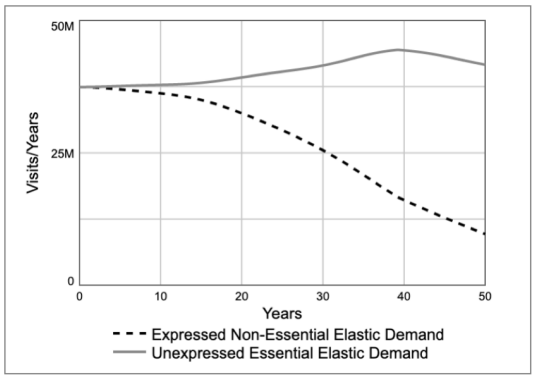
In this scenario, the Healthcare Fund does not face a significant shortage and the benefit package is sustained (Figure 7.12) but the aging of the population results in the generation of more healthcare demand than the public programme can cover. The essential portion of the uncovered demand continuously accumulates in Condition in Delay stocks and deteriorates the population health (Figure 7.13).



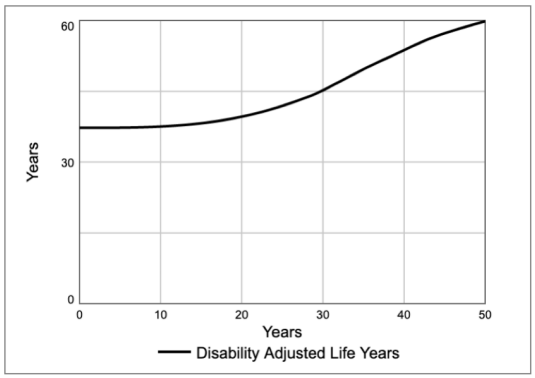
(a) Population Health Status



(b) Chronic Conditions



(c) Unnecessary vs Necessary



(d) DALY

Figure 7.13. Healthcare Demand sector behavior in Scenario 4.

In sum, the programme benefits are sustained due to sustained formal employment levels, but the increased healthcare demand with the same amount of coverage results in more unsatisfied demand which leads to the rise of chronic conditions via the operation of the R3 loop.

7.5. Scenario 5: Increasing Birth Rate Scenario

In an opposing case of scenario 4, we simulate our model for an increasing birth rate. A high and increasing birth rate would provide the population with a continuous source of workforce which would contribute to the public programme once formally employed. Therefore, compared to the previous scenarios including the base case scenario, this increasing birth rate scenario is expected to result in better health and financial outcomes.

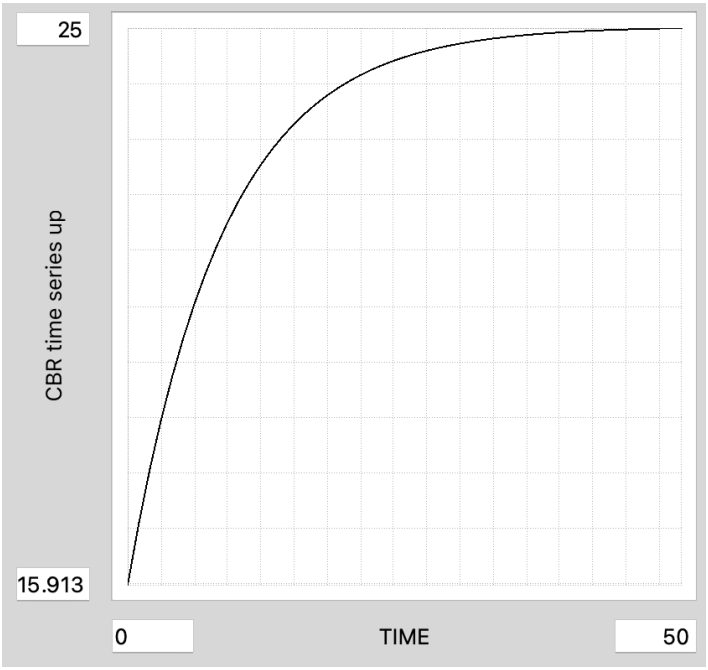
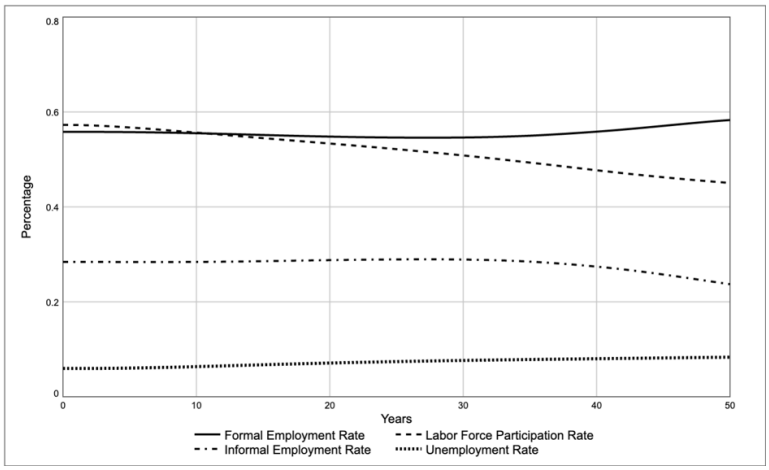


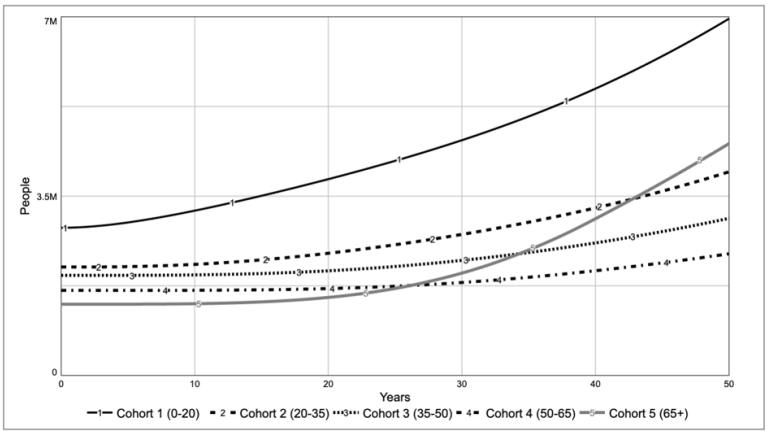
Figure 7.14. Crude Birth Rate time series input function in Scenario 5 (births per 1000 people).

In scenario 5, we simulate our model with an upward exponential decaying function of time as shown in Figure 7.14. The birth rate starts at its equilibrium level at time 0 and slowly saturates towards 25 births per 1000 people at time 50. Increasing birth rate input causes the population to grow considerably in size for this scenario (Figure 7.15b), from an initial 10 million people to 20 million people by year 50.

The direct and less delayed effect of increased birth rates is an increase in the size of the juvenile population, which initially decreases the fraction of the labor force and consequently formal employment. However, once the juveniles aging into the workforce manifested, the Formal Employment Rate starts an increasing behavior. Moreover, we can also observe a decrease in informal employment due to the beneficial operation of the R1 – Tax Evasion Spiral as a result of decreased Contribution Fraction (Figure 7.16f).



(a) Employment Variables

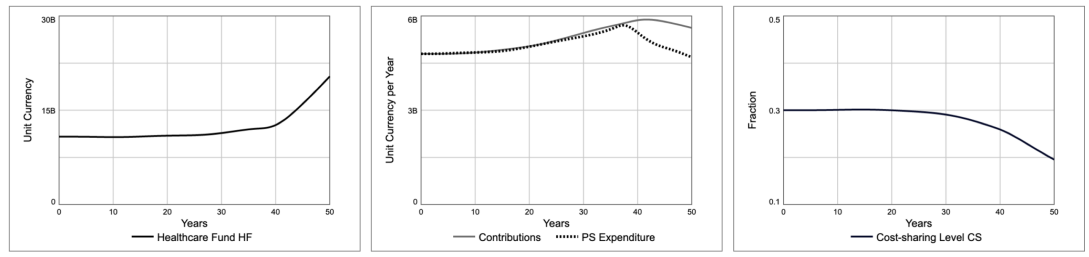


(b) Population by Age Cohorts

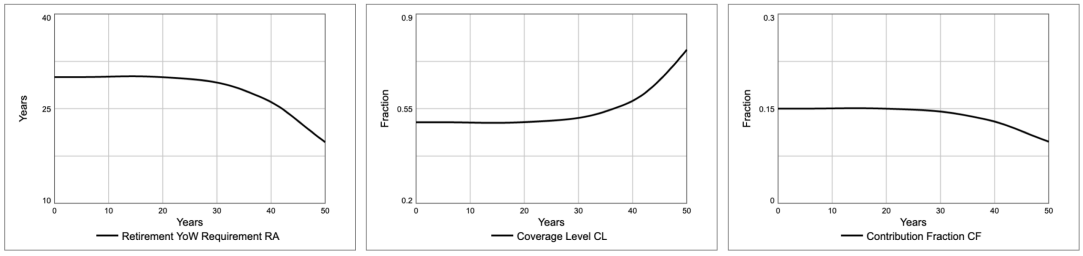
Figure 7.15. Population sector behavior in Scenario 5.

Public programme benefits start to see a major upgrade after the increased birth rate's effect on workforce enlarging reaches a tipping point after around 25 years when the upward trend in formal employment rate begins. The Healthcare Fund level starts

climbing above its desired level and economic prosperity induces a continuous generosity effect, increasing the coverages and decreasing the tax burden of employee contributions. Another critical point is reached around year 36 when the PS Expenditures start decreasing even though the increasing behavior of the total population continues. Against an increasing population level, a decrease in healthcare expenditure is only possible when the unit healthcare demand per person sees a significant decrease like in scenario 3, which can be traced via the Healthcare Demand sector.



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level



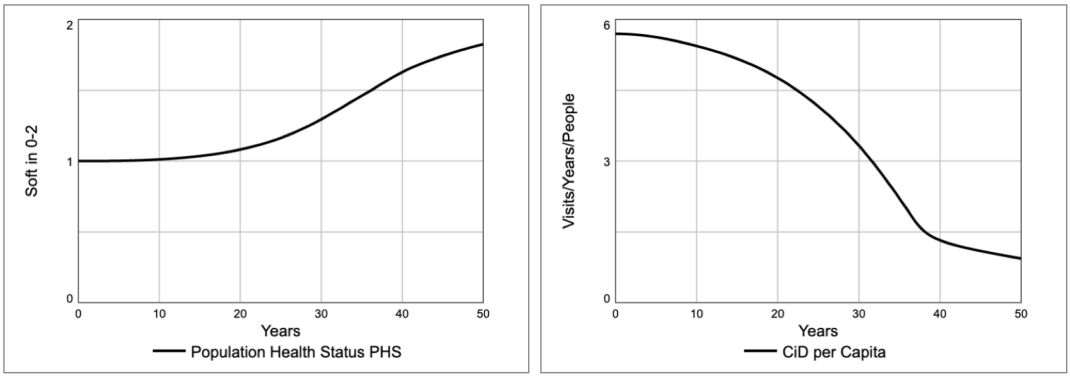
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.16. Public Scheme sector behavior in Scenario 5.

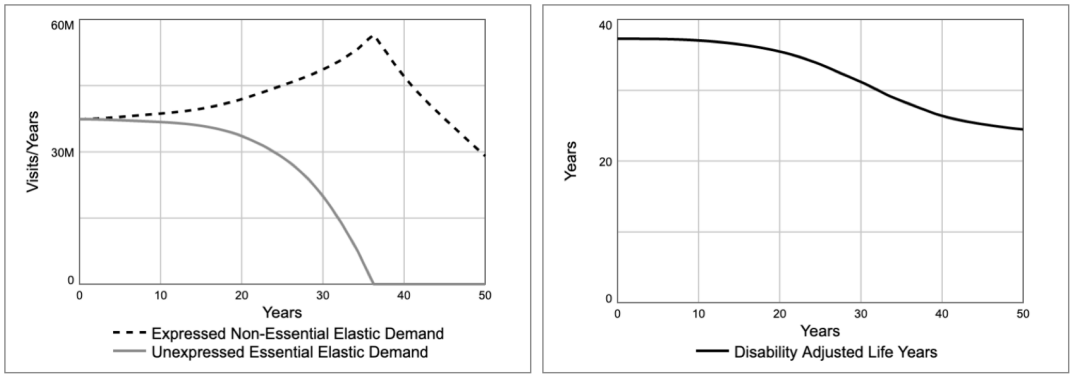
The behavior of the Healthcare Demand sector variables is shown in Figure 7.17. The second critical time point we have observed in the PS sector is very apparent Chronic Conditions and Unexpressed Essential Elastic Demand graphs in Figure 7.15.b and Figure 7.15.c respectively.

Similar to scenario 3, the increase in price distortion and decrease in average unit healthcare demand, increases the demand expression to a point where all of the essential demand is satisfied. PHS shows an exponential growth during this time period until the first chronic condition stock (Condition in Delay 1) reaches 0 at year 36. After that point, the R3 loop stops operating due to the nullified inflow of Unexpressed Essential

Demand, and PHS starts an exponential decaying behavior afterward. Scenario 5 shares the same critical point with Scenario 3 at year 36, the depletion point of chronic conditions. This critical point would be shared by any improving healthcare system or an "optimistic" scenario in our analysis.



(a) Population Health Status (b) Chronic Conditions



(c) Unnecessary vs Necessary (d) DALY

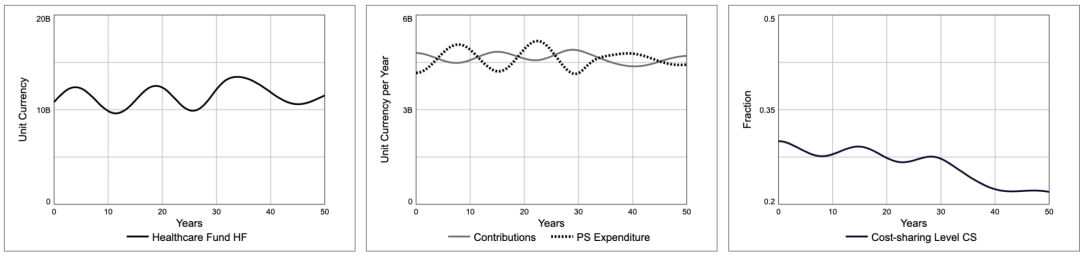
Figure 7.17. Healthcare Demand sector behavior in Scenario 5.

The improvement of public programme benefits and the population health continues beyond the simulation horizon as well until the system reaches a new equilibrium with population health status having its maximum level of 2.

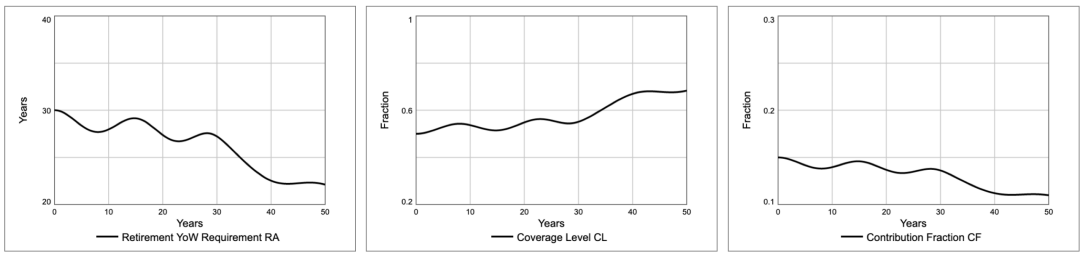
7.6. Scenario 6: Low Healthcare Cost Scenario

Our base case scenario was defined by setting the unit visit cost to a moderately higher (50 unit currency) than its default level (40.2 unit currency). In an opposing

case, a low initial healthcare costs scenario is defined with a low initial unit visit cost of 35 unit currency. This scenario represents a system where the annual healthcare fund expenditure is initially lower than annual employee contributions, and therefore initially a fund surplus exists in the Healthcare Fund.



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level



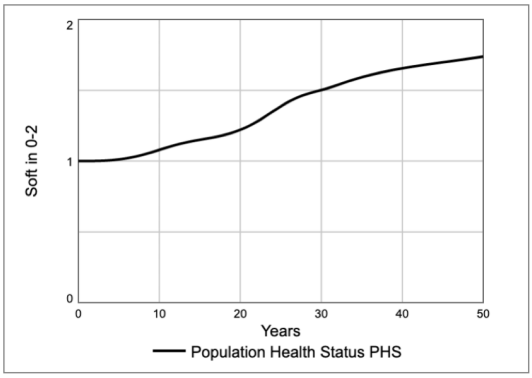
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.18. Public Scheme sector behavior in Scenario 6.

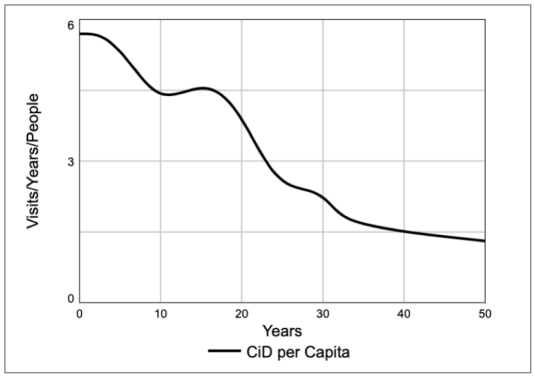
The initial Healthcare Fund surplus is visible by the discrepancy between PS Expenditures and Contributions in Figure 7.18.b at year 0. The initial discrepancy causes accumulation in the Healthcare Fund that causes the stock to exceed its desired level. Then the economic stress starts adjusting the public programme benefits to a more generous package with a high coverage level and a low tax burden.

Similar to the behavior of the base case scenario in section 7.1, delays in policy adjustment and implementation cause sequential generosity and austerity periods in the form of oscillations. One major difference is that the initial period in Low Healthcare Costs Scenario induces generosity, in contrast with the initial austerity period of scenario 1 which is caused by the sign of equilibrium disruption due to UVC input. The Healthcare Fund flows go through a behavior change at year 30 (best visible in Figure 7.18.b). This behavior change causes the policy variables to sharply improve

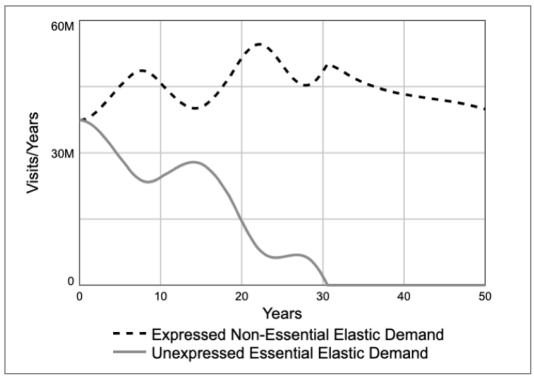
until year 40 and show a nearly stabilizing motion with diminishing oscillations around a generous policy level.



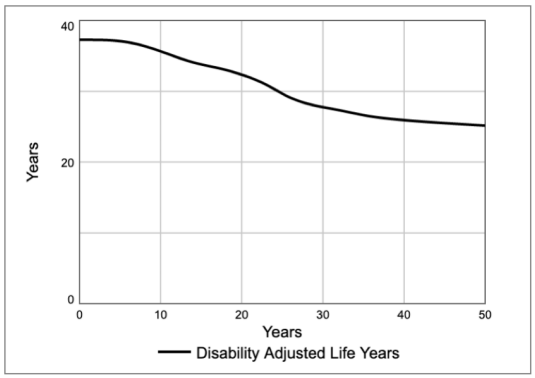
(a) Population Health Status



(b) Chronic Conditions



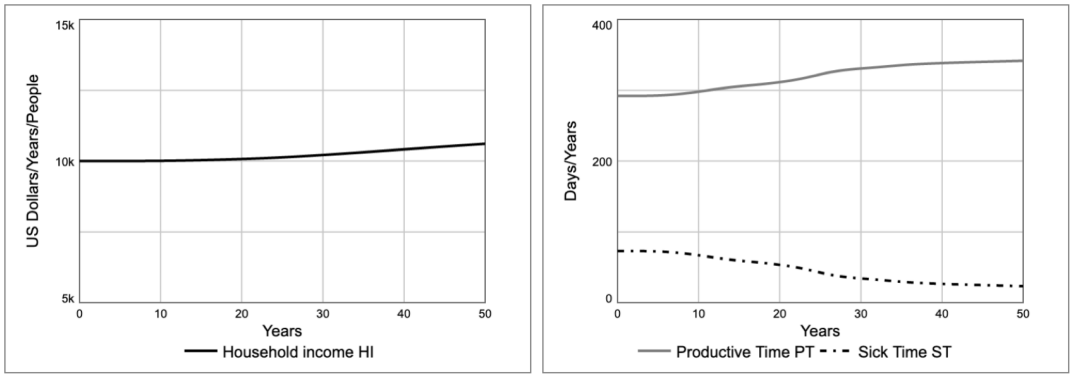
(c) Unnecessary vs Necessary



(d) DALY

Figure 7.19. Healthcare Demand sector behavior in Scenario 6.

The cause behind the behavior change at year 30 is the same occurrence as the other two optimistic scenarios we have analyzed so far: Increasing Birth Rate Scenario and Decreasing Healthcare Costs Scenario. An increase in price distortion activates the Moral Hazard loop and steadily decreases the Unexpressed Essential Elastic Demand during the generosity periods. The decline in Unexpressed Essential Elastic Demand causes the chronic condition accumulation to decline as well. At year 30, Unexpressed Essential Elastic Demand reaches 0, meaning that all the essential need for healthcare -that would develop into chronic conditions if left untreated- is expressed and satisfied, deactivating the main source of the chronic conditions. CiD per Capita follows an exponential decay thereafter.



(a) Household Income (b) Time

Figure 7.20. Socio-Economics Sector behavior in Scenario 6.

Along with the improvement in chronic conditions, Population Health Status also increases due to beneficial operation of R3 and B6 loops, and eventually starts an upward exponential decaying behavior to its possible maximum value of 2. The Health-Wealth Reinforcement structure of R4 also has a slow burning effect on the overall health improvement as shown in Figure 7.20. Starting from the midpoint of the simulation horizon, productive time shows a significant improvement, which increases the household income due to increased revenue generation capability. The increase in Household Income contributes to the Population Health Status as a result of R4.

7.7. Scenario 7: High and Decreasing Healthcare Cost Scenario

In Scenario 7, we simulate our model with a high initial and decreasing unit visit cost input. The initial high level and the magnitude of the trend are kept the same with the High Healthcare Cost (Scenario 1) and the Decreasing Healthcare Costs (Scenario 3) scenarios. In this regard, unit visit cost was set to 50 unit currency (default level being 40.2 unit currency) with a time-dependent downward trend of [-TIME/3] (annual 1/3 unit currency decrease). UVC input over the time horizon in comparison with the default UVC level is shown in Figure 7.21.

Public programme benefits show diminishing oscillations with an improving trend in Scenario 7 as shown in Figure 7.22. The oscillations in PS sector variables are caused

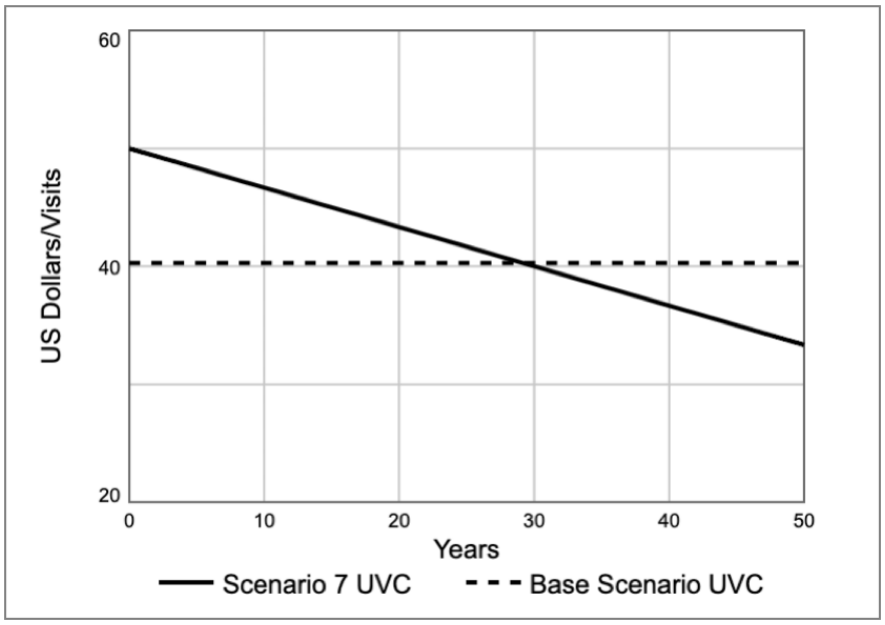
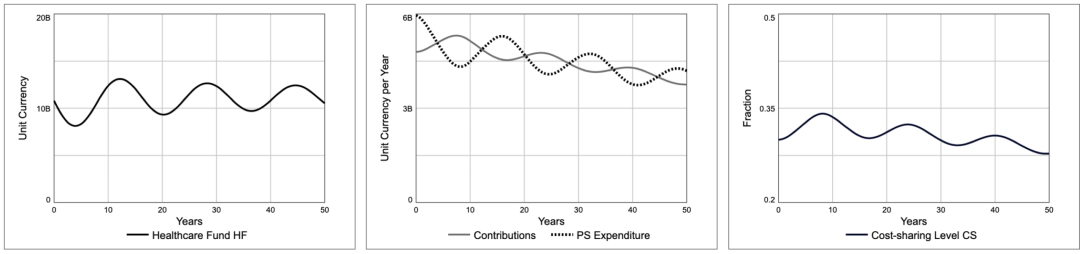
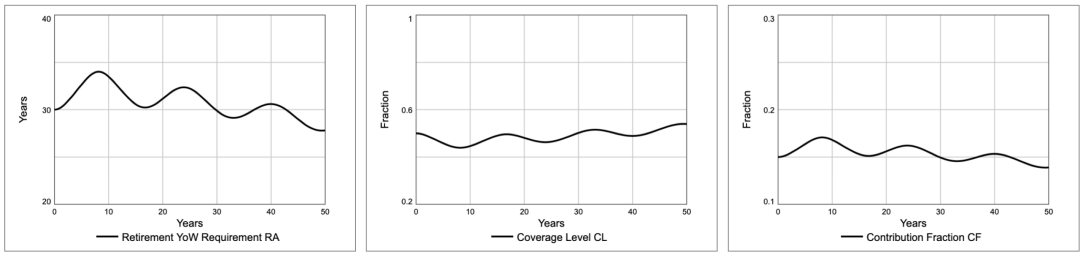


Figure 7.21. Unit Visit Cost in Scenario 7 (Unit Currency).



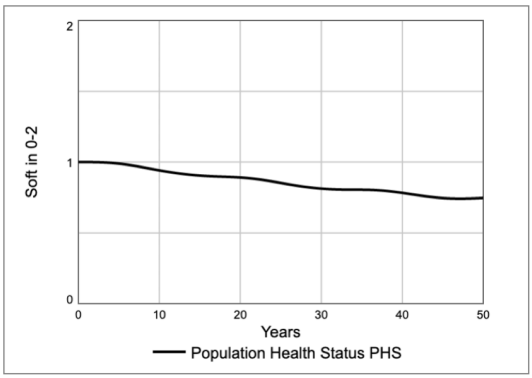
(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level



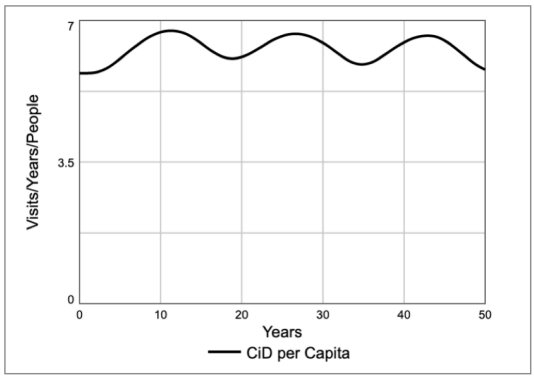
(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.22. Public Scheme sector behavior in Scenario 7.

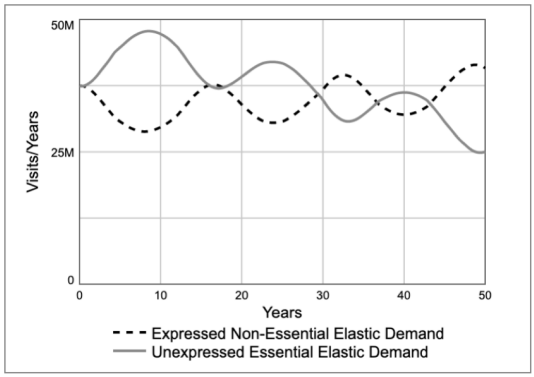
by the initial disturbance of initializing the model with a high UVC level, like the base case scenario. However, due to the effect of decreasing behavior of UVC, the oscillations in programme benefits reach higher levels in generosity periods compared to the base scenario. As a result, we observe an overall improvement trend in programme benefits like scenario 3. At the end of the time horizon, the system ends up with a more beneficial public health insurance programme than the initial configuration. However, since the earliest behavior in benefits is downward (an austerity period), the R3 – Austerity Payoff loop is first activated in the undesirable direction.



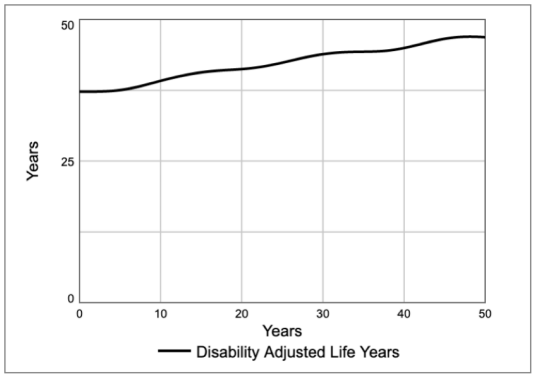
(a) Population Health Status



(b) Chronic Conditions



(c) Unnecessary vs Necessary



(d) DALY

Figure 7.23. Healthcare Demand sector behavior in Scenario 7.

The effect of the initial activation of the R3 loop is visible in population health metrics in Figure 7.23. The initial decade of austerity in public programme benefits caused the unexpressed essential demand to increase which contributes to the accumulation of chronic conditions that would deteriorate the Population Health Status.

Even though the overall improvement in the public programme would provide a cure for the accumulated chronic conditions in this period, it fails to fully reverse the damage inflicted on the population health in 50 years. Since the trend in public programme benefits continues well after the simulation horizon due to the ever-decreasing trend we have defined for this scenario, population health would eventually improve to its initial level, also with the support of the increase in Formal Employment Rate which starts at year 25, shown in Figure 7.24.

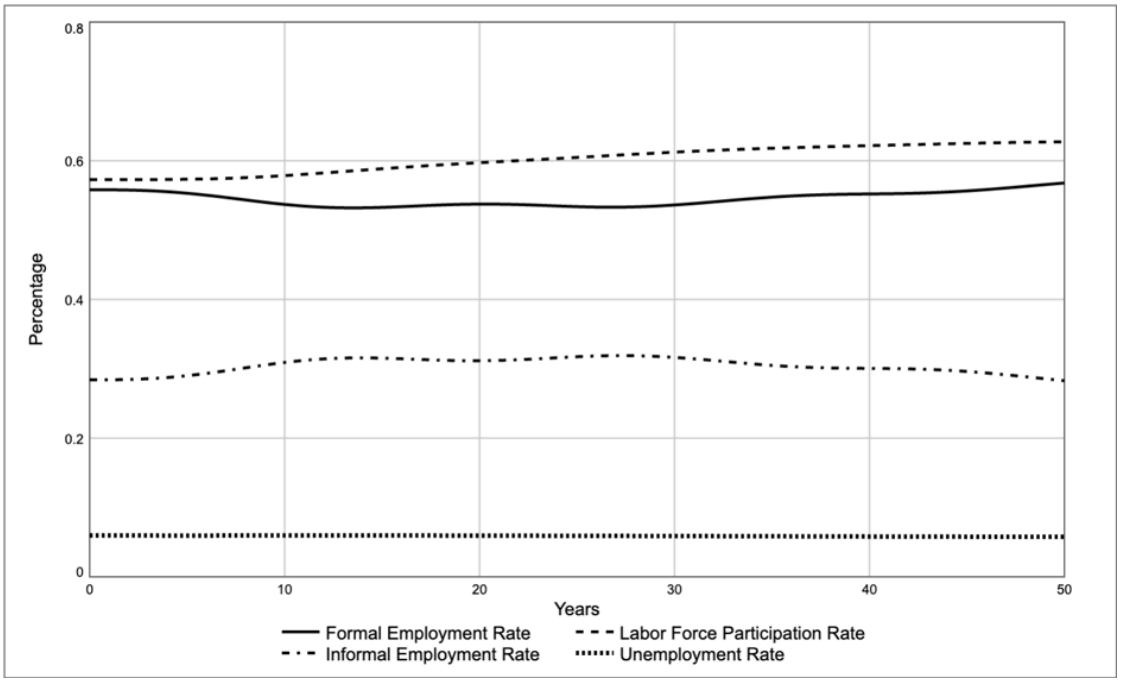


Figure 7.24. Employment variables in Scenario 7.

This scenario shows us that the leveling of UVC is highly influential on the population health outcomes over 5 decades. While the decreasing trend in UVC can compensate for the initial negative disturbance caused by the high initial leveling in terms of public scheme sustainability, access to healthcare, and chronic conditions; its compensation for Population Health Status is not as immediate and enough. Whether the initial decade is a period of generosity or austerity determines the status of population health in the short and mid-term. We also simulate our model for the low initial but increasing UVC to support this claim.

7.8. Scenario 8: Low and Rising Healthcare Cost Scenario

As an opposing case to the previous scenario, in Scenario 8, we simulate our model with a low initial and increasing unit visit cost input. The initial low level and trend are kept the same with Low Healthcare Cost (Scenario 6) and Increasing Healthcare Costs (Scenario 2) scenarios respectively. In this regard, unit visit cost was set to 34 unit currency (default level being 40.2 unit currency) with a time-dependent upward trend of [+TIME/3] (annual 1/3 unit currency increase). UVC input over the time horizon in comparison with the default UVC level is shown in Figure 7.25.

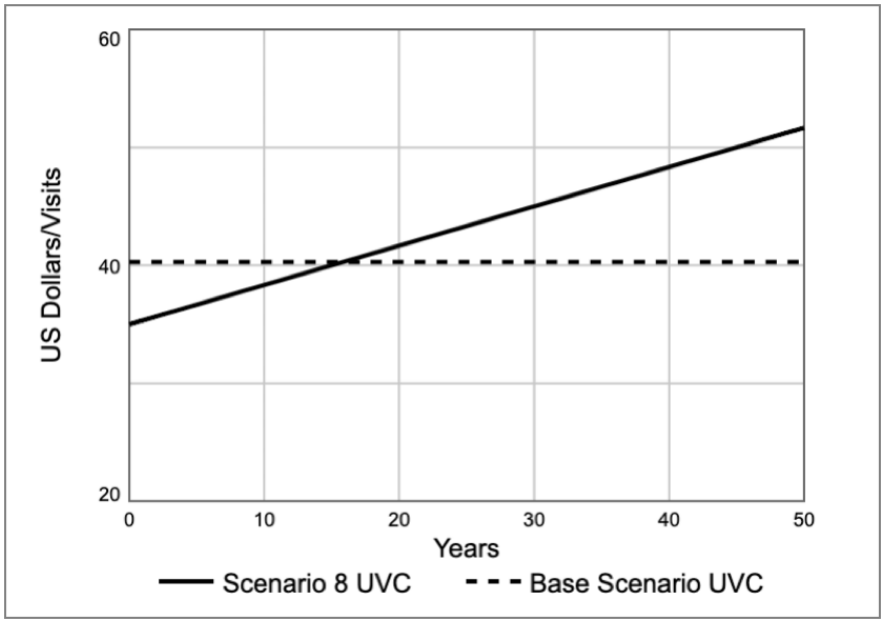
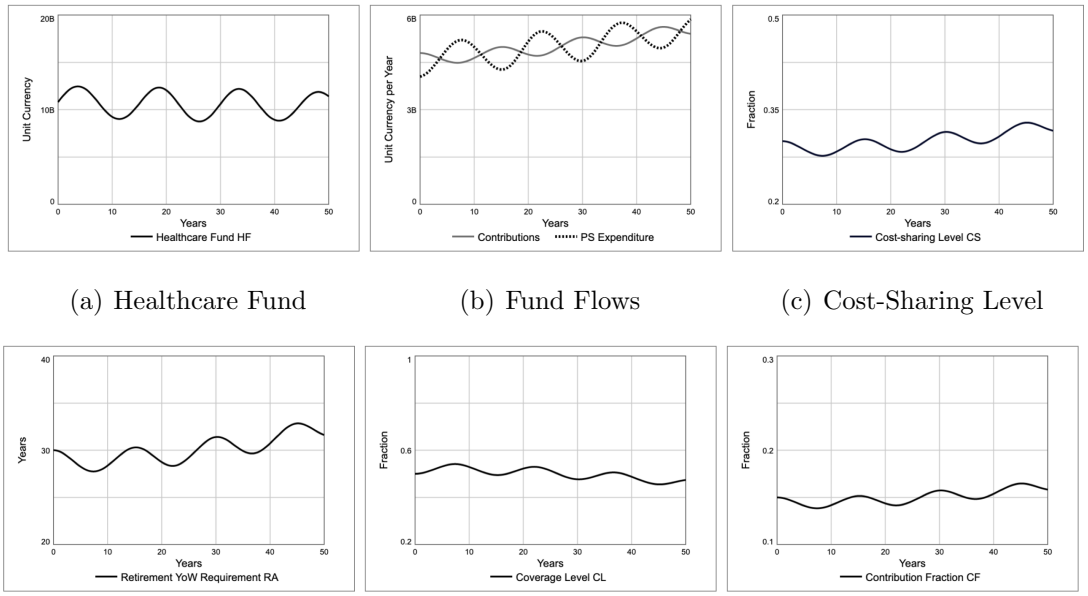


Figure 7.25. Unit Visit Cost in Scenario 8 (Unit Currency).

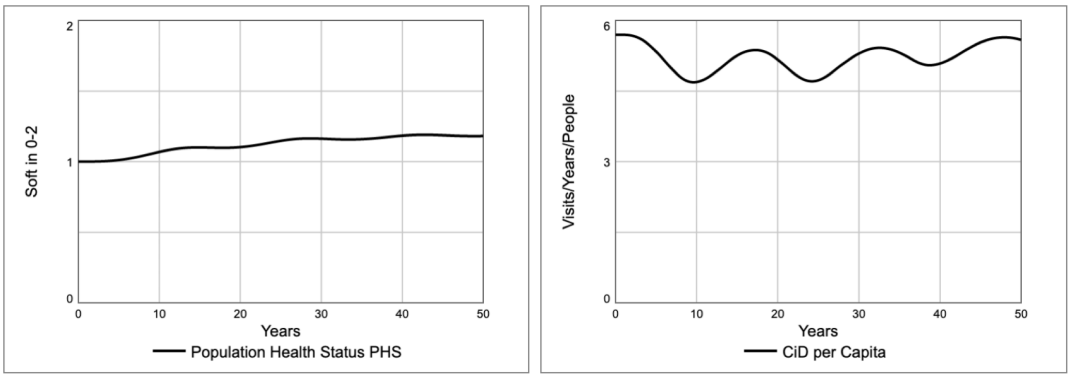
In Scenario 8, public programme benefits fluctuate with an overall worsening trend as shown in Figure 7.26. The model behavior in the PS sector for this scenario stands on the contrary side to scenario 7 mainly in 2 points: i) sign of the trend in the programme benefits, ii) the characteristic of the initial period of oscillation in terms of austerity/generosity distinction. Initially, the Healthcare Fund sees a surplus that induces the economic stress formulation to enlarge the benefit package, then the rising unit costs induce a slow burning regression effect. So, in this scenario, we observe



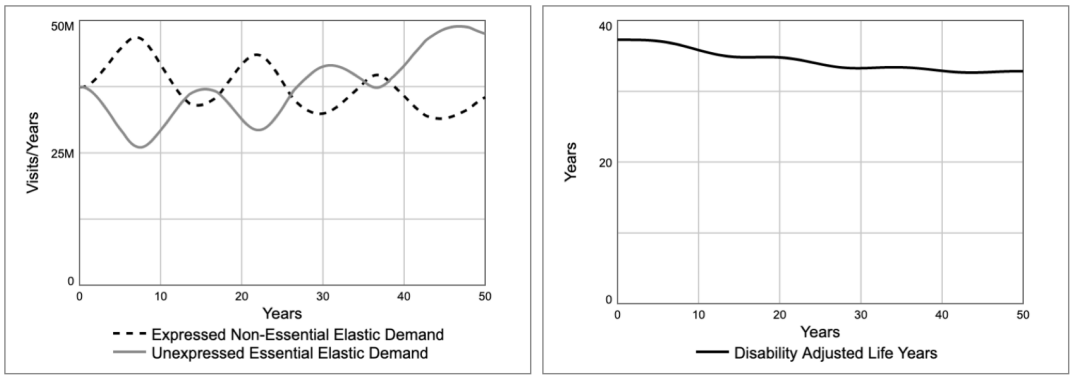
(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.26. Public Scheme sector behavior in Scenario 8.



(a) Population Health Status (b) Chronic Conditions



(c) Unnecessary vs Necessary (d) DALY

Figure 7.27. Healthcare Demand sector behavior in Scenario 8.

a healthcare system with an initial improving period followed by gradual coverage reduction, in exact opposition to scenario 7. Likewise, the end-time benefit package is more modest compared to the initial package.

If the initial period is generosity, the R3 loop would work in favor of population health via depletion of accumulated chronic conditions through increased healthcare service provided by the enlarged public insurance benefits. Such a case is present in Scenario 8, we observe an initial steep decline in CiD per Capita as seen in Figure 7.27b followed by the sequential increase and decreases due to benefit fluctuations. The effect of CiD through the R3 loop on PHS is visible after a time delay as an improvement. The overall reducing trend in benefits reflects itself as a decrease in PHS improvement. However, the health improvement achieved during the initial generosity period stands larger than the health status decline caused by reduced benefits further in the time horizon. Although the population is better off regarding the health status and chronic conditions, a steady reduction in programme benefits caused by the ever-increasing unit price level and slowly manifesting downward trend in the Formal Employment Rate (Figure 7.28) indicates a future sustainability issue in the Healthcare Fund and a worsening trend in population health beyond the simulation horizon in the long run.

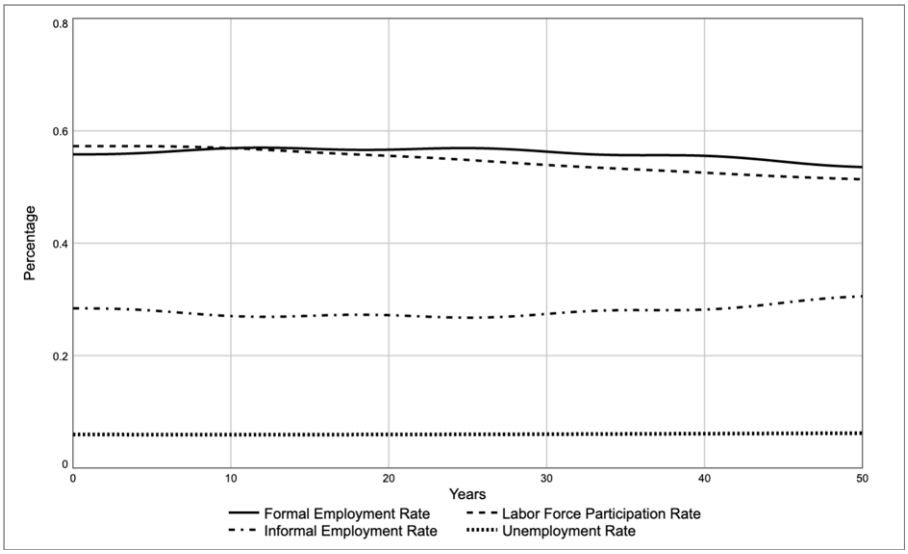


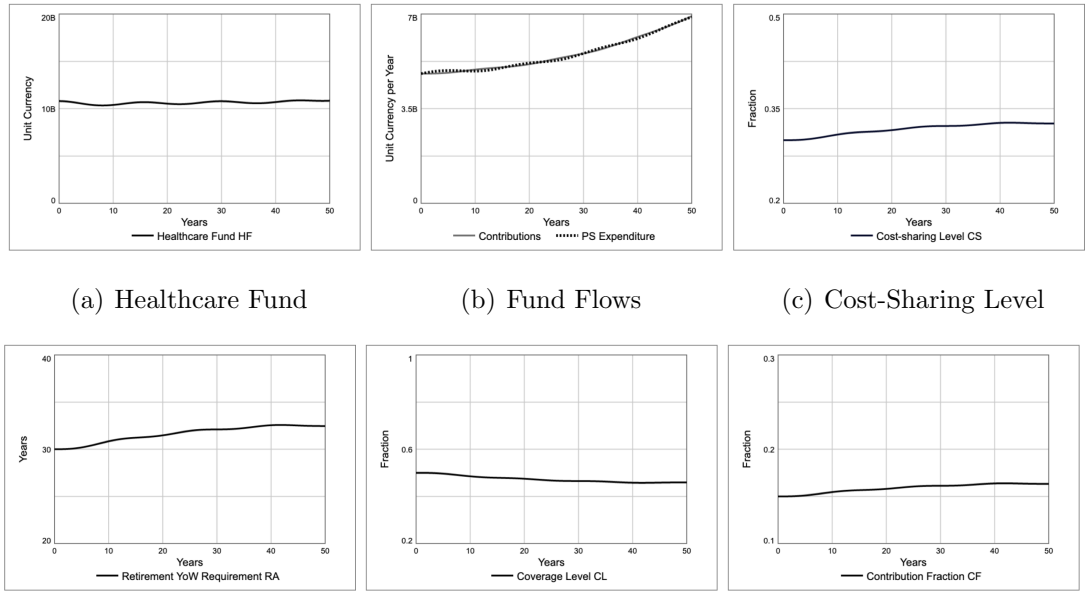
Figure 7.28. Employment variables in Scenario 8.

The analysis of scenario 8 supports the corollary we have deduced from scenario 7. The characteristic of the initial period generally determines the long-term behavior of the system, also naturally subjected to the scale of the scenario-defining inputs. Two mechanisms result in such behavior. Firstly, since the population health status adjustment flows are subjected to time delays, earlier impacts are more determining in setting the characteristics of model behavior than the latter in the mid-term. Secondly, because of the large difference in the price level from the default level, the initial advantage/disadvantage caused by this initial disruption can only be offset by the rising/decreasing costs further in the simulation horizon. In scenario 7, it takes 30 years for the UVC trend to carry the UVC level to the default (Figure 7.21) while it takes 20 years in scenario 8 (Figure 7.25). The extent of this period is also the extent of the advantage/disadvantage caused by the price leveling. It takes much time for the continuing trend to keep up with the developments that occurred during this time periods.

7.9. Scenario 9: Rising Healthcare Cost with Increasing Birth Rate Scenario

Scenario 9 presents the scenario where the finance-wise pessimistic positive trend at the UVC level is coupled with a finance-wise optimistic (increasing) birth rate input. For the UVC trend, we stand consistent with the previous rising costs scenarios by giving UVC a time-dependent upward trend of [+TIME/3]. As for the birth rates, we use the same Crude Birth Rate time series input function (Figure 7.14) we have used in scenario 5.

Public Scheme sector variables show a stabilizing behavior with minor oscillations to a more modest benefit package configuration than the initial in Scenario 9 (Figure 7.29). Taking scenario 2 (rising costs scenario) as the baseline, we observe a better outcome as the end-time benefit package is more generous compared to the former scenario, caused by the generation of more youth and employment due to optimistic birth rate input. However, the improvement cannot fully offset the decline in benefit package caused by rising costs. This is because the effect of birth rate on financial



(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

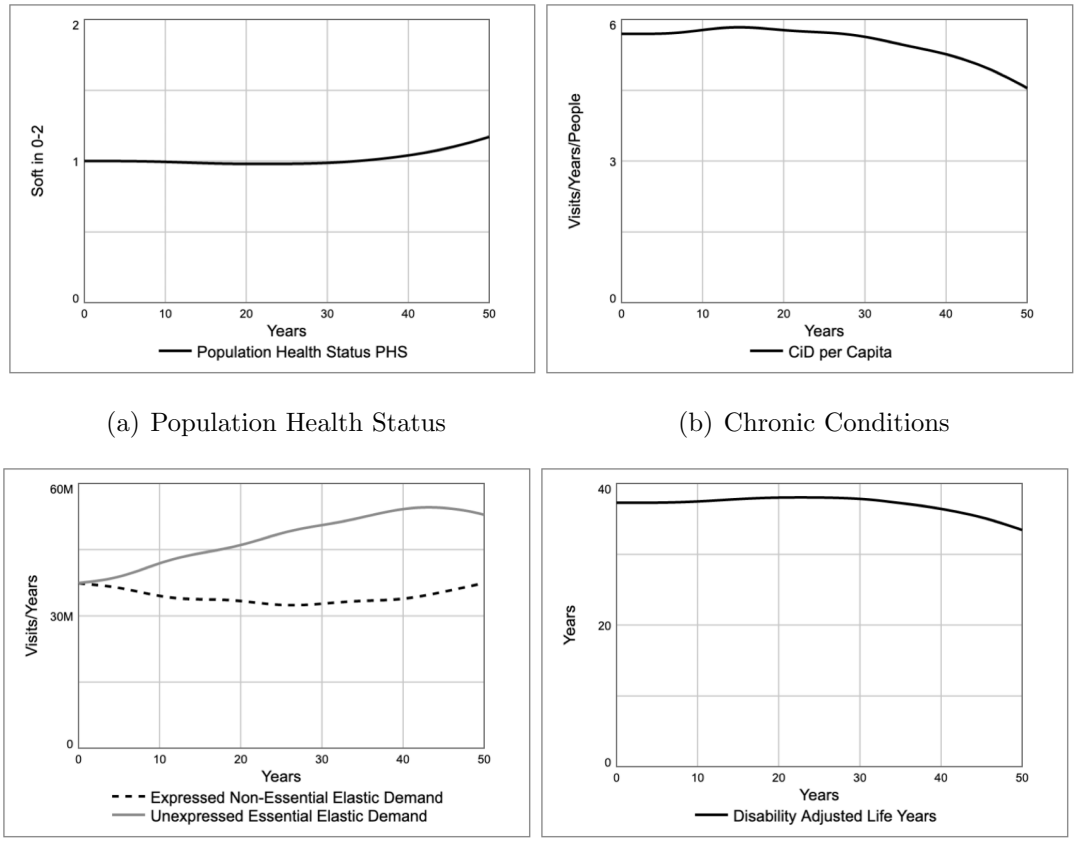
Figure 7.29. Public Scheme sector behavior in Scenario 9.

outcomes manifests slower than the rise in UVC, due to the delays in coming of age and employment of population compared to the direct expenditure escalation effect of UVC increase.

The increasing trend in birth rate has more immediate effects on population health metrics. In Figure 7.30, we observe that the increasing birth rate compensates for the negative effects of reduced public programme benefits caused by rising costs in terms of population health. PHS behavior in Figure 7.30a is initially a slight decrease followed by a significant increase towards the end of the simulation run. Similarly, we observe an initial increase and then a significant decrease in chronic conditions in Figure 7.30b. Even though the benefits reduce against rising costs, the increase in the young population offsets the negative effects of them via more formal employment (which increases Healthcare Fund Contributions) and less need for healthcare (which decreases Healthcare Fund Expenditures).

In sum, the negative effects of rising healthcare costs on population health are compensated by increased birth rates. However, the reduction trend in benefits still occurs due to the more immediate effect of rising costs. At the end of the horizon, the

population is healthier with decreased chronic conditions but the access to healthcare is reduced by a modest degree.



(a) Population Health Status

(b) Chronic Conditions

(c) Unnecessary vs Necessary

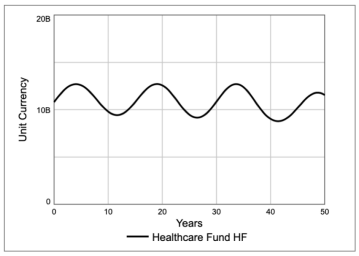
(d) DALY

Figure 7.30. Healthcare Demand sector behavior in Scenario 9.

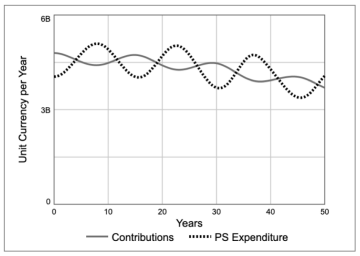
7.10. Scenario 10: Low Healthcare Cost with Decreasing Birth Rate Scenario

In Scenario 10, we simulate our model with a low UVC level with decreasing birth rate inputs. In this regard, the Unit Visit Cost was set to 34 unit currency against the default level of 40.2. The same Crude Birth Rate time series input function (Figure 7.10) of scenario 4 is utilized for this scenario.

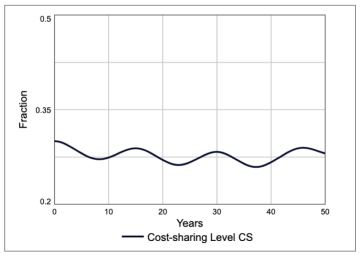
Public Scheme enjoys an initial generosity period that increases the programme benefits due to the low unit healthcare cost as shown in Figure 7.31. The oscillations



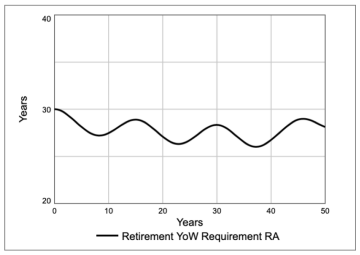
(a) Healthcare Fund



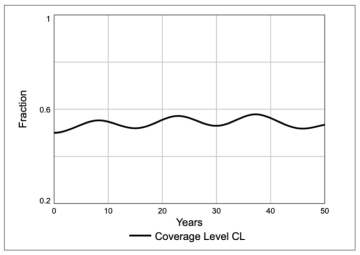
(b) Fund Flows



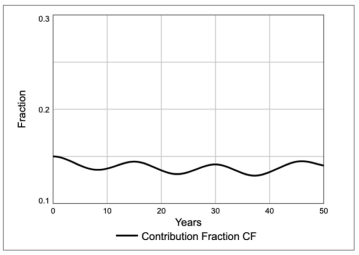
(c) Cost-Sharing Level



(d) Retirement Requirement

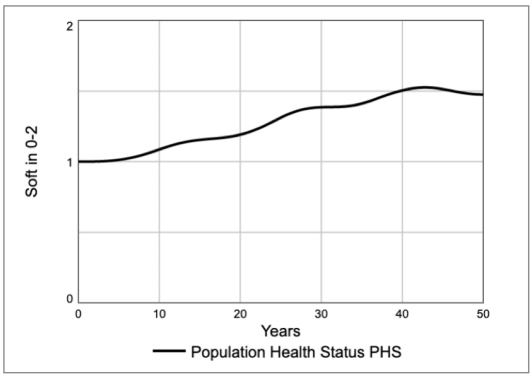


(e) Coverage Level

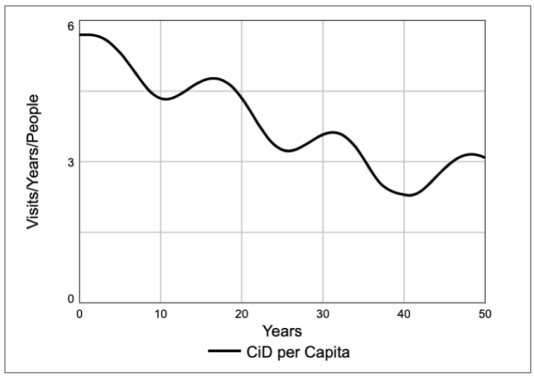


(f) Contribution Fraction

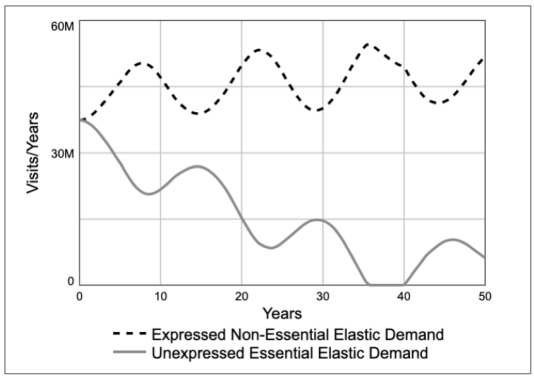
Figure 7.31. Public Scheme sector behavior in Scenario 10.



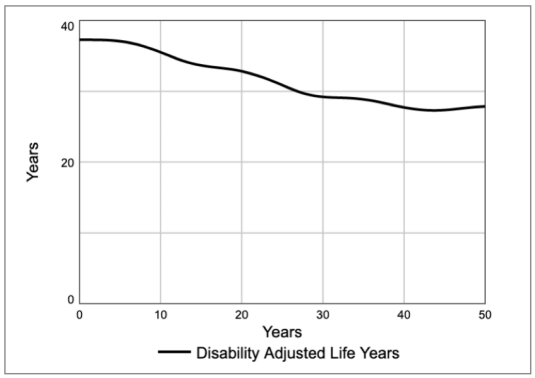
(a) Population Health Status



(b) Chronic Conditions



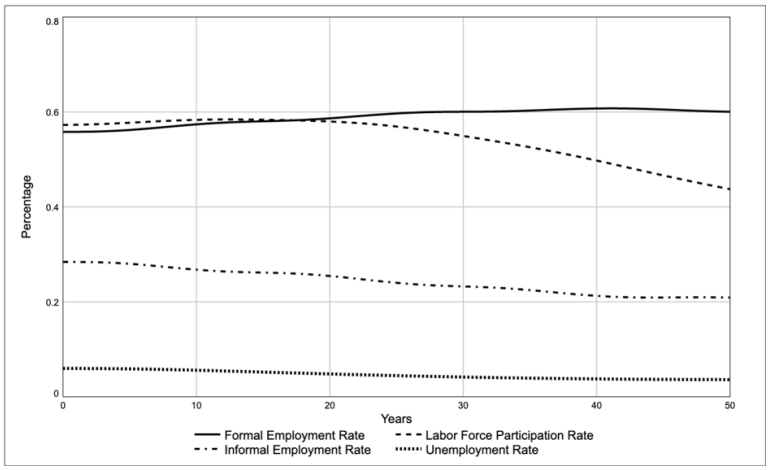
(c) Unnecessary vs Necessary



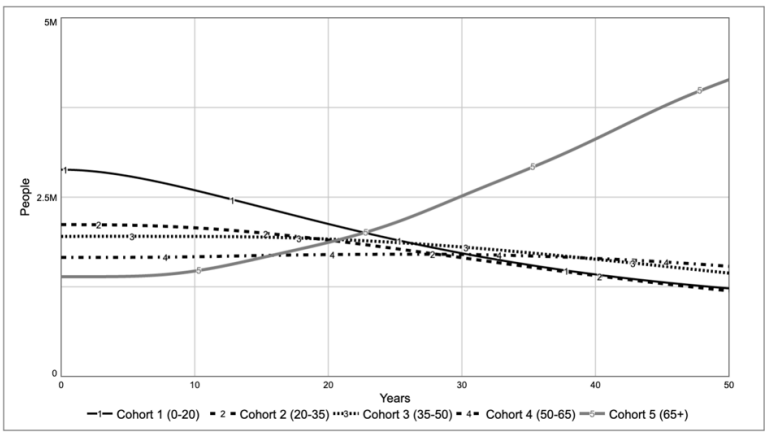
(d) DALY

Figure 7.32. Healthcare Demand sector behavior in Scenario 10.

persist throughout the simulation with a very slight improving trend. The overall decrease in fund flows in Figure 7.31b is an indicator of a decrease in population level caused by decreased birth rates. We find that the decreased birth rate does not pose a sustainability issue in public health insurance programme if coupled with low unit healthcare costs. The improvement in population health is much more visible than the public programme as presented in Figure 7.32. PHS (Figure 7.32a) shows an overall increasing behavior with several pausing periods when chronic conditions increase in scale (Figure 7.32b), which coincides with the austerity periods of the public scheme.



(a) Employment Variables



(b) Population by Age Cohorts

Figure 7.33. Population sector behavior in Scenario 10.

Increased benefits and population health causes Unexpressed Essential Elastic Demand to show a downward oscillating behavior which drops to 0 at year 35. Between

years 35 and 40, all of the essential demand is satisfied which leads the Condition in Delay stocks to show a decaying behavior. However, the following austerity period replenishes the Unexpressed Essential Elastic Demand above zero to increase Condition in Delay stocks.

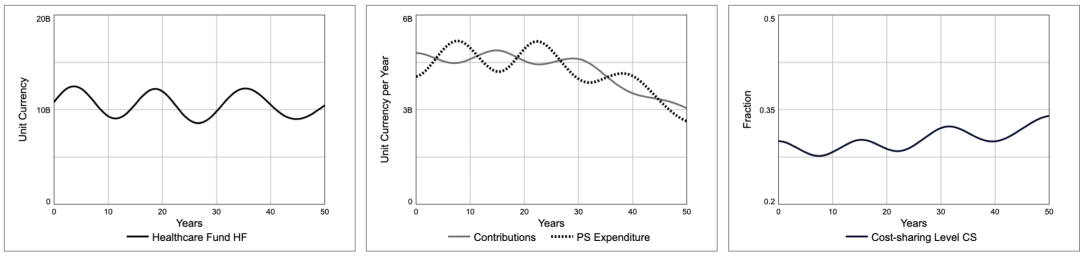
The observed improvement in population health decreases the death fractions which in turn leads to an increase in the elderly cohort within the population in Figure 7.33b. Having a more generous public programme and better population health, the population healthily ages in scenario 10. Moreover, even though the decreased birth rates decrease the Labor Force Participation Rate by reducing the workforce ratio, the decrease in contribution fraction activates the R1 – Tax Evasion Spiral in favor of formal employment and sustains the formal employment rate as shown in Figure 7.33a.

Scenario 10 shows the development of a healthy, aging, and socioeconomically better-off population. Its real-life counterpart may be northern block countries where the scenario inputs also resemble (as the proportion of unit healthcare cost to GDP).

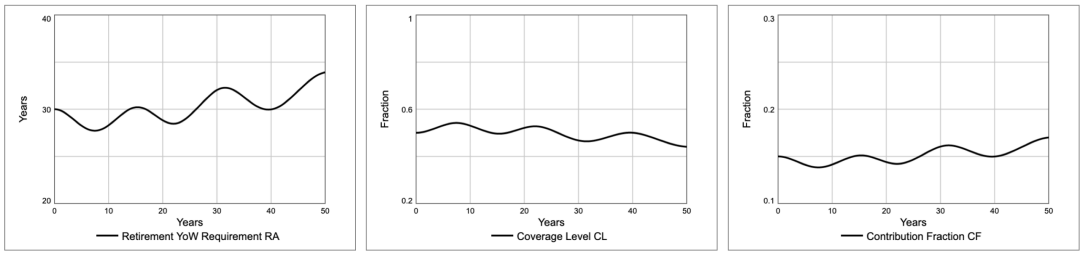
7.11. Scenario 11: Low and Rising Healthcare Cost with Decreasing Birth Rate Scenario

In scenario 11, we take a triple combination of three input parameters to define a low and rising healthcare cost with decreasing birth rate scenario. Following the framework of previous scenario definitions, scenario 10 is designed with a low UVC level of 34 unit currency, a time-dependent positive UVC trend of [+TIME/3] (function in Figure 7.24), and the decreasing crude birth rate time series input function of Figure 7.10.

In scenario 11, the Healthcare Fund stock shows nearly stable oscillations in Figure 7.34a. The oscillation period increases as time progresses which lengthens the periods of regime change. Since the time and extent healthcare fund stays below the desired fund level is longer than above, we observe an overall decreasing trend in programme benefits.

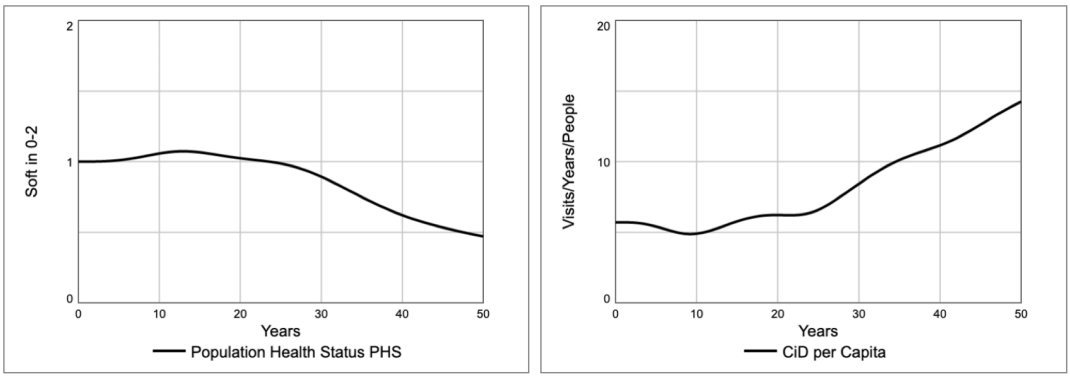


(a) Healthcare Fund (b) Fund Flows (c) Cost-Sharing Level

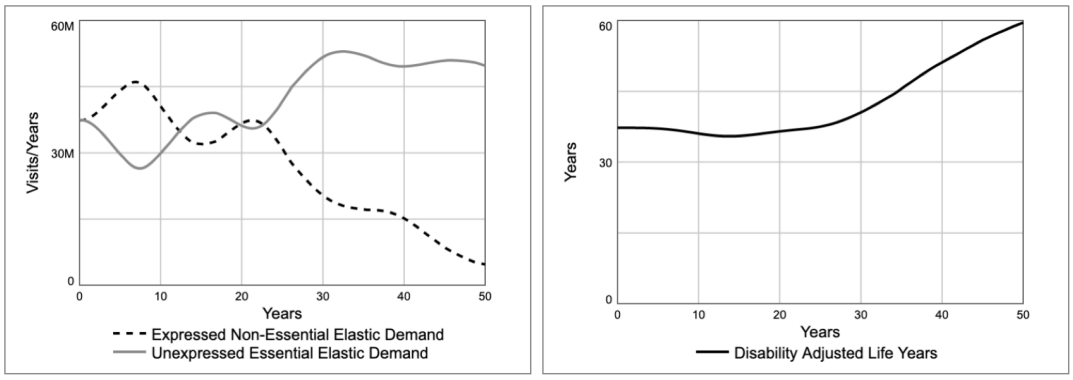


(d) Retirement Requirement (e) Coverage Level (f) Contribution Fraction

Figure 7.34. Public Scheme sector behavior in Scenario 11.



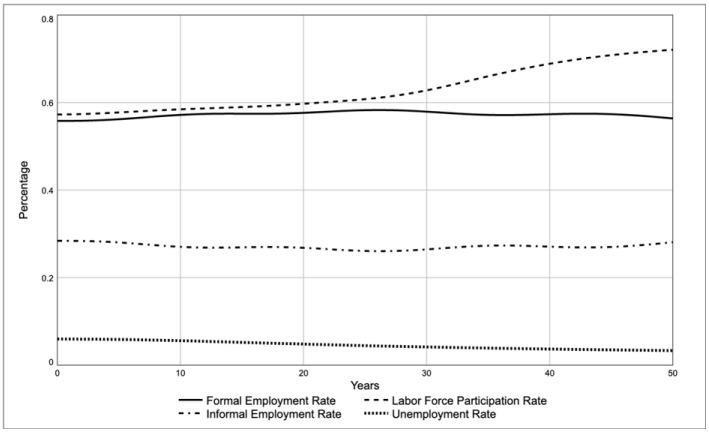
(a) Population Health Status (b) Chronic Conditions



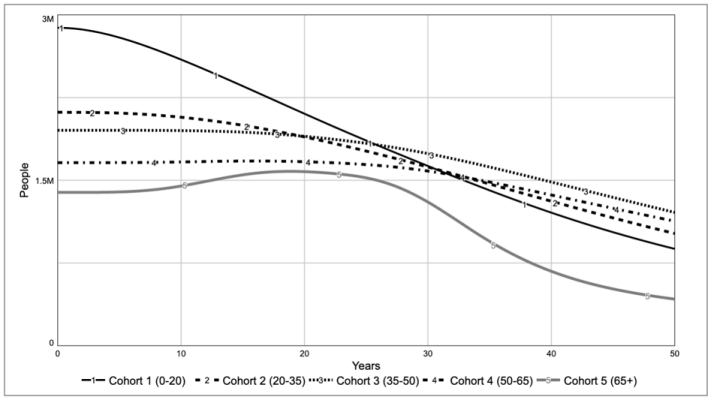
(c) Unnecessary vs Necessary (d) DALY

Figure 7.35. Healthcare Demand sector behavior in Scenario 11.

The initial benefit extension period shows itself in the PHS metric by a significant increase and in the CiD metric as a decrease in Figure 7.35a and Figure 7.35b respectively. As time progresses and programme benefits continue its shrinking behavior, improving behaviors in population health and chronic conditions stop and they start deteriorating. At year 25, the PHS level has already fallen below its initial level of 1. After this point, following the generosity period which extends the programme benefits cannot improve the PHS but only decrease the rate of decline in PHS. PHS continues its decline behavior to below 0.5 towards the end of the simulation.



(a) Employment Variables



(b) Population by Age Cohorts

Figure 7.36. Population sector behavior in Scenario 11.

The elderly cohort initially enjoys an increase caused by the higher level of PHS in the first half of the simulation while the juvenile population shows a decline shown in Figure 7.36b. As the PHS level goes below the default level at the latter half of

the simulation, death fractions increase, which causes the population level to decline, especially the elderly population. The decreased juvenile cohort and decreased elderly cohort causes the labor force participation rate to increase in this latter half (Figure 7.36a). However, the formal employment rate is sustained around the initial level since the declines in workforce cohorts (Cohorts 2, 3, and 4) are smaller compared to the declines observed in juvenile and elderly (non-revenue generating) cohorts and also the increase in contribution fraction is not sufficient enough to activate R1 – Tax Evasion Spiral.

The model behavior is within our expectations as we know that the low unit cost input would reflect an improvement only at the beginning of the simulation while the decreasing birth rate and rising costs would have a gradual effect that would manifest and increase in magnitude later in time. The initial advantage posed by low costs can save the population health for the first half of the time horizon. But as the gradual effects of rising costs and decreasing births bubble up later, they dominate over the initial improvement and derail the system to show a deteriorating behavior.

7.12. Summary Table

The end-time values of Population Health Status (PHS), CiD per Capita (CiD) and Coverage Level (CL) variables in each scenario is presented in Table 7.2. Across the scenarios, the end-time PHS level ranges between 0.469 (for the worst case of Scenario 4) and 1.826 (for the best case of Scenario 5). The range of CL level, which is presented here as a metric of the end-time benefits package level, is found to be between 0.389 (for the worst case of Scenario 7) and 0.932 (for the best case of Scenario 8). As the population health and public programme benefits do not share the same the best and worst case scenarios, we conclude that they also do not share the same dynamics and fate. A good population health outcome is not necessarily achieved by the best public programme and a generous public programme is not necessarily achieved by the healthiest population.

Table 7.2. Population Health Status (PHS), CiD per Capita (CiD) and Coverage Level (CL) variable levels in scenarios at year 50.

Scenario	**UVC Level**	**UVC Trend**	**CBR Trend**	**PHS**	**CiD**	**CL**
Scenario 1	High	-	-	0.549	9.939	0.458
Scenario 2	-	Increasing	-	0.549	10.325	0.437
Scenario 3	-	Decreasing	-	1.717	1.346	0.835
Scenario 4	-	-	Decreasing	0.469	13.300	0.503
Scenario 5	-	-	Increasing	1.826	0.935	0.768
Scenario 6	Low	-	-	1.738	1.305	0.683
Scenario 7	High	Decreasing	-	0.510	11.215	0.389
Scenario 8	Low	Increasing	-	1.781	1.204	0.932
Scenario 9	-	Increasing	Increasing	1.172	4.544	0.459
Scenario 10	Low	-	Decreasing	1.228	5.925	0.501
Scenario 11	Low	Increasing	Decreasing	1.600	2.047	0.682

8. POLICY ANALYSIS

In this section, we analyze several policy options in order to examine their efficacy and to provide a causal description of the mechanisms of policy actions and results. The policies we have included in this section consist of the following options:

(i) Government Contribution (GC) Policies
(ii) Labor Immigration Policies
(iii) Capacity Building

As the base scenario to implement policy options, we have selected Scenario 1 of section 7.1. This base scenario simulates a population with a high unit healthcare cost while all the other model parameters are at their default equilibrium levels. The scenario shows large oscillations in Healthcare Fund and related public programme benefits which creates sequential generosity and austerity periods. The impeded access to healthcare during austerity periods results in the detrimental operation of the R3 – Austerity Payoff loop and impedes the balancing potential of the B6 – Provision Offset loop. As a result, the population ends up with a less generous public healthcare programme, accumulated chronic conditions, and worsened population health. The economic adjustment policy consequences (periodical adjustments in coverages & copays and increased unemployment) observed in this scenario resembles the developments in public healthcare systems of Ireland and France following the shock of the global economic crisis of 2008 [36].

8.1. Government Contribution (GC) Policies

Elected governments tend to evade reductions in healthcare services and consequently the PS benefits due to their concern over their public popularity because of health policy's major effect on public opinion [5, 16]. One common policy is to inject public revenues from national budgets into healthcare funds to reduce economic stress [15]. We call this policy option "Government Contribution policies" or GC.

8.1.1. Direct Government Contribution (DGC) Policies

We incorporate GC into our model first as a direct inflow to the Healthcare Fund stock in discrete and continuous contributions. The discrete inflow is formulated using a PULSE function (Eq 8.1). In this section, varying frequencies (per year) and volumes (unit currency) of direct discrete and continuous GC policies are tested and the resulting model behaviors are analyzed. The policies in this subsection will be referred to in DGC (v)B/(p)Y format, which means direct government contribution of (v) billion unit currency once every (p) year as

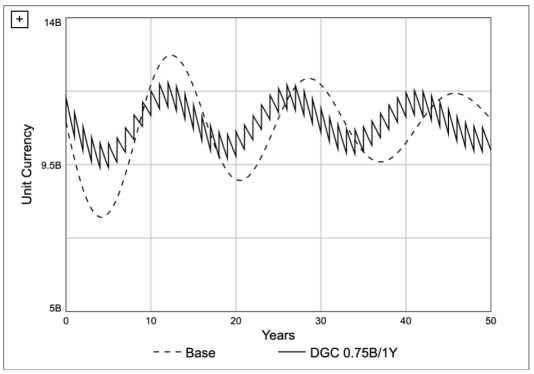
$$PULSE(v, t, p) = a\ flow\ of\ volume\ (v)\ at\ every\ (t + p \times k) \tag{8.1}$$

where k is a non-negative integer.

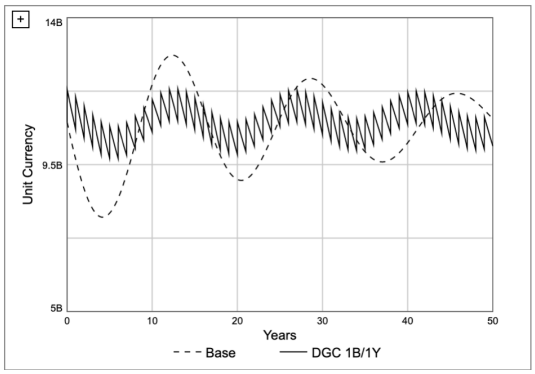
In the first DGC policy set, we simulate different pulse volumes for annual injections. In this regard, 0.75 billion unit currency, 1 billion unit currency, and 1.25 billion unit currency DGC policies are simulated with an injection period of 1 year.

In Figure 8.1, Healthcare Fund behavior in each simulated DGC policy is presented against the base scenario behavior alone, instead of a single comparative graphical output in order to avoid visual confusion due to noise-like behaviors. Each pulse causes HF to show a sudden increase that is dependent on the pulse volume. DGC policies manage to decrease the magnitude of oscillations in HF which shows itself as a major improvement in programme coverage in Figure 8.1d. Under DGC policies, the Coverage Level is saved from plummeting and fluctuates around a higher level than the base scenario.

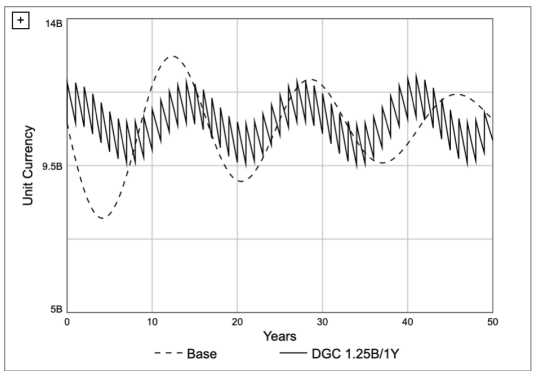
The degree of improvement, which can be measured by the dynamic mean of the CL oscillations, expectedly increases with the DGC volume. DGC 0.75B/1Y policy manages to improve the public programme but fails to carry it back to its initial level while DGC 1B/1Y policy leads the CL to fluctuate around the initial level. DGC 1.25B/1Y policy induces an upward trend in CL, carrying the system to an even more beneficial programme.



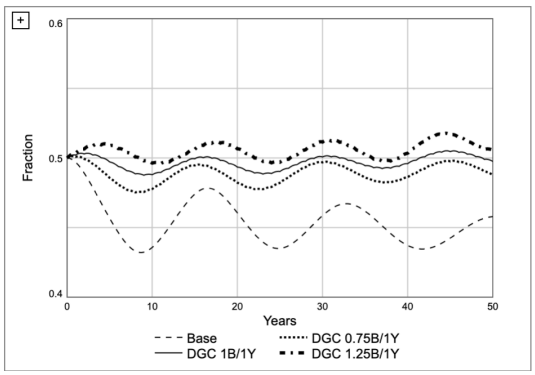
(a) Healthcare Fund



(b) Healthcare Fund

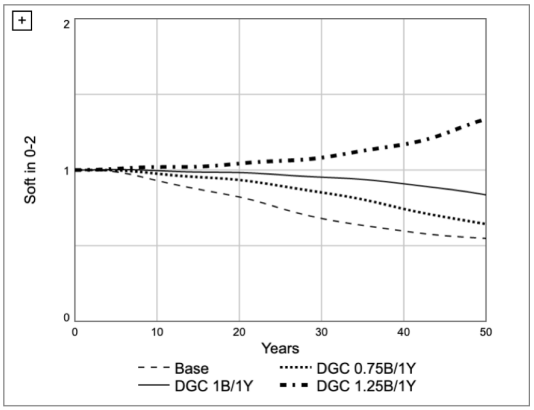


(c) Healthcare Fund

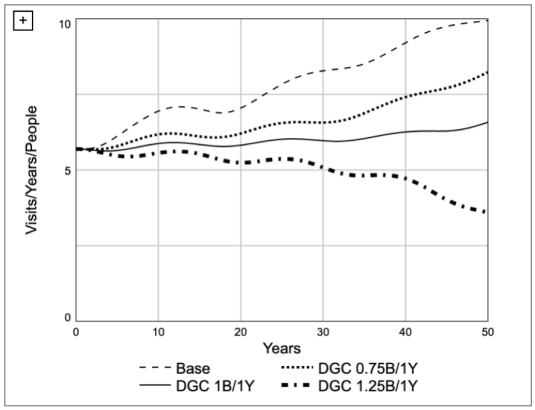


(d) Coverage Level

Figure 8.1. Healthcare Fund (HF) variable for each simulated DGC policy and Coverage Level (CL) comparative graph for volumes (0.75, 1, 1.25) billion unit currency per year.



(a) Population Health Status



(b) Chronic Conditions

Figure 8.2. Population Health Status (PHS) and Condition in Delay (CiD) variables for DGC policies with volumes (0.75, 1, 1.25) billion unit currency per year.

The policy effect on population health variables PHS and CiD is presented in Figure 8.2. The improvement in the public programme reflects an improvement in population health for all DGC policies. The most generous policy, DGC 1.25B/1Y increases PHS to significantly high levels while also reducing the CiD level of the population. DGC 0.75B/1Y and DGC 1B/1Y policies fall short of replenishing the PHS level. In the second set of DGC policy simulations, we try for varying pulse frequencies while keeping the total injected public revenue volume the same across policy configurations. This set is simulated to observe whether there would be a significant efficiency difference between steady but low and less frequent but high DGC policies and the importance of the timing of the public revenue injection. In this objective, we simulate our model for the DGC 1B/1Y, DGC 3B/3Y, and DGC 5B/5Y configurations.

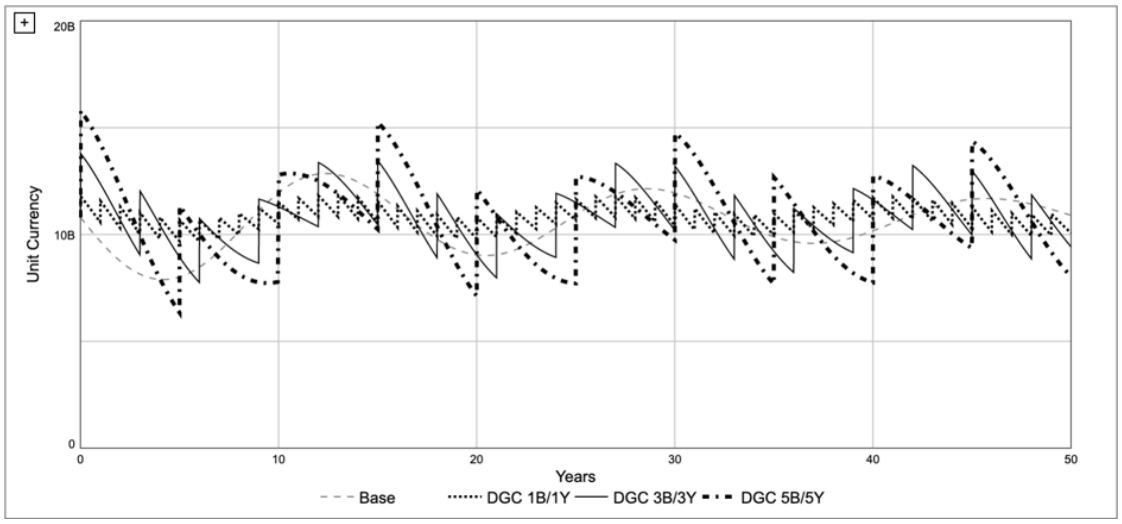


Figure 8.3. Healthcare Fund (HF) variable under DGC 1B/1Y, DGC 3B/3Y, and DGC 5B/5Y policies against the base scenario.

As the unit volume of the DGC policy goes up, the extent of the immediate increase in the Healthcare Fund enlarges (Figure 8.3). We see that HF level reaches higher maxima and lower minima with larger immediate shocks compared to the smaller ones. The DGC policy with the lowest unit volume, DGC 1B/1Y is shown to decrease the oscillation amplitudes significantly. In contrast, the DGC policy with the largest unit volume, DGC 5B/5Y is shown to be steering the HF stock in a larger range than

the base scenario. HF under DGC 5B/5Y reaches very high and very low points, which causes the economic stress formulation to easily take drastic turns in adjusting the policy variables of the public programme.

We observe that among the second set of DGC policies, none of them bests the other two in keeping the coverage level consistently above the others (Figure 8.4). CL motion in DGC policies is pretty similar to HF stock, although smoothed. The simulated DGC 5B/5Y policy has the highest magnitude oscillations while DGC 1B/1Y has the lowest. We deduce that more frequent (and lower volume) pulses keep the programme benefits more stable around the initial level. As pulse frequency decreases (and volume increases), the CL behavior reaches more extreme ends, at both high and low. If the pulse frequency increase until the pulse period decreases to an infinitesimal level, it makes the discrete nature of the pulse disturbance converge to a continuous disturbance effect. Hence, even though the disturbance is still and always will be considered discrete until the period equals the simulation's time step (year/100), a more smoothed continuous-like behavior is observed for more frequent pulses.

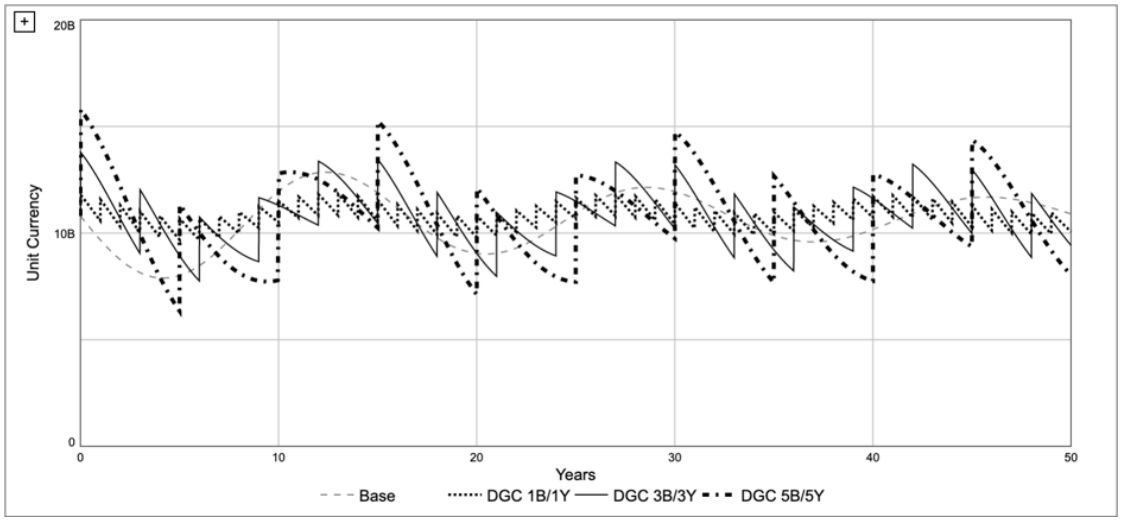
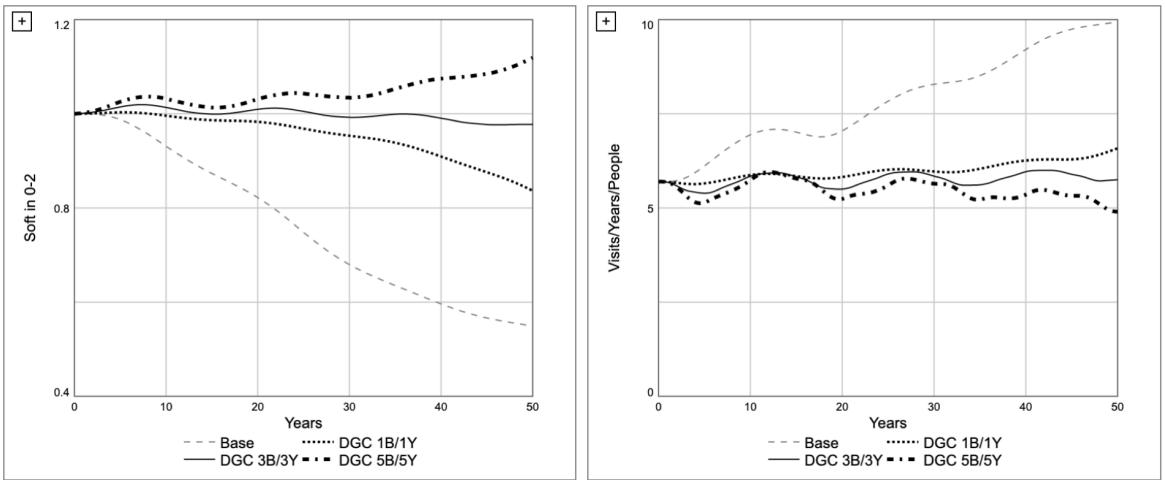


Figure 8.4. Coverage Level (CL) variable under DGC 1B/1Y, DGC 3B/3Y, and DGC 5B/5Y policies against the base scenario.

In Figure 8.4, three policies kept the oscillations in CL around the same level with differing amplitudes. Figure 8.5 shows that pulse frequency does not only have significant impacts on the stability of PS sector variables but on population health as well. DGC 5B/5Y is the most effective policy in end-time PHS and CiD levels while DGC 1B/1Y is the least. Even though the total amount of government contributions is the same for all the policies, the difference in policies' effectiveness on PHS and CiD improvement indicates that the timing of the policy is also an important factor. Based on the results of the second set, we conclude that giving the system pulses a higher level of volume with low frequency is more effective.



(a) Population Health Status (b) Chronic Conditions

Figure 8.5. Population Health Status (PHS) and Condition in Delay (CiD) variables under DGC 1B/1Y, DGC 3B/3Y, and DGC 5B/5Y policies against the base scenario.

The first set proved the intuition that the effectiveness of DGC policies is dependent on the volume of the public revenue injection. The second set in which each element comprises the same total amount of contributions helped us conclude that the timing of the injection is important as well as the volume in terms of population health improvement.

8.1.2. Government Contribution with Healthcare Buffer (HBGC) Policies

In this second subsection, we introduce a new stock to the system, Healthcare Buffer Fund (HBF). In this policy, the government makes its contribution to the HBF, to be transferred into the original HF stock when in need. The transfer mechanism is endogenized in the model as shown in Figure 8.6.

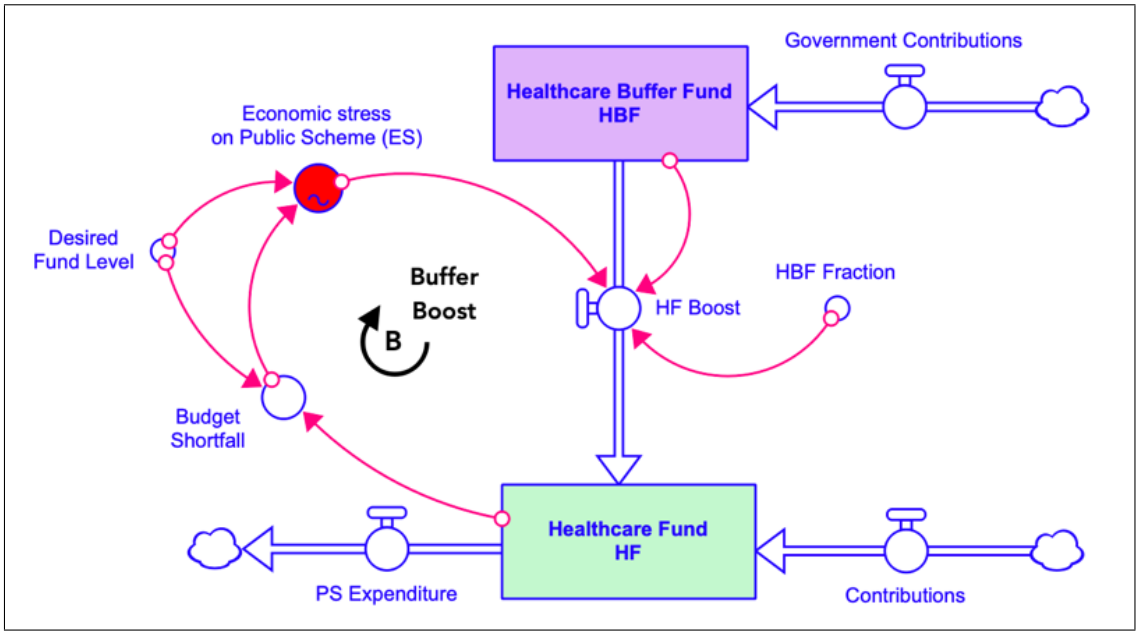


Figure 8.6. Stock-flow diagram of Buffer Boost mechanism.

In the first HBGC policy (HBGC Policy) HF Boost flow is formulated as a function of Economic Stress and HBF levels. As Economic stress increases due to budget shortage, the HF Boost flow increases the fund transfer from the HBF to HF, balancing the system.

We set the Government Contributions flow to 1 billion unit currency per year, the initial HBF level to 2 billion unit currency, and the normal HBF fraction to 0.5. In this setting, the net rate of change of HBF is zero for the default ES level. The effect of economic stress on HF Boost is formulated via a graphical function that would saturate HBF to 1 at a high ES level (Figure 8.7).

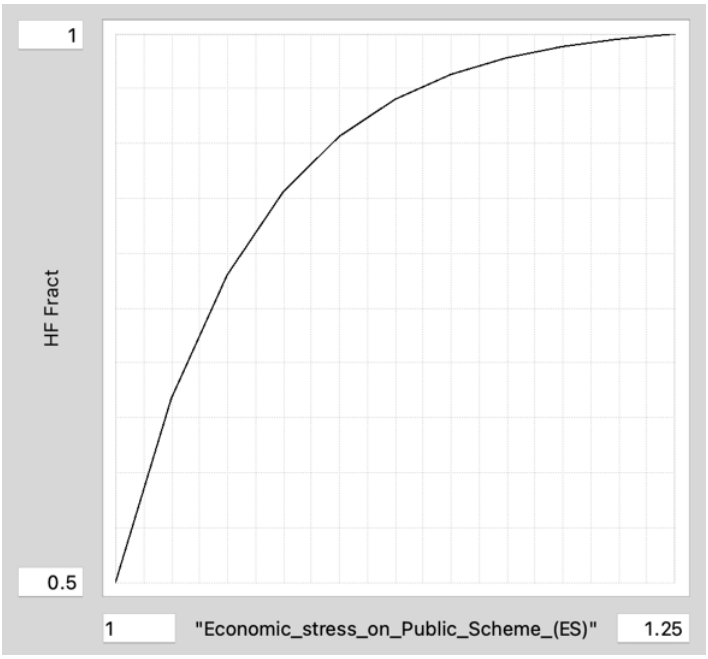
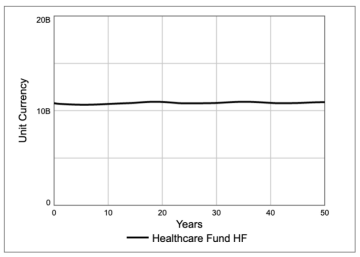
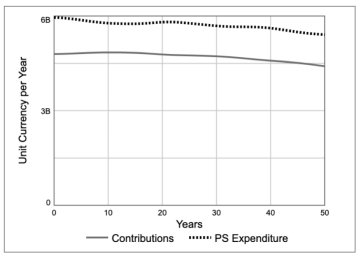


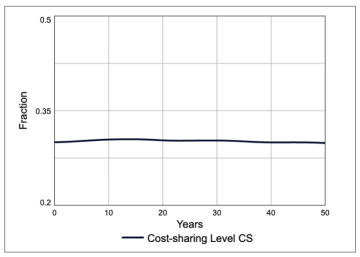
Figure 8.7. Graphical HF Fract variable as a function of economic stress (1/Years).



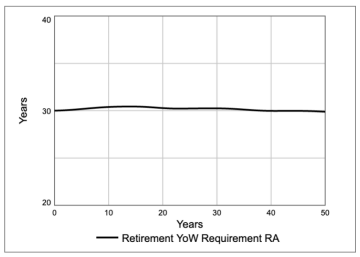
(a) Healthcare Fund



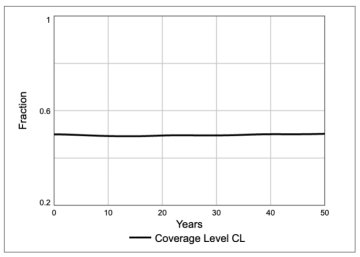
(b) Fund Flows



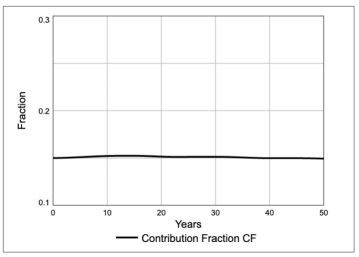
(c) Cost-Sharing Level



(d) Retirement Requirement



(e) Coverage Level



(f) Contribution Fraction

Figure 8.8. Public Scheme sector behavior in HBGC Policy.

When formulated as a function of ES as in HBGC Policy, HBGC policy works in stabilizing the public programme benefits (Figure 8.8). Whenever the economic stress rises and the model prepares for a reduction in programme coverage, the HBF fraction increases and boosts the supplementary HF Boost flow. This directly reduces the economic stress and hence stops the negative adjustment process.

In the first 10 years of the simulation, the base scenario faced its initial austerity period. The increased fund transfer from the Healthcare Buffer Fund during this period (first 7 years of Figure 8.9) compensates for the initial budget shortage by a great amount but not entirely. This can be observed by the initial slight reduction in HF level in Figure 8.8a.

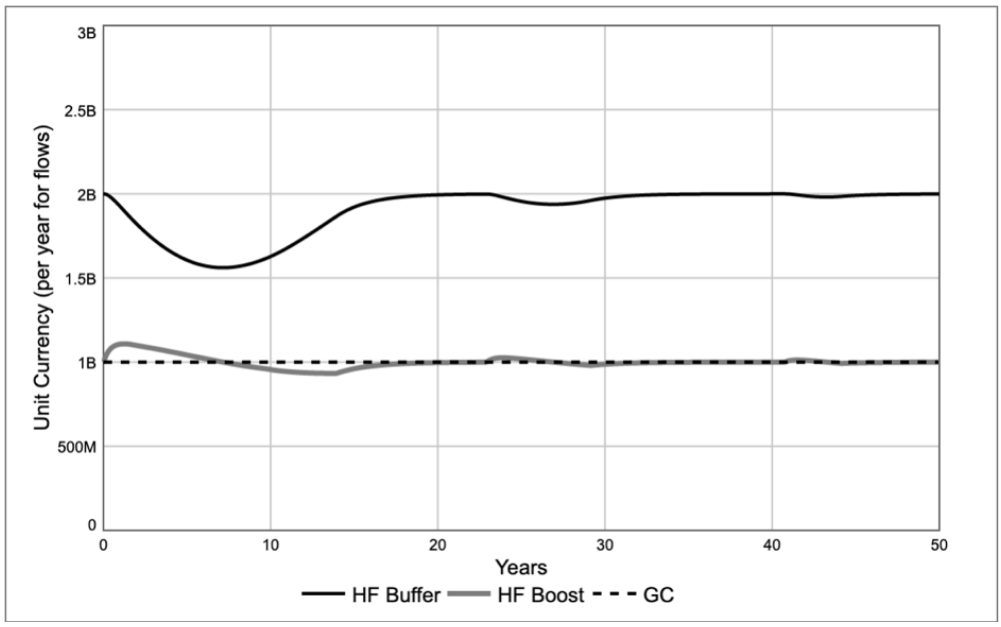
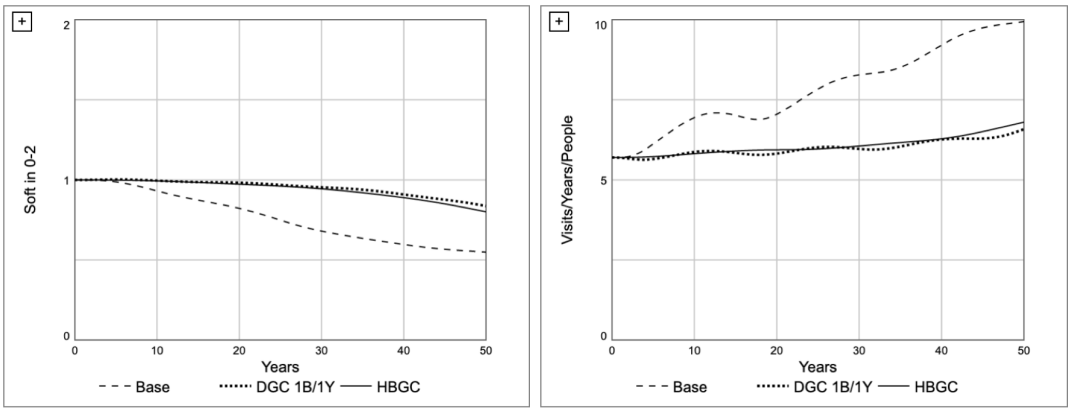


Figure 8.9. Healthcare buffer variables in HBGC Policy.

As we have covered in the previous subsection, stabilization of programme variables does not necessarily mean a better population health outcome. In Figure 8.10, we observe that the PHS and CiD levels worsen even with a sustained public programme. It is because the initial small benefit reduction caused by the initial bump we observed in HF in Figure 8.8a has led to a snowball effect of chronic disease accumula-

tion through the operation of the R3 – Austerity Payoff loop. Although we see a major improvement compared to the base scenario outcome, HBGC falls short of confining PHS and CiD.



(a) Population Health Status (b) Chronic Conditions

Figure 8.10. Population Health Status (PHS) and Condition in Delay (CiD) variables for HBGC and DGC 1B/1Y policies.

It should be noted that HF Buffer stock level stabilizes around 2 billion unit currency at year 50 which is also the stock's initial level. This means that the total HF Boost occurred during the 50 years under HBGC equals 50 billion unit currency, the same volume as the DGC 1B/1Y policy. HBGC policy performs slightly worse in improving population health compared to DGC 1B/1Y policy.

As a general deduction from the GC policies, we conclude that stabilizing the public programme benefits is not the best option when the objective is to improve population health. Initial reduction, even if it is too small, can activate the vicious cycle of R3 which can only be undone for an enlarged generosity period. In that sense, the very smooth behavior of HBGC performs worse than DGC 1B/1Y due to the inexistence of the coverage expansion periods and hence the oscillations. The magnitude of the oscillations is also an important determinant here. Having the greatest magnitude oscillations among the policies we have simulated, DGC 5B/5Y policy performs the best by providing the HF with a lump sum contribution that would result in a generous period. Even though the years without government contributions (pulse period)

in DGC 5B/5Y is higher than DGC 1B/1Y and DGC 3B/3Y, the large amount of contributions provided is able to keep the programme sustained until the next pulse.

8.2. Labor Immigration Policies

The 20th Century oversaw the widespread promotion of workforce immigration in many industrial countries in an attempt to evade the downfalls of their aging populations, in order to preserve: the continuity of industrial production, and the ratio of revenue-generating population to sustain the public services that are financed by public revenues. Labor immigration policies are relevant to Bismarckian healthcare in particular, where the healthcare funds live on contributions from the formally employed workforce. Per the work status disaggregation of our model, we analyze the impact of immigration policies by periodically in-migrating unemployed workforce (UW) and formally employed workforce (FEW).

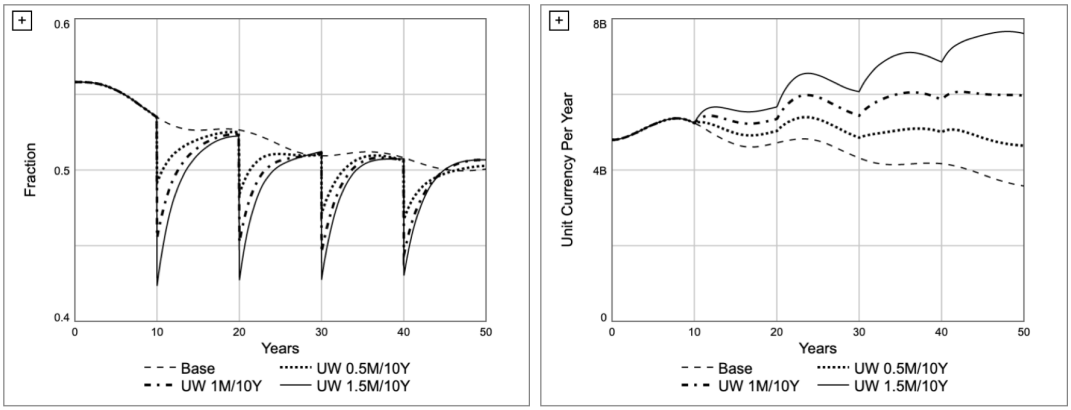
As such policies would mostly be implemented once the problem occurs, we initiate all the labor immigration policies of this subsection at the 10th year of the simulation horizon (i.e., immigration starts at year 10). It should be noted that the incoming population is assumed to have a uniformly distributed age distribution across three cohorts of the working age population (i.e., 20-35, 35-50, 50-65). Also, as a major assumption for our policy testing simulations, the incoming immigrant population is assumed not to change the population health status upon their arrival, in other words, their population health status is assumed equal to the population at the time of their arrival.

8.2.1. Unemployed Workforce (UW) Immigration Policies

The first type of labor force immigration we have analyzed is the labor force that is not informally or formally employed. Being initially in unemployed status, it would take some delay for this group to get employed and contribute to the public revenues. Hence, the effect on finances of this policy is more mediate than the more direct effect of immigration of formally employed workforce.

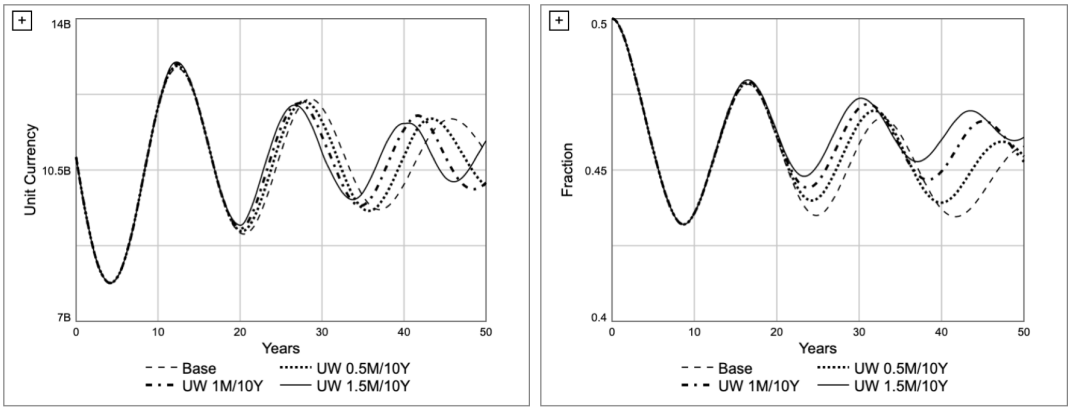
We model the process of immigration as a direct inflow to the Unemployed Workforce (UW) stock of the Population sector. The inflow is defined with a PULSE function which we have simulated with varying levels of frequency and volume. The first pulse of immigration comes at year 10. The first set of simulation runs are taken for a period of 10 years with volumes of 500 thousand, 1 million, and 1.5 million; uniformly distributed across three age cohorts of the workforce. We present the simulation results with the base scenario behavior to analyze the effects of the policy with a benchmark.

The first ten years of the simulation follow the same pattern in all runs, after which the first immigration pulse occurs that creates differing behaviors. Each pulse of UW immigration is observed to reduce the formal employment rate in Figure 8.11a. The magnitudes of these reductions increase with the volume of immigration. During the 10 years between immigration pulses, FER is observed to be able to replenish itself to the level in the base scenario (blue line). Contributions flow of healthcare fund (product of formally employed workforce and contribution fraction) also increases with the UW volume. It should be noted that this increase is not entirely caused by the sustained FER levels but by the overall increase in population due to increased immigration volume. Hence, for the runs with higher UW volumes, healthcare expenditures also rise along with the contributions due to the increase in population.



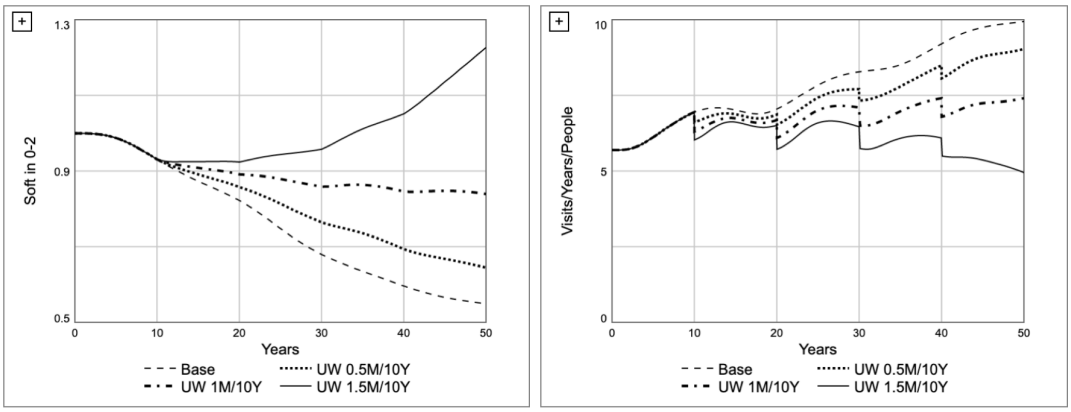
(a) Formal Employment Rate (b) Contributions

Figure 8.11. Formal Employment Rate (FER) and Healthcare Fund Contributions variables in UW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.



(a) Healthcare Fund (b) Coverage Level

Figure 8.12. Healthcare Fund (HF) and Coverage Level (CL) variables in UW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.



(a) Population Health Status (b) Chronic Conditions

Figure 8.13. Population Health Status (PHS) and Condition in Delay (CiD) variables in UW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.

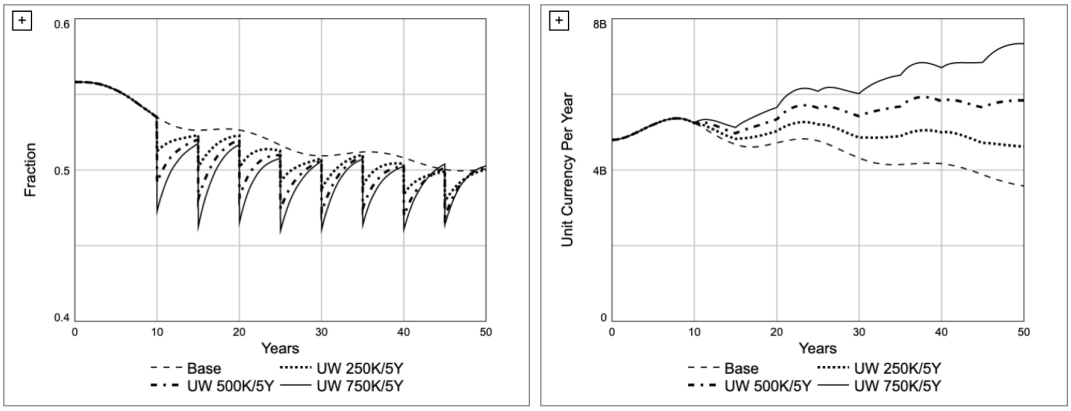
The volume of immigration is observed to gradually decrease the period of oscillations in the Healthcare Fund in Figure 8.12a, pulling the behavior leftwards for higher volume. The oscillation amplitudes are shown to be affected very little by the UW immigration disturbances. If we look at the behavior of HF in Figure 8.12a, it can be observed that this decrease in the oscillation period occurs mostly during the austerity periods. UW 1.5M/10Y run and base run enters the austerity period at almost the same time at year 16.5, UW 1.5M exit the austerity and enters a benefit expansion period at year 23.5 while base run does so in year 25. This reduced time of austerity

saves the programme benefits from falling too low and sail around a higher level for the rest of the simulation.

The level of preservation in programme benefits increases with the volume of immigration, indicated by the orderly lineup of runs in Figure 8.12b's CL behavior. The effect of sustained benefits shows itself in population health metrics in Figure 8.13. The PHS level shows an initial decrease in all of the runs in Figure 8.13a. Upon the first wave of immigration in year 10, we observe improvements in UW-migrated simulation runs. The extent of improvement is subjected to the UW volume. While the UW 500K/10Y and UW 1M/10Y runs make small to mediocre improvements, UW 1.5M/10Y run carries the system to an even healthier state than the initial, completely offsetting the base scenario's problematic developments.

A similar deduction can be made for the population's chronic condition status presented in Figure 8.13b. Base scenario oversees a major increase in chronic conditions that boosts up during every austerity period. With unemployed workforce immigration, accumulation in CiD decreases at every pulse, and also, the net flow of CiD decreases during the intervals between pulses. This occurrence is both due to the increased healthcare access caused by sustained programme benefits and the increased PHS level for UW-migrated simulation runs. The improvement in CiD scales up according to the UW volume same as the PHS behavior.

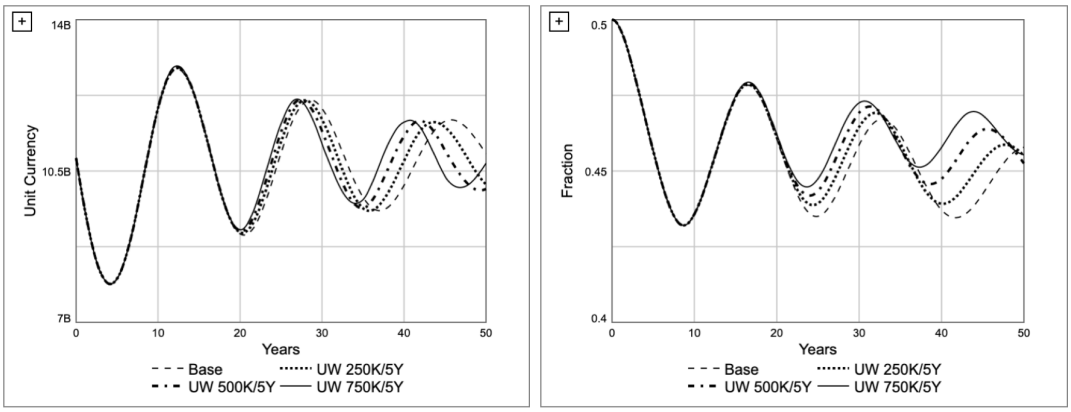
In order to analyze whether the immigration frequency has an effect on model behavior under these policies, the second set of UW migration policies is simulated with the migration period of 5 years. Halving the migration frequency from the previous scenario, we also halved the immigration volume at each pulse to have a total of the same volume of immigration between two simulation sets for corresponding simulation configurations. In other words, UW 1M/10Y and UW 500k/5Y simulation runs would have the same number of incoming immigrants within the 50 years of the simulation horizon, and the same applies to the other two configuration pairs.



(a) Formal Employment Rate (b) Contributions

Figure 8.14. Formal Employment Rate (FER) and Healthcare Fund Contributions variables in UW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.

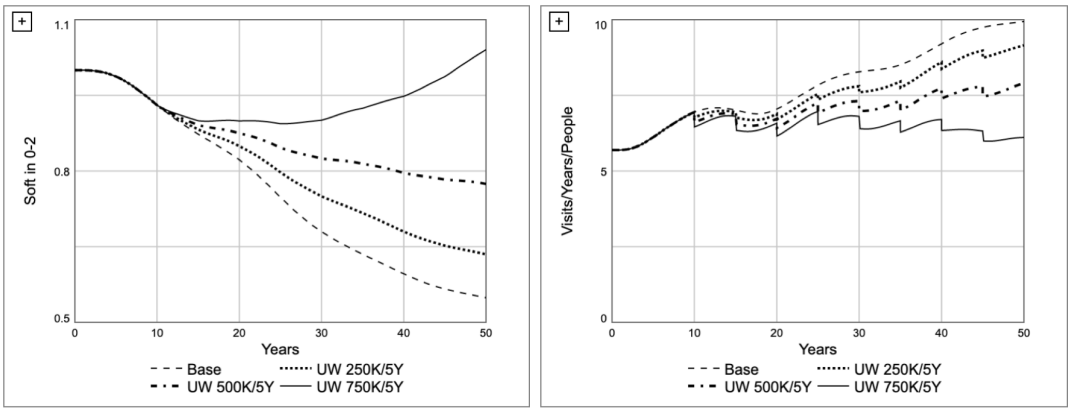
FER experiences sudden drops at each of the pulses in Figure 8.14a. The magnitude of these drops is much less compared to the model behavior under 10 years period UW immigration policy due to halved UW volume. With a smaller period and volume, FER manages to replenish itself from the sudden drop caused by the pulse until the next pulse arrives. Due to the increased number of pulses, we observe more peak-like points in HF Contributions in Figure 8.14b.



(a) Healthcare Fund (b) Coverage Level

Figure 8.15. Healthcare Fund (HF) and Coverage Level (CL) variables in UW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.

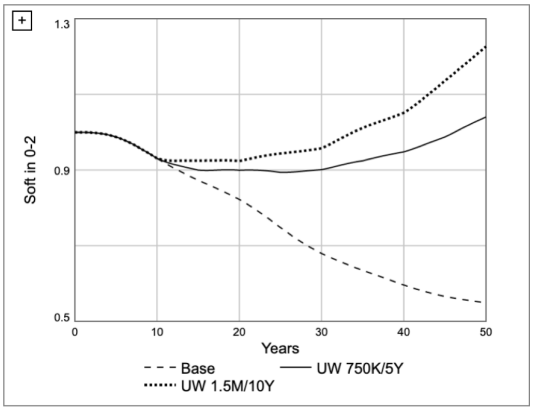
Decreasing the interval between immigration pulses along with the volume is found to have only little impact on the overall behavior of PS sector variables of the system. This can be evidenced by the little change between the behaviors we observed in Figure 8.12 and Figure 8.15. However, a major difference is observed in population health metrics between the two sets of simulation runs. If we look at the end-time levels of PHS in Figure 8.13a and Figure 8.16a, the PHS level reaches a higher point at the end of the simulation in 10-years period configurations than in 5-years period ones. Similarly, policies with a period of 10 years also seem to be more effective in easing the burden of chronic diseases than 5 years.



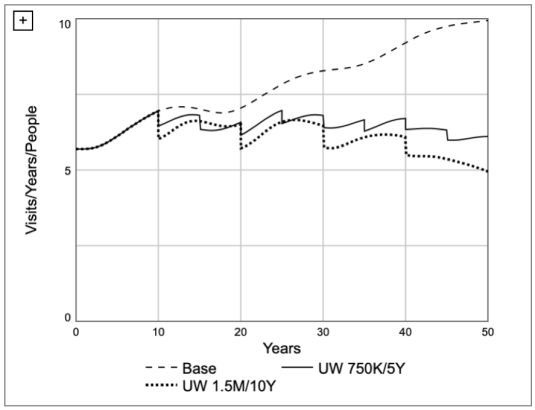
(a) Population Health Status (b) Chronic Conditions

Figure 8.16. Population Health Status (PHS) and Condition in Delay (CiD) variables in UW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.

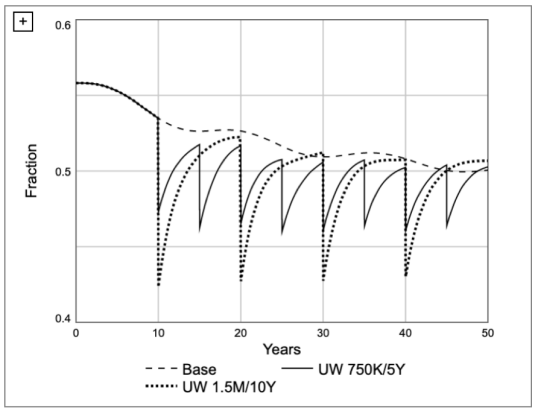
Selected central variables from previously presented 750K/5Y and 1.5M/10Y policies are recompiled comparatively in Figure 8.17. Two policies introduce the same volume of immigration to their simulated populations at different timing. It can be observed in Figure 8.17d that, although minimal, there exists a discrepancy in the policies' effectiveness in programme benefits. 1.5M/10Y always stays above 750K/5Y and performs better. In the same manner, PHS and CiD metrics show that 1.5M/10Y performs better in improving population health and alleviating chronic condition burden than 750K/5Y by consistently having better values in these two metrics throughout the simulation horizon.



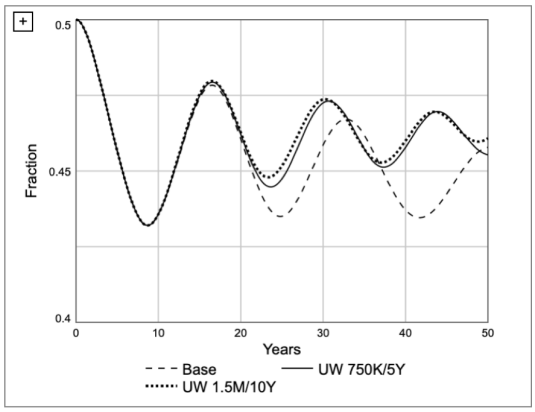
(a) Population Health Status



(b) Chronic Conditions



(c) Formal Employment Rate



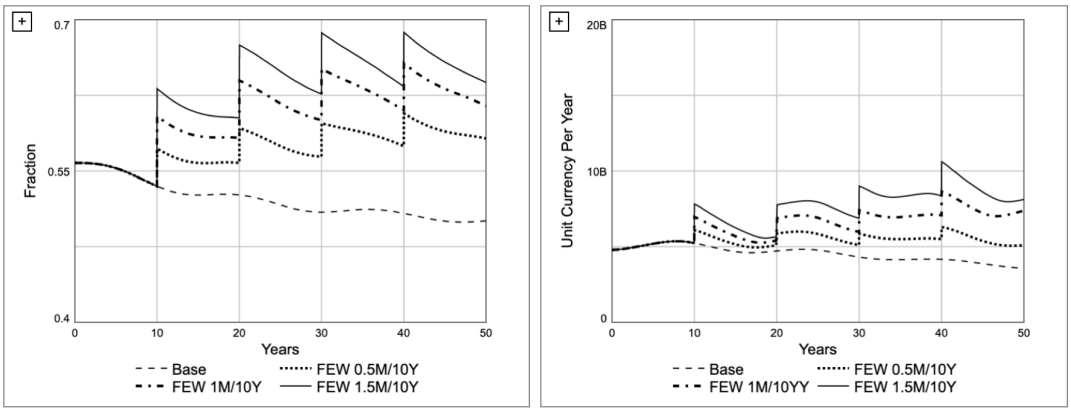
(d) Coverage Level

Figure 8.17. Population Health Status (PHS), Condition in Delay (CiD), Formal Employment Rate (FER), and Coverage Level (CL) in 750K/5Y and 1.5M/10Y UW immigration policies.

We find the reasoning behind this difference to be the delays in the status change to formal employment. After each drop in FER caused by UW immigration pulse, FER shows an upward decaying behavior towards its former base level and almost catches it before the next drop occurs (can be traced using Figure 8.17c). The difference between one big (2 unit) drop and two small (1 unit) drops is that the big drop replenishes itself faster than the small drop since the behavior is an exponential decay. In total, the area under the FER function of 10-years period policies turns out higher than the 5-years period policies which means that 10-years period policies would have cumulatively higher formal employment in this timespan of 50 years. Hence 10-years period policies in UW immigration perform better than 5-years period policies.

8.2.2. Formally Employed Workforce (FEW) Immigration Policies

The second type of labor force immigration we have included in our policy analysis is the formally employed workforce. Labor force immigration of this status people would join directly to the formal employment and contribute to the public revenues. Naturally, compared to the unemployed workforce immigration, formally employed workforce immigration would have more direct effects with greater potential.



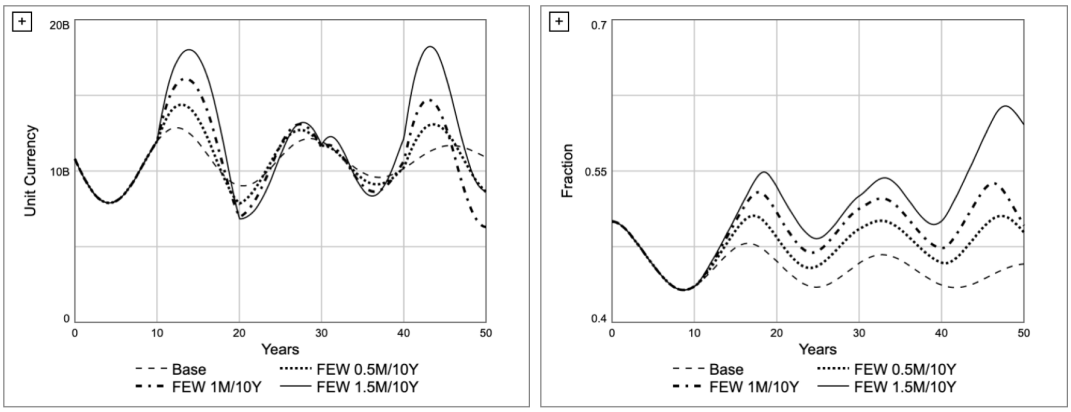
(a) Formal Employment Rate (b) Contributions

Figure 8.18. Formal Employment Rate (FER) and Healthcare Fund Contributions variables in FEW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.

Assumptions and modeling of this policy are the same as the UW immigration case: we model a direct inflow to Formally Employed Workforce (FEW) stock of the Population sector and formulate its equation as a PULSE function. In year 10, the first pulse of immigration occurs. We simulate the pulse periods of the first 10 years and then 5 years with FEW volumes of 500 thousand, 1 million, and 1.5 million people/pulse. The simulation results are presented comparatively with the base case scenario.

Since the incoming FEW groups directly join Formally Employed Workforce stock, at each pulse of immigration a sudden increase occurs in FER levels shown in Figure 8.18a. The level of the sudden increase is proportional to the FEW volumes of the policy. The system treats these sudden increases as overloads and starts a slow decaying behavior afterward due to shifts to unemployed and informally employed

states. Decaying behavior lasts until the next pulse which occurs at a point where the FER level is still above both the initial and base scenario levels for all policy volumes. FEW immigrations evidently improve the system in terms of employment level, which directly increases the Contributions flow at each pulse in Figure 8.8b. Only from this picture, we can deduce that system would be better off than the base thanks to the increased public revenue sourcing of the formal employment sector.

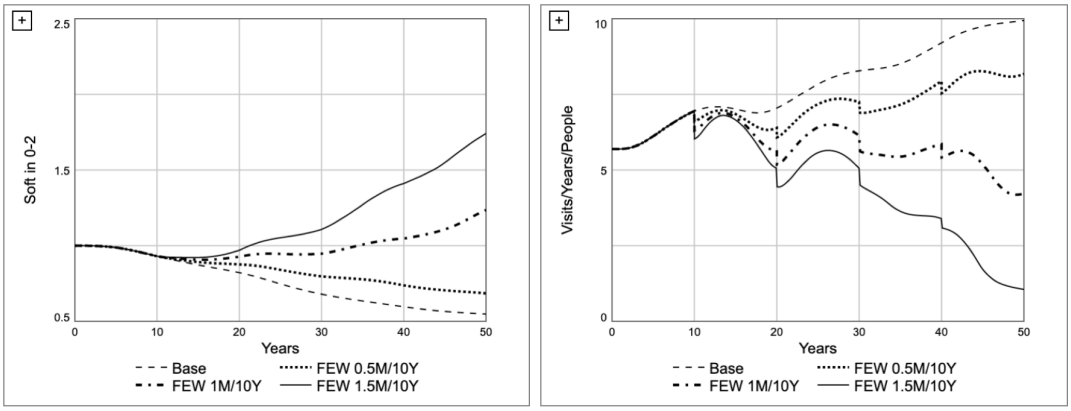


(a) Healthcare Fund (b) Coverage Level

Figure 8.19. Healthcare Fund (HF) and Coverage Level (CL) variables in FEW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.

After the initial 10 years of no disturbance, FEW policies are shown to have a direct effect on Healthcare Fund as oscillations with higher amplitude in Figure 8.19a. FEW immigration immediately increases Contributions at the point of occurrence. This instant effect is the reason for the less smoothed behavior of the Healthcare Fund in FEW policy compared to the UW case. The behavior of Coverage Level in Figure 8.19b is a little bit more smoothed than the healthcare fund due to the delayed adjustment formulation of economic stress.

FEW policy greatly improves the public programme benefits compared to the base scenario. The extent of this improvement expectedly goes up with the FEW volumes. Even the FEW migration policy with the lowest volume, 500K/10Y, can offset the damage inflicted on the system financially in the base case scenario by eliminating the downward trend in CL, among other policy variables of PS.



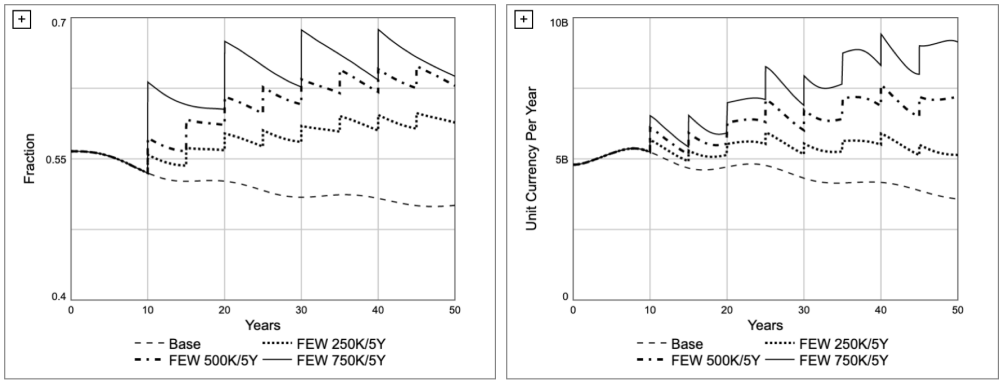
(a) Population Health Status (b) Chronic Conditions

Figure 8.20. Population Health Status (PHS) and Condition in Delay (CiD) variables in FEW immigration policies with volumes (0.5, 1, 1.5) million per 10 years.

The picture in population health metrics is similar. In Figure 8.20a, PHS levels are shown to greatly improve for FEW policies with high volumes. FEW 500K/10Y policy, which was shown to be able to sustain the public programme financially, fails to replenish the PHS to its initial level.

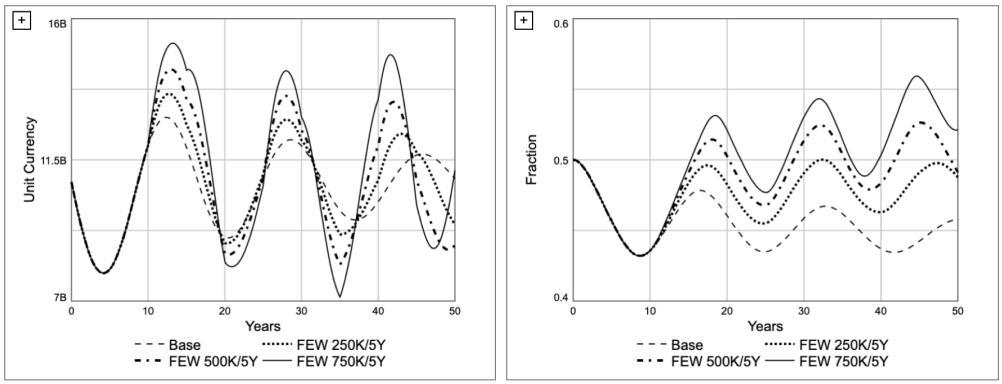
The same performance goes for the improvement in chronic conditions in Figure 8.20b as well. FEW 1M/10Y and FEW 1.5M/10Y policies manage to reduce the chronic disease burden well below the initial level while the FEW 500K/10Y policy can only induce an improvement. This is because even though the public programme is sustained and shows a stable oscillating behavior, the first period being austerity initiates the R3 – Austerity Payoff loop earlier than the generosity policies. Once R3 is activated, stabilizing the public programme is not enough to recover the population health. Instead, major improvements are necessary to offset the initial damage done by R3 via lowered access-induced chronic condition accumulation.

In the second set of simulation experiments of FEW immigration, we shorten the immigration period to 5 years while halving the immigration volumes to keep the volume of total immigration the same as the first set. In this regard, we simulate the 250 thousand, 500 thousand, and 750 thousand people/pulse with 5 years in between.



(a) Formal Employment Rate (b) Contributions

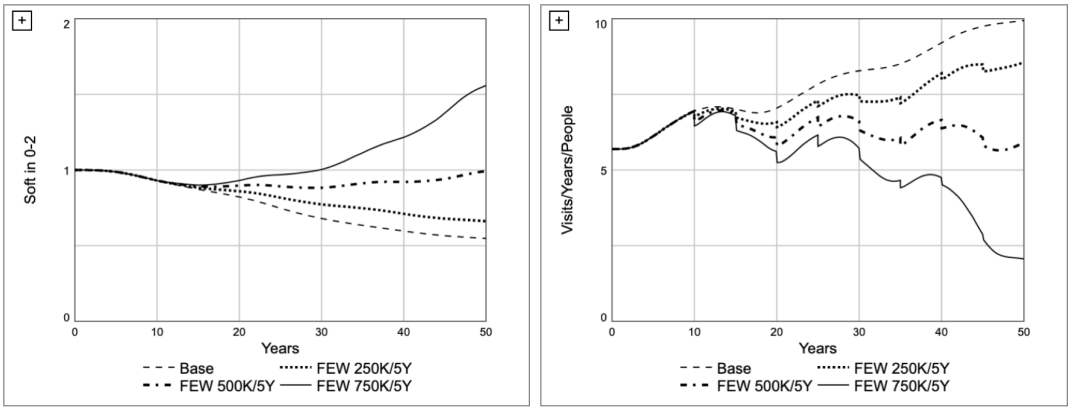
Figure 8.21. Formal Employment Rate (FER) and Healthcare Fund Contributions variables in FEW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.



(a) Healthcare Fund (b) Coverage Level

Figure 8.22. Healthcare Fund (HF) and Coverage Level (CL) variables in FEW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.

More frequent sudden disturbances are observed in FER and Contributions in Figure 8.21 due to increased pulse count. The lowered magnitude and increased number of pulses leads healthcare fund to show a more smoothed behavior in Figure 8.22a compared to the behavior in 10-years period cases in Figure 8.19a. Accordingly, the Coverage Level also shows a more smoothed behavior with nearly no rough edges. Other than disturbance count and rough edges at the directly affected variables, the overall end-time model outcome looks very similar between the 10-years period and 5-years period.

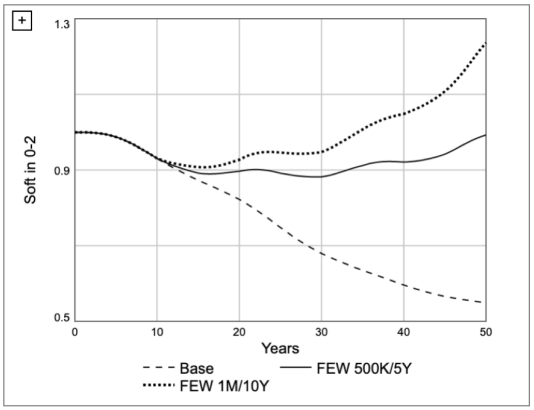


(a) Population Health Status (b) Chronic Conditions

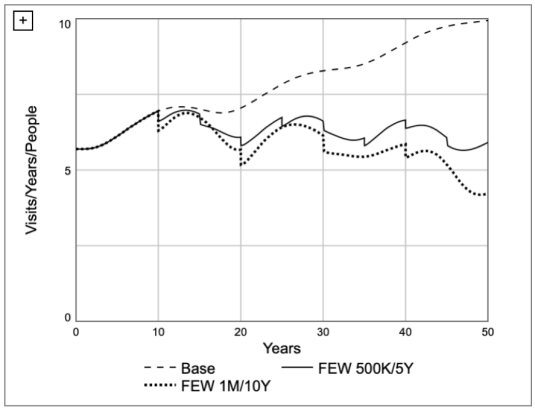
Figure 8.23. Population Health Status (PHS) and Condition in Delay (CiD) variables in FEW immigration policies with volumes (0.25, 0.5, 0.75) million per 5 years.

We proceed to present the outputs comparatively for a selected pair with equal total immigration volume in Figure 8.24, the selected pair for this subsection is FEW 500K/5Y and FEW 1M/10Y policies. The difference between the two policies' performances is significant in PHS and CiD outputs of Figure 8.24a and Figure 8.24b, FEW 1M/10Y beats FEW 500K/5Y. Also, Figure 8.24d shows that FEW 1M/10Y leads the system to achieve higher peaks in coverage level compared to FEW 500K/5Y. Although the difference between two CL behaviors seems minimally significant, it is what makes the difference in terms of long terms outcomes of population health and chronic conditions.

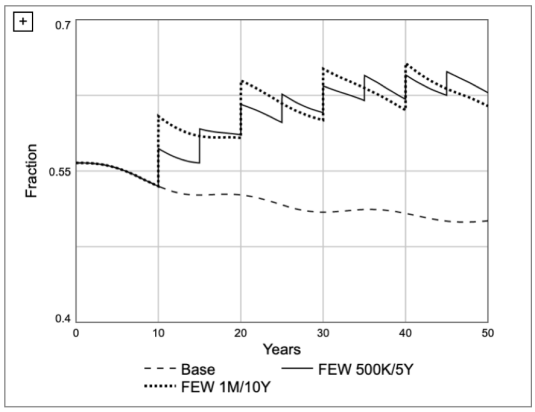
Our corollary at the end of section 8.1.2 holds in this case as well. Exponential decaying behavior of FER level in Figure 8.24c between each pulse makes the "area under the FER" of 10-years period policies larger than the 5-years period policies. This discrepancy between cumulative employment rates leads to 10-years period policies performing better than 5-years period policies with the same immigration volume. Lastly, in order to test the extreme end of this deduction, we also simulate a one shot and continuous FEW immigration cases.



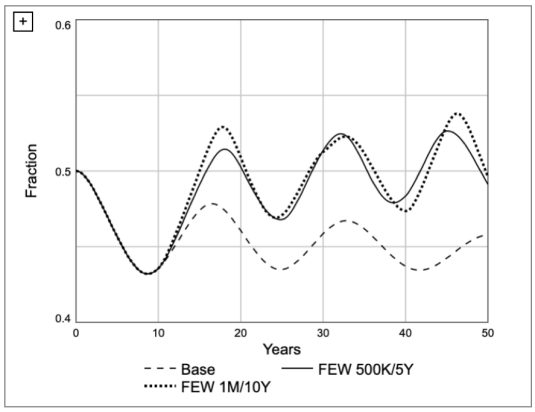
(a) Population Health Status



(b) Chronic Conditions



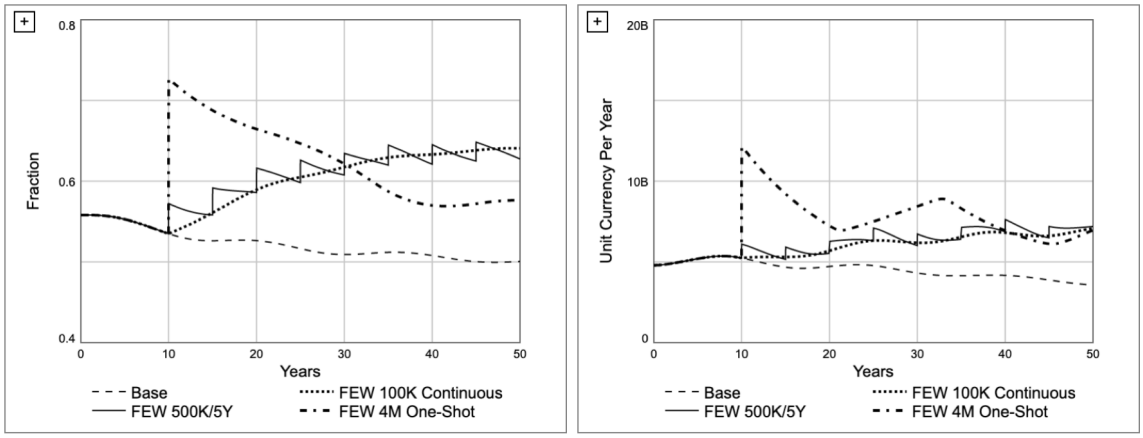
(c) Formal Employment Rate



(d) Coverage Level

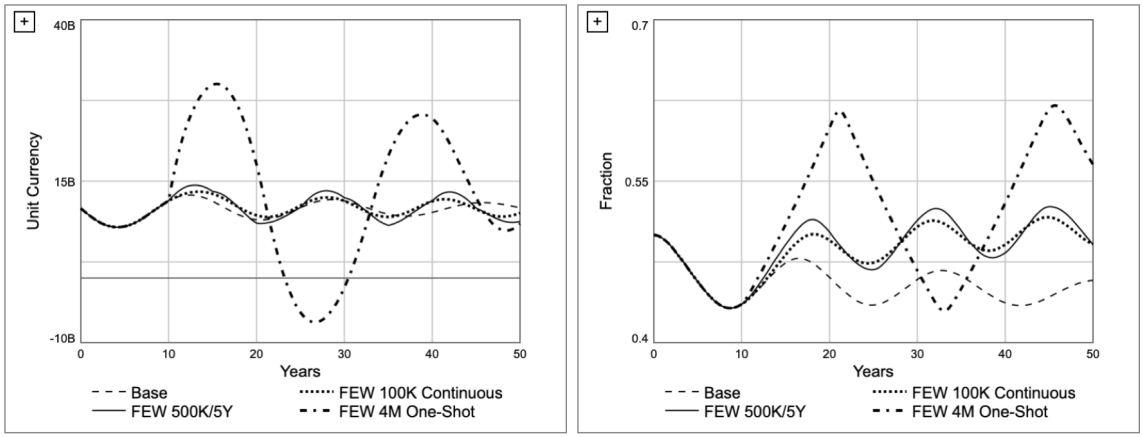
Figure 8.24. Population Health Status (PHS), Condition in Delay (CiD), Formal Employment Rate (FER), and Coverage Level (CL) in 500K/5Y and 1M/10Y FEW immigration policies.

The comparative results for FEW 500K/5Y, FEW 4M One-shot (single pulse having 4 million volume at year 10), and FEW 100K Continuous (continuous flow of annual 100K immigration after year 10) policies are presented in Figures 8.25, 8.26 and 8.27. All three policy runs presented have the same total immigration volume of 4 million people, scattered over 40 years. The policies differ from each other by the time period between pulses and the strength of each pulse. The extreme ends are represented by FEW 4M One-shot and FEW 100K Continuous policies. Generated model outputs support our previous deduction as the improvements in population health (Figure 8.27) and public programme (Figure 8.26) are the most in FEW 4M One-shot policy.



(a) Formal Employment Rate (b) Contributions

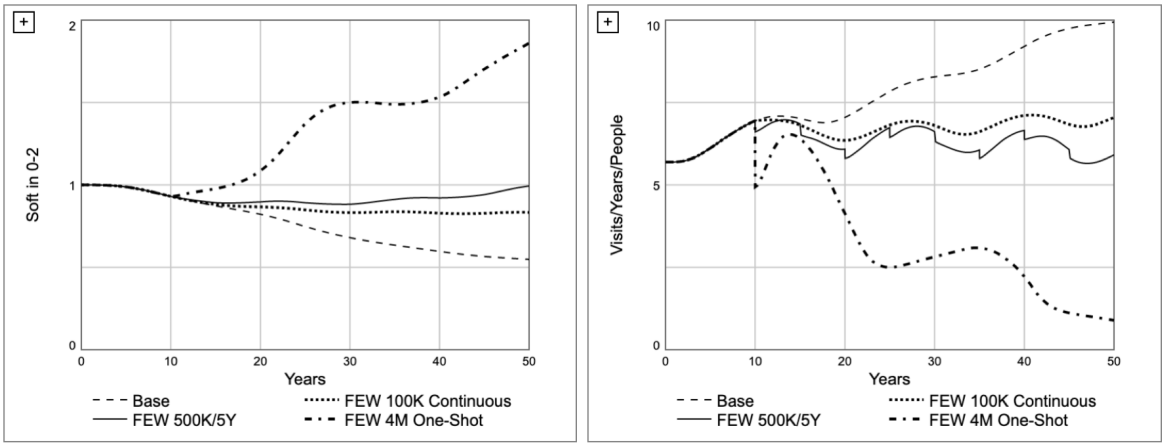
Figure 8.25. Formal Employment Rate (FER) and Healthcare Fund Contributions variables in selected FEW immigration policies with the same total volume.



(a) Healthcare Fund (b) Coverage Level

Figure 8.26. Healthcare Fund (HF) and Coverage Level (CL) variables in selected FEW immigration policies with the same total volume.

The model behaviors under FEW 500K/5Y and FEW 100K Continuous policies are observed to be very similar. We can say that as the frequency goes down across the policies with the same total volume, the behavior would converge to the continuous policy FEW 100K Continuous.



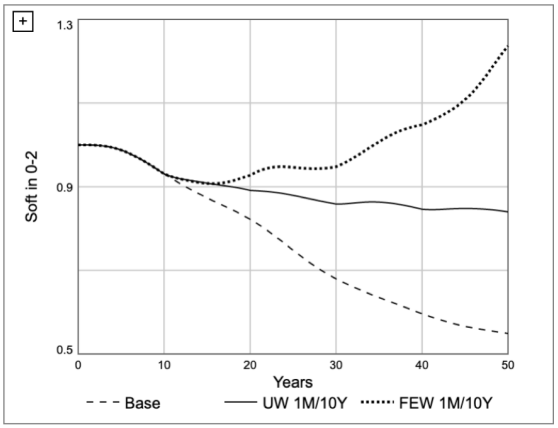
(a) Population Health Status (b) Chronic Conditions

Figure 8.27. Population Health Status (PHS) and Condition in Delay (CiD) variables in selected FEW immigration policies with the same total volume.

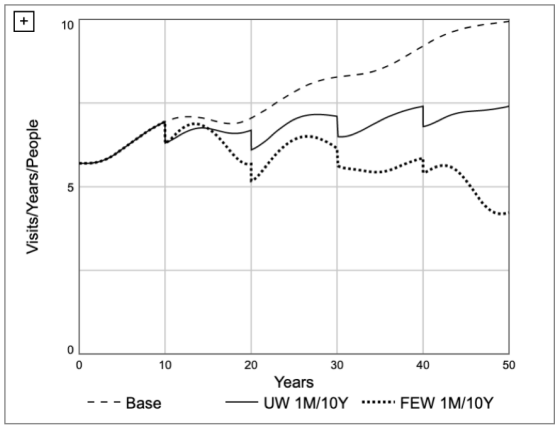
As a downside to this otherwise good outcome, the enormous volume of immigration occurred in the single shot of FEW 4M One-shot policy makes the system to show drastic behavior changes in public programme benefits. Figure 8.26 shows that the huge Contributions increase at the point of immigration shot results in a very swift overshoot and collapse behavior. The behavior even results in an 8 years long period (between years 23-31) when the Healthcare Fund goes negative. This results in a drastic austerity period in programme benefits between years 27 and 37, where the benefit package becomes less generous than other policies. However, due to the already enhanced PHS and CiD at this point, even this drastic benefit reduction poses only a little detriment to population health.

To provide a general comparison of UW immigration versus FEW immigration policies, graphical outputs for 1M/10Y UW and 1M/10Y FEW policies are presented comparatively in Figure 8.28. The great difference in their effectiveness can be traced just by observing the FER behavior in Figure 8.28c. Having the same volume of workforce immigration, the two policies raise the Labor Force Participation Rate by the same percentage. However, the effect on FER is naturally different. The incoming group's direct participation in formal employment raises the FER for FEW immigration policies, which directly increases the inflow to the Healthcare Fund that nurtures the

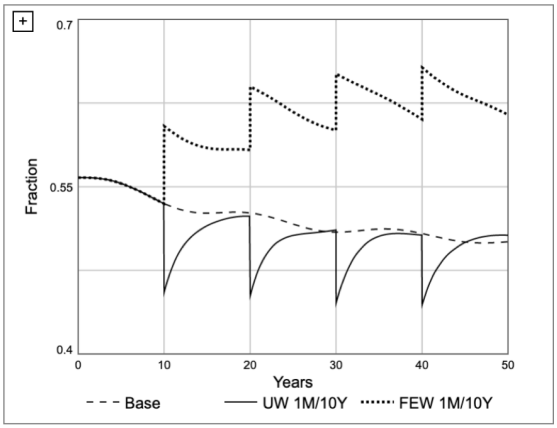
public programme. UW immigration policy's belated employment delays this boost to the Healthcare Fund inflow. As a result, FEW immigration policies perform better than UW immigration policies.



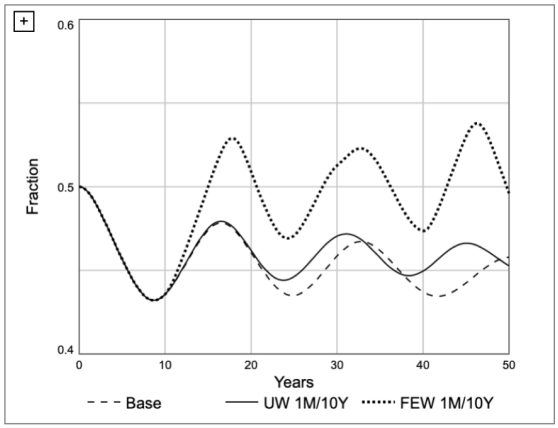
(a) Population Health Status



(b) Chronic Conditions



(c) Formal Employment Rate



(d) Coverage Level

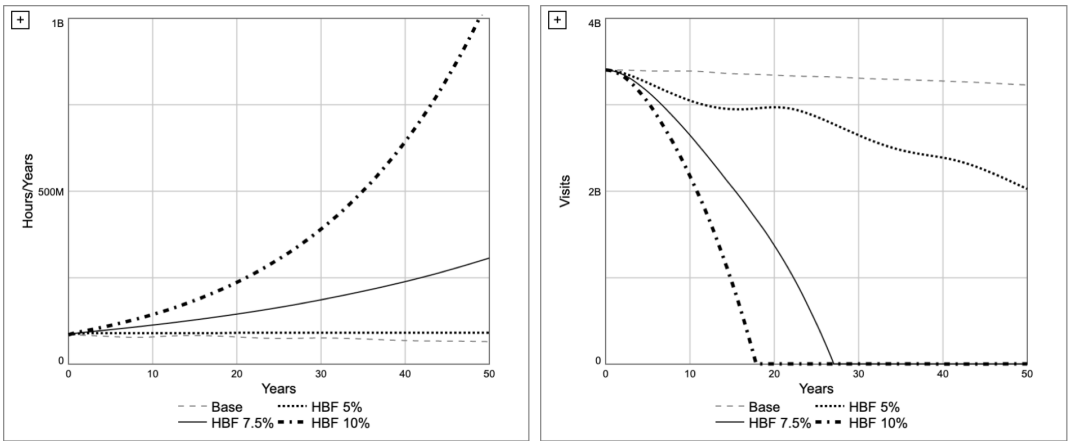
Figure 8.28. Population Health Status (PHS), Condition in Delay (CiD), Formal Employment Rate (FER), and Coverage Level (CL) in 1M/10Y UW and 1M/10Y FEW immigration policies.

8.3. Capacity Building

A significant portion of chronic conditions stems from reneging. With increased waiting times, patients renege more from the healthcare visit order queue. The essential portion of these reneged healthcare demands is modeled to join the second chronic

condition stock (Condition in Delay 2). Therefore, by increasing the healthcare capacity and consequently decreasing the waiting times, we can minimize the reneging occurrence and therefore cut off one of the major sources of chronic conditions.

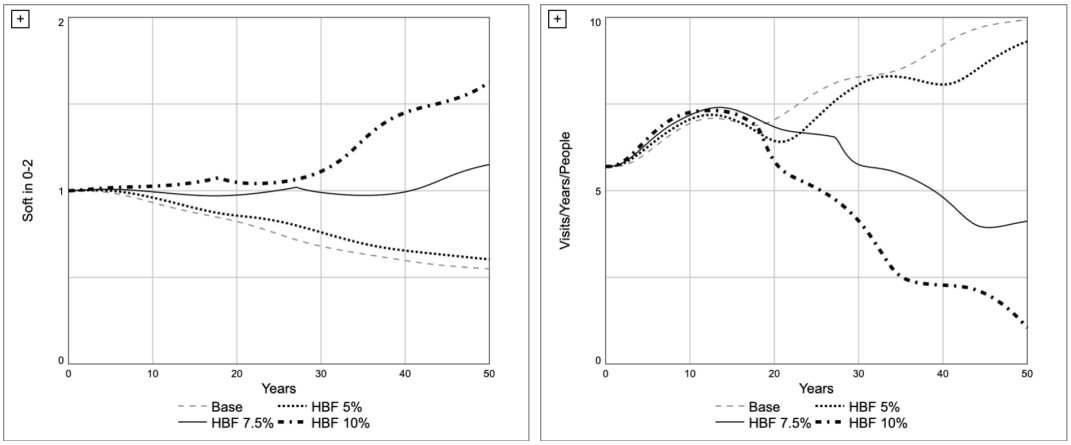
In order to test this policy, we introduce a new inflow to the Healthcare Capacity stock and name it Capacity Building. We define a fraction (CB fraction) and formulate Capacity Building flow as the product of the stock and the new fraction. Meaning that a fraction of the stock is added to itself per year to increase the capacity. We simulate the CB fraction levels of 5, 7.5, and 10% and present the results comparatively.



(a) Healthcare Capacity (b) Visit-in Waiting

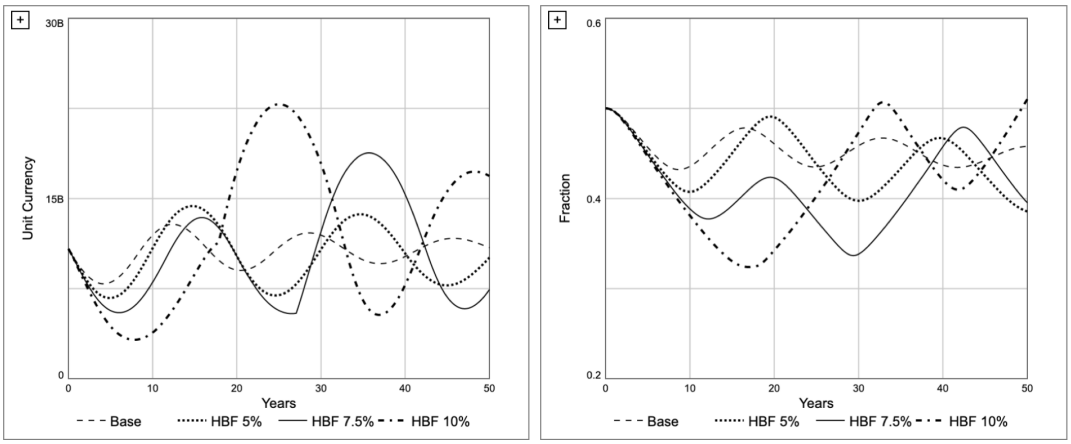
Figure 8.29. Healthcare Capacity (HC) and Visit-in Waiting (ViW) variables for capacity building policies with HB Fraction levels 5, 7.5, and 10%.

In Figure 8.29, different levels of HB Fraction are shown to result in exponentially growing behaviors in Healthcare Capacity but on different scales. Increased HC levels increase the health service rate and decrease waiting time for healthcare provision. This increase in health service rate causes Visit-in Waiting stock to deplete in mid-term for HBF 7.5% and HBF 10% policies. HBF 5% policy does some improvement in decreasing waiting times but does not result in complete depletion of Visit-in Waiting stock in 50 years of time.



(a) Population Health Status (b) Chronic Conditions

Figure 8.30. Population Health Status (PHS) and Condition in Delay (CiD) variables for capacity building policies with HB Fraction levels 5, 7.5, and 10%.



(a) Healthcare Fund (b) Coverage Level

Figure 8.31. Healthcare Fund (HF) and Coverage Level (CL) variables for capacity building policies with HB Fraction levels 5, 7.5, and 10%.

The sharp decreasing behavior in ViW results in less reneging which decreases the CiD accumulation, easing the negative operation of the R3 loop. After ViW depletes at year 18 for HBF 10% and year 27 for HBF 7.5%, the declining behavior of CiD becomes more visible (Figure 8.30b). As another mechanism, the increased service rate increases total healthcare provision and activates B6 – Provision Offset. With more provision, the population's healing gets faster, and the outcome is very visible even from the beginning in Figure 8.30a.

With more healthcare provision, Healthcare Fund Expenditures naturally increase and oscillation in PS sector variables gets greater for higher HB Fraction levels (Figure 8.31). But in the long run, the increase in PHS level decreases the generated healthcare demand and eventually the Healthcare Fund Expenditures for the policies with a major improvement on PHS.

In this picture, we see that the capacity building may work well in the long term, but if left midway may leave the system with an overshot capacity that would generate more expenditure than the public programme may provide and with a worse than usual benefit package if the policy is stopped during the pits of HF oscillations.

8.4. Policy Performances in Different Scenarios

In this subsection we present the end-time levels of main model variables under different policies in 11 scenarios we have defined in chapter 7. Population Health Status levels at year 50 are presented in Table 8.1.

Table 8.1. End-time Population Health Status (PHS) variable levels (dimensionless) under different policies (columns) across different scenarios (rows).

PHS	**DGC 1B/1Y**	**DGC 3B/3Y**	**HBF**	**FEW 500K/5Y**	**FEW 1M/10Y**	**UW 500K/5Y**	**UW 1M/10Y**	**CB 7.5%**
S1	0.836	0.977	0.800	0.993	1.237	0.774	0.840	1.150
S2	1.535	1.592	1.505	1.217	1.444	0.901	1.033	1.148
S3	1.799	1.804	1.795	1.892	1.901	1.885	1.894	1.999
S4	1.587	1.595	1.586	1.444	1.653	0.831	0.988	0.740
S5	1.911	1.913	1.910	2.000	2.000	2.000	2.000	1.999
S6	1.808	1.813	1.805	1.901	1.907	1.898	1.906	1.999
S7	0.549	0.558	0.547	0.661	0.686	0.643	0.655	0.663
S8	1.815	1.820	1.812	1.911	1.915	1.910	1.915	2.000
S9	1.901	1.908	1.897	1.978	2.000	1.722	1.810	1.987
S10	1.630	1.636	1.626	1.756	1.777	1.744	1.762	1.975
S11	1.636	1.641	1.635	1.788	1.800	1.785	1.797	2.000

FEW 1M/10Y performs consistently better than FEW 500K/5Y in all scenarios, supporting our claim of larger period policies performing better than lower period policies with same total immigration volume. The same applies for the DGC case: DGC 3B/3Y beats DGC 1B/1Y in all scenarios. Although the difference in performance is smaller in DGC policies than FEW policies

Difference between UW and FEW policies are expectedly on the favor of FEW policy. Compared to their FEW counterparts, UW policies results in worse PHS levels in all scenarios. Though in optimistic scenarios, UW policy with the more advantageous immigration policy type, UW 1M/10Y, performs better than FEW 500K/5Y by a small margin. FEW 1M/10Y and CB 7.5% are found to be the most effective policies in population health improvement in most scenarios. CB 7.5% bests FEW 1M/10Y in Scenarios 3, 6, 8, 10 and 11, where the last of them are defined with a low initial UVC input. So, we can infer that under an optimistic price level, capacity building would be more advantageous than FEW immigration.

Table 8.2. End-time CiD per Capita (CiD) variable levels (visits/years/people) under different policies (columns) across different scenarios (rows).

CiD	**DGC 1B/1Y**	**DGC 3B/3Y**	**HBF**	**FEW 500K/5Y**	**FEW 1M/10Y**	**UW 500K/5Y**	**UW 1M/10Y**	**CB 7.5%**
S1	6.581	5.749	6.805	5.909	4.225	7.912	7.406	4.122
S2	2.199	1.765	2.757	5.297	3.359	7.585	6.827	4.950
S3	1.160	1.145	1.172	0.864	0.838	0.886	0.863	0.000
S4	2.117	2.126	2.102	3.389	1.676	9.170	8.149	7.744
S5	0.728	0.719	0.734	0.414	0.342	0.410	0.347	0.000
S6	1.143	1.131	1.152	0.841	0.821	0.851	0.827	0.000
S7	10.281	10.111	10.332	9.689	9.274	10.116	9.972	7.741
S8	1.103	1.091	1.113	0.799	0.781	0.805	0.787	0.000
S9	0.774	0.755	0.786	0.619	0.489	1.090	0.835	0.001
S10	1.935	1.913	1.958	1.415	1.366	1.435	1.399	0.000
S11	1.915	1.896	1.918	1.329	1.302	1.334	1.310	0.000

Among the remaining scenarios where FEW 1M/10Y beats the CB 7.5%, Scenario 4 deserves a particular attention where the CB 7.5% policy which is strong in other scenarios performs the worst among the 8 policies simulated. We find that in a setting with a decreasing crude birth rate and default level of UVC with no trend (Scenario 4), capacity building is not an effective policy option to improve population health.

CiD per Capita levels at year 50 under different policies across different scenarios are presented in Table 8.2. The findings from the results for CiD are mostly in the same direction as PHS. What works for population health usually works for chronic conditions as well. However, there is a significant difference in the performance of capacity building policies between PHS and CiD outcome.

CB 7.5% policy performs the best in nine out of eleven scenarios (all but Scenarios 2 and 4) in terms of chronic diseases per capita. In seven of those nine scenarios, CB 7.5% policy led the CiD level to deplete almost completely. Since the CB policy works by increasing the healthcare capacity to decrease reneging and chronic conditions, such an advantage in CiD metric is expected.

Table 8.3. End-time Coverage Level (CL) variable levels (percentage) under different policies (columns) across different scenarios (rows).

CL	**DGC 1B/1Y**	**DGC 3B/3Y**	**HBF**	**FEW 500K/5Y**	**FEW 1M/10Y**	**UW 500K/5Y**	**UW 1M/10Y**	**CB 7.5%**
S1	49.8%	49.7%	50.2%	49.1%	49.6%	45.3%	45.3%	39.5%
S2	52.3%	53.1%	50.5%	48.4%	49.4%	44.6%	44.0%	36.9%
S3	96.0%	96.2%	93.3%	99.8%	99.9%	99.4%	99.5%	89.9%
S4	53.5%	52.6%	54.0%	53.7%	58.5%	49.6%	48.5%	42.8%
S5	99.5%	99.5%	99.3%	99.0%	99.4%	93.7%	95.4%	81.3%
S6	84.0%	84.3%	81.9%	99.1%	99.2%	99.0%	99.3%	87.3%
S7	45.2%	45.9%	45.0%	45.0%	45.5%	39.0%	39.0%	33.3%
S8	97.5%	97.4%	98.3%	100.0%	100.0%	100.0%	100.0%	98.4%
S9	84.9%	88.9%	87.4%	69.7%	76.2%	54.1%	57.0%	69.9%
S10	59.4%	59.3%	57.3%	70.1%	73.9%	66.7%	68.0%	73.9%
S11	70.3%	70.6%	71.9%	94.6%	95.8%	89.8%	92.5%	96.8%

We present Coverage Level values at year 50 in Table 8.3 as a single metric representing the public programme benefits across simulation runs. Differing from the PHS and CiD cases, HBF works better than DGC policies in some cases (Scenarios 1, 4, 8, 11). This performance improvement is largely due to the balancing loop created by HBF policies aiming to stabilize the programme benefits.

Larger period policies are found to be better in keeping the programme benefits high than lower period policies always in FEW immigration policies and most of the UW immigration policies (all but Scenarios 2 and 4). However, the effect of period is found to be insignificant in DGC policies, DGC 3B/3Y beats DGC 1B/1Y in only six out of eleven scenarios in terms of Coverage Level.

Table 8.4. End-time Formal Employment Rate (FER) variable levels (percentage) under different policies (columns) across different scenarios (rows).

FER	**DGC 1B/1Y**	**DGC 3B/3Y**	**HBF**	**FEW 500K/5Y**	**FEW 1M/10Y**	**UW 500K/5Y**	**UW 1M/10Y**	**CB 7.5%**
S1	55.9%	55.4%	56.0%	62.8%	61.4%	50.2%	50.7%	42.9%
S2	56.3%	56.6%	56.1%	61.7%	61.0%	50.4%	50.2%	43.3%
S3	59.3%	59.3%	59.3%	60.4%	59.2%	58.3%	58.5%	59.5%
S4	61.1%	61.1%	61.3%	67.7%	66.5%	56.3%	56.5%	53.5%
S5	58.1%	58.0%	58.3%	60.5%	59.4%	58.3%	58.5%	57.2%
S6	59.8%	59.7%	59.8%	61.9%	60.7%	58.6%	58.7%	59.3%
S7	52.1%	51.9%	52.0%	60.2%	59.2%	42.4%	42.6%	35.6%
S8	56.9%	56.8%	57.2%	57.0%	55.8%	55.4%	55.4%	59.5%
S9	58.7%	58.8%	58.8%	60.9%	60.5%	53.3%	54.3%	54.1%
S10	61.1%	61.0%	61.1%	67.0%	65.6%	60.6%	61.4%	60.3%
S11	60.4%	60.4%	60.5%	64.3%	62.8%	59.9%	60.3%	61.1%

Lastly, the comparative results for Formal Employment Rate at year 50 are presented in Table 8.4. Differing from the other policies, FEW policies directly affect the FER by increasing the Formally Employed Workforce at the point of policy implementation. Hence, FEW policies generally perform better than other policies in all scenarios.

FEW 500K/5Y policy is observed to consistently produce higher formal employment outcomes compared to FEW 1M/10Y policy. This indicates that low volume but high frequency FEW immigration policies works better in keeping the formal employment level high. However, this is not the case for UW immigration, where the FER level is mostly (in nine out of eleven scenarios) higher in 1M/10Y than 500K/5Y.

9. CONCLUSIONS AND FUTURE RESEARCH

Public health insurance systems are facing financial sustainability issues due to population aging and other demographic factors. This thesis constructs a dynamic simulation model in order to capture and analyze the development of inefficiencies in a publicly funded single-payer health insurance system. We considered a closed population with limited external effects in order to analyze the endogenous dynamics in isolation.

The simulation model is constructed to represent a state-run public health insurance programme with a single centralized healthcare fund. The fund is financed by employee contributions which makes it heavily dependent on employment level in formal sector. We account for the causal relationships between public programme, population health and socioeconomic development via intersectoral feedback links.

The model is initialized for a dynamic equilibrium on the principle of collective annual equivalence. We then conduct a scenario analysis to observe the model behavior under different conditions by disturbing the initial equilibrium, aiming to provide a causal explanation in development of systemic problems. We then conduct a policy analysis by simulating several policy options aiming to sustain the system financially and improve population health. While our aim is not to find an optimal allocation of healthcare funds, our insights can inform health insurance policy to develop effective measures to sustain the system financially while conserving population health.

Our scenario analysis shows that the austerity policies -as an endogenized response to increased expenditure- carry the danger of overlooking the necessary healthcare demand which would leave collateral damage on population health lasting long after the first administration of the policy. Because of the delays in the development of chronic conditions, the belated generosity in plan benefits does little help in improving population well-being.

We also find that the population health and public programme benefits do not share the same the best- and worst-case scenarios within our scenario analysis. A good population health outcome is not necessarily achieved by the best public programme and similarly, a generous public programme is not necessarily achieved by the healthiest population. Although highly related, we conclude that the population health and public programme do not share the same exact dynamics and eventual fate.

In our policy analysis, options such as government contribution, labor immigration and healthcare capacity building policies were tested in terms of their ability to sustain the programme and improve population health. We also test the effect of systemic interventions such as introducing a buffer-safety fund stock for government contributions in which the public revenue injections would accumulate to boost the healthcare fund in the most effective time.

We find that low-frequency and high-volume labor immigration and government contributions are more effective in improving population health than their high-frequency and low-volume counterparts with the same total volume. This finding holds true for immigration and government contributions policies in all scenarios. The performance difference between policy configurations is found to be smaller in government contributions policies than immigration policies.

Formally employed workforce immigration policy with the lower frequency and capacity building are found to be the most effective policies in population health improvement in most scenarios. Under an optimistic price level, capacity building is more advantageous than formally employed workforce immigration. However, against a decreasing crude birth rate setting, capacity building is not an effective policy option, performing worst among the 8 policies simulated.

Our policy analysis shows that sustaining the public programme benefits does not necessarily lead to a better population health outcome. Replenishing the benefits to default settings fails to compensate for the mediate and immediate negative effects of a benefit reduction period. In those cases, a generous benefit expansion later in time is

found to be necessary. Therefore, against worsening conditions, stabilization of public programme is not the remedy but a generous benefit expansion is.

Currently, the model includes one state-run mandatory insurance plan where the risk pooling spans the whole population. A promising direction would be to expand our model with a private insurance sector with multiple plans and thus multiple risk pools, to further examine the health insurance-related agency problems. The population will be able to opt for multiple plans depending on their projected individual health costs. Post-ante moral hazard arising from the information asymmetry between agents (insurers) and principals (citizens) due to the price distortion effect is included in the current model. In the planned extension, by giving the citizens the option to select differing plans, we will also be able to observe the adverse selection death spirals and analyze the causal mechanisms surrounding such inefficiencies. A comparative simulation analysis the performances of single-payer (PS), multi-payer (private insurance), and hybrid health insurance models (PS & private insurance) in the same scenarios and conditions can also be made possible.

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APPENDIX A: MODEL EQUATIONS

********** Healthcare Demand: **********

CiD Correct 1 =

(Unexpressed Essential Elastic DemandCondition in Delay 1 CiD1)/CiD Delay

UNITS: Visits/Years/Years

CiD Correct 2 =

(Condition in Delay 1 CiD1+Essential RenegersCondition in Delay 2 CiD2)/CiD Delay

UNITS: Visits/Years/Years

CiD Delay = 1

UNITS: Years

CiD Nudge = GRAPH(CiD per Capita/Normal CiD per cap)

Points: (0.000, 0.0000), (0.100, 0.0357658231466), (0.200, 0.0659504691908), (0.300, 0.0912071358316), (0.400, 0.112189020768), (0.500, 0.128259641033), (0.600, 0.141822476773), (0.700, 0.153171028632), (0.800, 0.162598797255), (0.900, 0.169819792412), (1.000, 0.1760), (1.100, 0.181013200396), (1.200, 0.185249369906), (1.300, 0.188493972179), (1.400, 0.191232261489), (1.500, 0.193523494594), (1.600, 0.195426928251), (1.700, 0.19688482203), (1.800, 0.198115214729), (1.900, 0.199144732126), (2.000, 0.2000)

UNITS: Dimensionless

CiD per Capita = Condition in Delay 2 CiD2/Population

UNITS: Visits/Years/People

Cohort Sizing[1] = 20

UNITS: $Years^2$

Cohort Sizing[2] = 15

UNITS: $Years^2$

Cohort Sizing[3] = 15

UNITS: $Years^2$

Cohort Sizing[4] = 15

UNITS: $Years^2$

Cohort Sizing[5] = 15

UNITS: $Years^2$

Condition in Delay 1 CiD1(t) = Condition in Delay 1 CiD1(t - dt) + (CiD Correct 1) * dt NON-NEGATIVE

INIT Condition in Delay 1 CiD1 = Initial CiD1

UNITS: Visits/Years

Condition in Delay 2 CiD2(t) = Condition in Delay 2 CiD2(t - dt) + (CiD Correct 2) * dt NON-NEGATIVE

INIT Condition in Delay 2 CiD2 = Initial CiD2

UNITS: Visits/Years

Demand Coefficient = 10

UNITS: Visits/People/Years

Demand Distribution by Age[1] = 1

UNITS: dmnl

Demand Distribution by Age[2] = 1.5

UNITS: dmnl

Demand Distribution by Age[3] = 2

UNITS: dmnl

Demand Distribution by Age[4] = 4

UNITS: dmnl

Demand Distribution by Age[5] = 6

UNITS: dmnl

Effect of Income Elasticity of Demand on Demand Expression =

GRAPH(Income Elasticity of Demand/Normal IED)

Points: (0.000, 1.98661429815), (0.050, 1.98096761863), (0.100, 1.97532093911), (0.150, 1.96967425959), (0.200, 1.96402758008), (0.250, 1.94930774847), (0.300, 1.93458791686), (0.350, 1.91986808525), (0.400, 1.90514825364), (0.450, 1.86925972922), (0.500, 1.8333712048), (0.550, 1.79748268038), (0.600, 1.76159415596), (0.650, 1.68672490628), (0.700, 1.61185565661), (0.750, 1.53698640693), (0.800, 1.46211715726), (0.850, 1.34658786795), (0.900, 1.23105857863), (0.950, 1.11552928932), (1.000, 1.000), (1.050, 0.884470710685), (1.100, 0.76894142137), (1.150, 0.653412132055), (1.200, 0.53788284274), (1.250, 0.463013593066), (1.300, 0.388144343392), (1.350, 0.313275093718), (1.400,

0.238405844044), (1.450, 0.202517319622), (1.500, 0.1666287952), (1.550, 0.130740270777), (1.600, 0.0948517463551), (1.650, 0.0801319147474), (1.700, 0.0654120831397), (1.750, 0.0506922515319), (1.800, 0.0359724199242), (1.850, 0.0303257404053), (1.900, 0.0246790608864), (1.950, 0.0190323813675), (2.000, 0.0133857018486)

UNITS: Dimensionless

Effect of PHS on DF = GRAPH(Population Health Status PHS)

Points: (0.000, 2.23661429815), (0.0666666666667, 2.23088884254), (0.133333333333, 2.22335993652), (0.200, 2.21402758008), (0.266666666667, 2.19892621902), (0.333333333333, 2.17929977688), (0.400, 2.15514825364), (0.466666666667, 2.11723851119), (0.533333333333, 2.06938714529), (0.600, 2.01159415596), (0.666666666667, 1.92729735358), (0.733333333333, 1.82747168734), (0.800, 1.71211715726), (0.866666666667, 1.52470571909), (0.933333333333, 1.28733333333), (1.000, 1.000), (1.06666666667, 0.847333333333), (1.13333333333, 0.721333333333), (1.200, 0.622), (1.26666666667, 0.558666666667), (1.33333333333, 0.498333333333), (1.400, 0.441), (1.46666666667, 0.405666666667), (1.53333333333, 0.370333333333), (1.600, 0.335), (1.66666666667, 0.317416307668), (1.73333333333, 0.301073780977), (1.800, 0.285972419924), (1.86666666667, 0.276640063482), (1.93333333333, 0.269111157457), (2.000, 0.263385701849)

UNITS: Dimensionless

Effect of Price Distortion on Demand Expression =

GRAPH(Effective PD/Normal PD)

Points: (0.000, 0.500), (0.050, 0.501), (0.100, 0.502), (0.150, 0.505), (0.200, 0.508), (0.250, 0.520), (0.300, 0.532), (0.350, 0.544), (0.400, 0.556), (0.450, 0.572), (0.500, 0.588), (0.550, 0.604), (0.600, 0.620), (0.650, 0.648), (0.700, 0.676), (0.750, 0.7075), (0.800, 0.739), (0.850, 0.7905), (0.900, 0.842), (0.950, 0.921), (1.000, 1.000), (1.050, 1.1245), (1.100, 1.249), (1.150, 1.4005), (1.200, 1.552), (1.250, 1.63005958095), (1.300, 1.70811916191), (1.350, 1.75869724334), (1.400, 1.80927532476), (1.450, 1.84395111837), (1.500, 1.87862691197), (1.550, 1.90137275744), (1.600, 1.92411860292), (1.650, 1.93860951686), (1.700, 1.9531004308), (1.750, 1.96466124743), (1.800, 1.97622206406), (1.850, 1.98332147793), (1.900, 1.99042089179), (1.950, 1.9952104459), (2.000, 2.000)

UNITS: Dimensionless

Effective PD = IF MultiPayer Switch THEN Weighted Price Distortion ELSE Price Distortion

UNITS: Dimensionless

Elastic Demand by Age Cohort[PopAge] = Unit Elastic Demand by Age*(2-Population Health Status PHS)*Population by Age Group

UNITS: Visits/Years

Elastic Demand Expression Percentage =

MIN(Normal Demand Expression Percentage*Effect of Income Elasticity of Demand on Demand Expression*Effect of Price Distortion on Demand Expression, 1)

UNITS: Dimensionless

Elderly DF = Normal DF by PopAge[5]*((Effect of PHS on DF-1)*1.5+1)

UNITS: Per Year

Essential Renegers = Reneging VIW*"Essential/All"

"Essential/All" =

(Expressed Elastic Demand*Percentage of Essential Elastic Demand+Total Inelastic Demand)/Total Demand for Healthcare

Expressed Elastic Demand =

Total Elastic Demand*Elastic Demand Expression Percentage

UNITS: Visits/Years

"Expressed Non-Essential Elastic Demand" =

Expressed Elastic Demand*Percentage of Essential Elastic Demand

UNITS: Visits/Years

Inelastic Demand by Age Cohort[PopAge] = Unit Inelastic Demand by Age*(2-Population Health Status PHS)*Population by Age Group

UNITS: Visits/Years

Initial CiD1 = 37414771.1754

UNITS: Visits/Years

Initial CiD2 = 37414771.1754+19557721.2962

UNITS: Visits/Years

Initial PHS = 1

UNITS: Dimensionless

Juvelines DF = Normal DF by PopAge[1]*((Effect of PHS on DF-1)*0.7+1)

UNITS: Per Year

Life Expectancy = (1-Juvelines DF)*Cohort Sizing[1]+(1-

WF DF by Age[1])*Cohort Sizing[2] + (1-WF DF by Age[2])*Cohort Sizing[3]+ (1-

WF DF by Age[3])*Cohort Sizing[4] + (1-Elderly DF)*Cohort Sizing[5]

UNITS: Years

MultiPayer Switch = 0

UNITS: Dimensionless

Normal CiD per cap = Initial CiD2/INIT(Population)

UNITS: Visits/Years

Normal Demand Expression Percentage = 0.5

UNITS: Dimensionless

Normal DF by PopAge[1] = 0.0052

UNITS: Per Year

DOCUMENT: https://www.ssa.gov/oact/STATS/table4c6.html

https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?most recent value desc=false

Normal DF by PopAge[2] = 0.0015

UNITS: Per Year

DOCUMENT: https://www.ssa.gov/oact/STATS/table4c6.html

https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?most recent value desc=false

Normal DF by PopAge[3] = 0.0055

UNITS: Per Year

DOCUMENT: https://www.ssa.gov/oact/STATS/table4c6.html

https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?most recent value desc=false

Normal DF by PopAge[4] = 0.0118

UNITS: Per Year

DOCUMENT: https://www.ssa.gov/oact/STATS/table4c6.html

https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?most recent value desc=false

Normal DF by PopAge[5] = 0.0796

UNITS: Per Year

DOCUMENT: https://www.ssa.gov/oact/STATS/table4c6.html

https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?most recent value desc=false

Normal IED = -0.17

UNITS: Dimensionless

DOCUMENT:

https://www.rand.org/content/dam/rand/pubs/monograph reports/2005/MR1355.pdf

Normal PD = 0.35

UNITS: Dimensionless

Percentage of Essential Elastic Demand = 0.3

UNITS: Dimensionless

PHS CiD Adjustment = CiD Nudge*"PHS Dependent CiD-Ng Leveling"/"PHSCiD Delay"

UNITS: Per Year

"PHS Dependent CiD-Ng Leveling" = GRAPH(Population Health Status PHS)

Points: (0.000, 0.5000), (0.050, 0.5041), (0.100, 0.5082), (0.150, 0.514656115376), (0.200,

0.523712936589), (0.250, 0.537929090011), (0.300, 0.559601461011), (0.350,

0.591212761903), (0.400, 0.634470710685), (0.450, 0.688770334399), (0.500, 0.7500),

(0.550, 0.811229665601), (0.600, 0.865529289315), (0.650, 0.908787238097), (0.700,

0.940398538989), (0.750, 0.962070909989), (0.800, 0.976287063411), (0.850,

0.985343884624), (0.900, 0.991006895019), (0.950, 0.994506528685), (1.000, 1.0000)

UNITS: Dimensionless

"PHS Dependent Pr-Ng Leveling" = GRAPH(Population Health Status PHS)

Points: (1.000, 1.0000), (1.050, 0.996636913335), (1.100, 0.994170791723), (1.150,

0.989932941807), (1.200, 0.982721884857), (1.250, 0.970654912504), (1.300,

0.951015597851), (1.350, 0.920454026143), (1.400, 0.87606455572), (1.450,

0.817647424661), (1.500, 0.7500), (1.550, 0.682352575339), (1.600, 0.62393544428),

(1.650, 0.579545973857), (1.700, 0.548984402149), (1.750, 0.529345087496), (1.800,

0.517278115143), (1.850, 0.510067058193), (1.900, 0.505829208277), (1.950,

0.503363086665), (2.000, 0.5000)

UNITS: Dimensionless

PHS Provision Adjustment = (Provision Nudge*"PHS Dependent PrNg Leveling")/

"PHS-Provision Delay"

UNITS: Per Year

PHS Wealth Adjustment = Wealth Nudge/"PHS-Wealth Delay"*0

UNITS: Per Year

"PHS-CiD Delay" = 1

UNITS: Years

"PHS-Provision Delay" = 1

UNITS: Years

"PHS-Wealth Delay" = 1

UNITS: Years

Population Health Status PHS(t) = Population Health Status PHS(t - dt) +

(PHS Wealth Adjustment + PHS Provision Adjustment - PHS CiD Adjustment) * dt

NON-NEGATIVE

INIT Population Health Status PHS = Initial PHS

UNITS: Dimensionless

Provision Nudge = GRAPH(Visits Served/Normal Service Rate)

Points: (0.000, 0.0000), (0.100, 0.0357658231466), (0.200, 0.0659504691908), (0.300, 0.0912071358316), (0.400, 0.112189020768), (0.500, 0.128259641033), (0.600, 0.141822476773), (0.700, 0.153171028632), (0.800, 0.162598797255), (0.900, 0.169819792412), (1.000, 0.1760), (1.100, 0.181013200396), (1.200, 0.185249369906), (1.300, 0.188493972179), (1.400, 0.191232261489), (1.500, 0.193523494594), (1.600, 0.195426928251), (1.700, 0.19688482203), (1.800, 0.198115214729), (1.900, 0.199144732126), (2.000, 0.2000)

UNITS: Dimensionless

Total Demand for Healthcare = Total Elastic Demand+Total Inelastic Demand

UNITS: Visits/Years

Total Elastic Demand = SUM(Elastic Demand by Age Cohort)

UNITS: Visits/Years

Total Inelastic Demand = SUM(Inelastic Demand by Age Cohort)

UNITS: Visits/Years

Unexpressed Elastic Demand = Total Elastic Demand*(1-

Elastic Demand Expression Percentage)

UNITS: Visits/Years

Unexpressed Essential Elastic Demand =

Unexpressed Elastic Demand*Percentage of Essential Elastic Demand

UNITS: Visits/Years

Unit Elastic Demand by Age[PopAge] =

Demand Distribution by Age*Demand Coefficient

UNITS: Visits/People/Years

DOCUMENT: https://bmchealthservres.biomedcentral.com/articles/10.1186/s12913-020-05295-2/figures/2

Unit Inelastic Demand by Age[PopAge] =

Demand Distribution by Age*Demand Coefficient

UNITS: Visits/People/Years

DOCUMENT: https://bmchealthservres.biomedcentral.com/articles/10.1186/s12913-020-05295-2/figures/2

Wealth Nudge = GRAPH(Net Income/Reference NI)

Points: (0.000, -0.0986614298151), (0.100, -0.0978026114739), (0.200, -0.0964027580076), (0.300, -0.0941375538497), (0.400, -0.0905148253645), (0.500, -0.0848283639958), (0.600, -0.0761594155956), (0.700, -0.0635148952387), (0.800, -0.046211715726), (0.900, -0.0244918662404), (1.000, 0.0000), (1.100, 0.0244918662404), (1.200, 0.046211715726), (1.300, 0.0635148952387), (1.400, 0.0761594155956), (1.500, 0.0848283639958), (1.600, 0.0905148253645), (1.700, 0.0941375538497), (1.800, 0.0964027580076), (1.900, 0.0978026114739), (2.000, 0.0986614298151)

UNITS: Dimensionless

WF DF by Age[1] = Normal DF by PopAge[2]*Effect of PHS on DF

UNITS: Per Year

WF DF by Age[2] = Normal DF by PopAge[3]*Effect of PHS on DF

UNITS: Per Year

WF DF by Age[3] = Normal DF by PopAge[4]*Effect of PHS on DF

UNITS: Per Year

********** Healthcare Service: **********

Capacity Adjustment = Desired Adjustment/Capacity Adjustment Time UNIFLOW

UNITS: Hours/Years/Years

Capacity Adjustment Time = Normal CAT*Effect of Budget Shortfall on CAT

UNITS: Years

Capacity Building = Healthcare Capacity in Working Hours HC*CB fraction

UNIFLOW

UNITS: Hours/Years/Years

Capacity Erosion = Healthcare Capacity in Working Hours HC/Decay Delay

UNIFLOW

UNITS: Hours/Years/Years

Capacity Target = Perceived Demand PD*Standard Hours per Visit

UNITS: Hours/Years

Capacity Target Discrepancy = Capacity TargetHealthcare Capacity in Working Hours HC

UNITS: Hours/Years

CB fraction = 0

Decay Delay = 20

UNITS: Years

"Demand-Supply Delay" = Initial VIW/Normal Service Rate

UNITS: Years

Desired Adjustment = Capacity Target Discrepancy

UNITS: Hours/Years

Effect of Budget Shortfall on CAT =

GRAPH("Economic stress on Public Scheme (ES)")

Points: (0.000, 0.210708561479), (0.200, 0.228777935939), (0.400, 0.275881397084), (0.600, 0.390724675235), (0.800, 0.630306274192), (1.000, 1.000), (1.200, 1.36969372581), (1.400, 1.60927532476), (1.600, 1.72411860292), (1.800, 1.77122206406), (2.000, 1.78929143852)

UNITS: Dimensionless

Effect of Price Distortion on Demand[Plan] =

GRAPH("Price Distortion [Plan]"/Normal PD)

Points: (0.000, 0.0133857018486), (0.200, 0.0359724199242), (0.400, 0.0948517463551), (0.600, 0.238405844044), (0.800, 0.53788284274), (1.000, 1.000), (1.200, 1.46211715726), (1.400, 1.76159415596), (1.600, 1.90514825364), (1.800, 1.96402758008), (2.000, 1.98661429815)

UNITS: Dimensionless
Effect of Workload on HSR = GRAPH(Hours per Visit/Standard Hours per Visit)
Points: (0.000, 1.98661429815), (0.200, 1.96402758008), (0.400, 1.90514825364), (0.600, 1.76159415596), (0.800, 1.46211715726), (1.000, 1.000), (1.200, 0.53788284274), (1.400, 0.238405844044), (1.600, 0.0948517463551), (1.800, 0.0359724199242), (2.000, 0.0133857018486)
UNITS: Dimensionless
"Elastic Demand [Plan] Distribution"[Plan] =
Effect of Price Distortion on Demand*PH Distribution/SUM(Effect of Price Distortio n on Demand*PH Distribution)
UNITS: Dimensionless
"Estimated Visits [Plan]"[Plan] = Visits Served*(1-
"SupplyDelayed Elastic/Total Fraction")*PH Distribution+Visits Served*"Supply Delayed
Elastic/Total Fraction"*"Elastic Demand [Plan] Distribution"
UNITS: Visits/Years
Health Service Rate = Healthcare Capacity in Working Hours HC/Hours per Visit
UNITS: Visits/Years
Healthcare Capacity in Working Hours HC(t) =
Healthcare Capacity in Working Hours HC(t - dt) + (Capacity Adjustment + Capacity Building - Capacity Erosion) * dt NON-NEGATIVE
INIT Healthcare Capacity in Working Hours HC = Initial HC
UNITS: Hours/Years
Hours per Visit = GRAPH("Visit In-Waiting VIW"/Initial VIW)
Points: (0.000, 0.346221807613), (0.050, 0.345131403031), (0.100, 0.344040998449), (0.150, 0.342950593867), (0.200, 0.341860189286), (0.250, 0.339620684993), (0.300, 0.337381180699), (0.350, 0.335141676406), (0.400, 0.332902172113), (0.450, 0.328636854984), (0.500, 0.324371537854), (0.550, 0.320106220725), (0.600, 0.315840903596), (0.650, 0.308772244226), (0.700, 0.301703584856), (0.750, 0.294634925486), (0.800, 0.287566266117), (0.850, 0.278174699587), (0.900, 0.268783133058), (0.950, 0.259391566529), (1.000, 0.2500), (1.050, 0.240608433471), (1.100, 0.231216866942), (1.150, 0.221825300413), (1.200, 0.212433733883), (1.250,

0.205365074514), (1.300, 0.198296415144), (1.350, 0.191227755774), (1.400, 0.184159096404), (1.450, 0.179893779275), (1.500, 0.175628462146), (1.550, 0.171363145016), (1.600, 0.167097827887), (1.650, 0.164858323594), (1.700, 0.162618819301), (1.750, 0.160379315007), (1.800, 0.158139810714), (1.850, 0.157049406133), (1.900, 0.155959001551), (1.950, 0.154868596969), (2.000, 0.153778192387)

UNITS: Hours/Visits

Initial HC = 85033570.853182

UNITS: Hours/Years

Initial PD = 374147711.754

UNITS: Visits/Years

Initial VIW = 3401342834.1273

UNITS: Visits

Normal CAT = 2

UNITS: Years

Normal Service Rate = INIT(Health Service Rate)

UNITS: Visits/Years

PD Correction = ((Total Inelastic Demand+Expressed Elastic Demand)-Perceived Demand PD)/PD Info Delay

UNITS: Visits/Years/Years

PD Info Delay = 1

UNITS: Years

Perceived Demand PD(t) = Perceived Demand PD(t - dt) + (PD Correction) * dt NON-NEGATIVE

INIT Perceived Demand PD = Initial PD

UNITS: Visits/Years

Reneging Fraction = 0.01

UNITS: Per Year

Reneging VIW = "Visit In-Waiting VIW"*Reneging Fraction UNIFLOW OUTFLOW PRIORITY: 2

UNITS: Visits/Years

Standard Hours per Visit = 0.25

UNITS: Hours/Visits

"Supply-Delayed Elastic/Total Fraction" =

DELAY1(Elastic Demand Expression Percentage, "Demand-Supply Delay")

UNITS: Dimensionless

"Visit In-Waiting VIW"(t) = "Visit In-Waiting VIW"(t - dt) + (Visits Ordered - Visits Served - Reneging VIW) * dt NON-NEGATIVE

INIT "Visit In-Waiting VIW" = Initial VIW

UNITS: Visits

Visits Ordered = Total Inelastic Demand+Expressed Elastic Demand UNIFLOW

UNITS: Visits/Years

Visits Served = Health Service Rate UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: Visits/Years

Waiting TIme = "Visit In-Waiting VIW"/Visits Served

********** Population Sector: **********

Active Workyears[WfAge] = Formally Employed Workforce FEW*Year per Person UNIFLOW

UNITS: Dimensionless

Age Distribution[PopAge] =

Population by Age Group/SUM(Population by Age Group)

UNITS: Dimensionless

Births =

Population*(Crude Birth Rate*1+0*CBR time series down/1000+0*CBR time series up/1000) UNIFLOW

UNITS: People/Years

CBR time series down = GRAPH(TIME)

Points: (0.00, 15.913), (1.00, 15.0739686881), (2.00, 14.299445169), (3.00, 13.5844698478), (4.00, 12.9244644416), (5.00, 12.3152026624), (6.00, 11.7527831548), (7.00, 11.2336045138), (8.00, 10.7543422236), (9.00, 10.3119273693), (10.00, 9.90352698541), (11.00, 9.52652591518), (12.00, 9.17851006465), (13.00, 8.85725094422), (14.00, 8.56069139872), (15.00, 8.2869324346), (16.00, 8.03422105985), (17.00, 7.80093905889), (18.00, 7.5855926305), (19.00,

7.38680282231), (20.00, 7.20329670088), (21.00, 7.03389920052), (22.00, 6.8775255989), (23.00, 6.7331745711), (24.00, 6.59992177773), (25.00, 6.47691394596), (26.00, 6.36336340572), (27.00, 6.25854304589), (28.00, 6.16178165829), (29.00, 6.0724596397), (30.00, 5.99000502425), (31.00, 5.91388982089), (32.00, 5.84362663246), (33.00, 5.77876553467), (34.00, 5.71889119506), (35.00, 5.66362021343), (36.00, 5.61259866681), (37.00, 5.56549984311), (38.00, 5.52202214905), (39.00, 5.48188717896), (40.00, 5.44483793202), (41.00, 5.41063716654), (42.00, 5.37906588086), (43.00, 5.34992191098), (44.00, 5.32301863599), (45.00, 5.29818378307), (46.00, 5.27525832438), (47.00, 5.25409545871), (48.00, 5.23455967148), (49.00, 5.21652586695), (50.00, 5.19987856719)

CBR time series up = GRAPH(TIME)

Points: (0.00, 15.913), (1.00, 16.911273975), (2.00, 17.8002122158), (3.00, 18.5917896943), (4.00, 19.2966698262), (5.00, 19.9243481191), (6.00, 20.483280087), (7.00, 20.980995156), (8.00, 21.4241980933), (9.00, 21.8188593277), (10.00, 22.1702953786), (11.00, 22.4832404745), (12.00, 22.7619103287), (13.00, 23.0100589293), (14.00, 23.2310291098), (15.00, 23.4277975807), (16.00, 23.6030150287), (17.00, 23.7590418248), (18.00, 23.897979821), (19.00, 24.0217006641), (20.00, 24.1318710095), (21.00, 24.2299749725), (22.00, 24.3173341208), (23.00, 24.3951252779), (24.00, 24.4643963759), (25.00, 24.5260805723), (26.00, 24.5810088209), (27.00, 24.6299210654), (28.00, 24.6734762071), (29.00, 24.7122609818), (30.00, 24.7467978626), (31.00, 24.7775520993), (32.00, 24.804937985), (33.00, 24.8293244378), (34.00, 24.8510399697), (35.00, 24.8703771129), (36.00, 24.8875963598), (37.00, 24.9029296725), (38.00, 24.9165836075), (39.00, 24.9287420984), (40.00, 24.9395689333), (41.00, 24.9492099615), (42.00, 24.9577950582), (43.00, 24.9654398741), (44.00, 24.9722473933), (45.00, 24.9783093205), (46.00, 24.9837073164), (47.00, 24.9885140981), (48.00, 24.992794418), (49.00, 24.9966059369), (50.00, 25.000)

CE Deaths = Covered Elderly CE*Elderly DF UNIFLOW

UNITS: People/Years

CF Ratio = Contribution Fraction CF/Reference CF

UNITS: Dimensionless

CoA Lenght = 20

UNITS: Years

Cohort Age Means[1] = 10

UNITS: Years

Cohort Age Means[2] = 27.5

UNITS: Years

Cohort Age Means[3] = 42.5

UNITS: Years

Cohort Age Means[4] = 57.5

UNITS: Years

Cohort Age Means[5] = 72.5

UNITS: Years

Covered Elderly CE(t) = Covered Elderly CE(t - dt) + (Exit WF Covered[1] +

Exit WF Covered[2] + Exit WF Covered[3] - CE Deaths) * dt NON-NEGATIVE

INIT Covered Elderly CE = Initial CE

UNITS: People

Covered Fraction =

Covered Elderly CE/(Covered Elderly CE+Uncovered Elderly UE)

UNITS: Dimensionless

Crude Birth Rate = (15.913)/1000

UNITS: Per Year

DOCUMENT:

https://data.worldbank.org/indicator/SP.DYN.CBRT.IN?most recent value desc=false

Crude Death Rate = INIT(Total Deaths/Population)

UNITS: Per Year

Death Age Means[PopAge] =

Deaths by Age Group[PopAge]*Cohort Age Means[PopAge]

UNITS: People

Deaths by Age Group[1] = Juvenile Deaths

UNITS: People/Years

Deaths by Age Group[2] = WF1 Deaths

UNITS: People/Years

Deaths by Age Group[3] = WF2 Deaths

UNITS: People/Years

Deaths by Age Group[4] = WF3 Deaths

UNITS: People/Years

Deaths by Age Group[5] = Elder Deaths

UNITS: People/Years

Effect of CF on Formalization = GRAPH(CF Ratio)

Points: (0.000, 0.0493307149076), (0.100, 0.0489013057369), (0.200, 0.0482013790038), (0.300, 0.0470687769249), (0.400, 0.0452574126822), (0.500, 0.0424141819979), (0.600, 0.0380797077978), (0.700, 0.0317574476194), (0.800, 0.023105857863), (0.900, 0.0122459331202), (1.000, 0), (1.100, -0.0122459331202), (1.200, -0.023105857863), (1.300, -0.0317574476194), (1.400, -0.0380797077978), (1.500, -0.0424141819979), (1.600, -0.0452574126822), (1.700, -0.0470687769249), (1.800, -0.0482013790038), (1.900, -0.0489013057369), (2.000, -0.0493307149076)

UNITS: Per Year

Effective RA = IF MultiPayer Switch THEN INIT(Retirement YoW Requirement RA) ELSE Retirement YoW Requirement RA

UNITS: Years

Elder Deaths = CE Deaths + UE Deaths SUMMING CONVERTER

UNITS: People/Years

Elderly = Covered Elderly CE + Uncovered Elderly UE SUMMING CONVERTER

UNITS: People

Enter WF[1] = Juveniles JN/CoA Lenght UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: People/Years

Enter WF[2] = 0 UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: People/Years

Enter WF[3] = 0 UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: People/Years

Exit WF Covered[1] = 0 UNIFLOW

OUTFLOW PRIORITY: 2

UNITS: People/Years

Exit WF Covered[2] = 0 UNIFLOW

OUTFLOW PRIORITY: 2

UNITS: People/Years

Exit WF Covered[3] = Pensioners PS[3]/Years Per Cohort UNIFLOW

OUTFLOW PRIORITY: 2

UNITS: People/Years

Exit WF Uncovered[1] = 0 UNIFLOW

OUTFLOW PRIORITY: 5

UNITS: People/Years

Exit WF Uncovered[2] = 0 UNIFLOW

OUTFLOW PRIORITY: 5

UNITS: People/Years

Exit WF Uncovered[3] =

Unemployed Workforce in Job Market UW[3]/Years Per Cohort UNIFLOW

OUTFLOW PRIORITY: 5

UNITS: People/Years

"FER[Age]"[WfAge] = Formally Employed Workforce FEW/"WF[Age]"

UNITS: Dimensionless

FEW Aging[1] = -Formally Employed Workforce FEW[1]/Years Per Cohort

UNITS: People/Years

FEW Aging[2] = Formally Employed Workforce FEW[1]/Years Per Cohort-

Formally Employed Workforce FEW[2]/Years Per Cohort

UNITS: People/Years

FEW Aging[3] = Formally Employed Workforce FEW[2]/Years Per Cohort

UNITS: People/Years

FEW Deaths[WfAge] = Formally Employed Workforce FEW*WF DF by Age

UNIFLOW

OUTFLOW PRIORITY: 4

UNITS: People/Years

FEW Immigration[WfAge] = PULSE(FEWM Volume/3, Migration Start Time,
FEWM Frequency) UNIFLOW
UNITS: People/Years
FEW Uncovered Exit[1] = 0 UNIFLOW
OUTFLOW PRIORITY: 6
UNITS: People/Years
FEW Uncovered Exit[2] = 0 UNIFLOW
OUTFLOW PRIORITY: 6
UNITS: People/Years
FEW Uncovered Exit[3] = Formally Employed Workforce FEW[3]/Years Per Cohort
UNIFLOW
OUTFLOW PRIORITY: 6
UNITS: People/Years
FEWM Frequency = 100
UNITS: Years
FEWM Volume = 0
UNITS: People
Formal Employment Rate = Formally Employed/Workforce
UNITS: Dimensionless
Formal Employments & Layoffs[WfAge] =
Net Formal EL Fraction*Unemployed Workforce in Job Market UW
OUTFLOW PRIORITY: 2
UNITS: People/Years
Formal Retirement[WfAge] =
Formally Employed Workforce FEW*YoW Distribution/Effective RA UNIFLOW
OUTFLOW PRIORITY: 5
UNITS: People/Years
Formally Employed = SUM(Formally Employed Workforce FEW[*]) SUMMING
CONVERTER
UNITS: People
Formally Employed Workforce FEW[WfAge](t) =
Formally Employed Workforce FEW[WfAge](t - dt) +

(Formal Employments & Layoffs[WfAge] + FEW Aging[WfAge] +
Net Formalization[WfAge] + FEW Immigration[WfAge] - FEW Deaths[WfAge] -
Formal Retirement[WfAge] - FEW Uncovered Exit[WfAge]) * dt NON-NEGATIVE
INIT Formally Employed Workforce FEW[WfAge] = "Initial FEW[Age]"
UNITS: People
"IER[Age]"[WfAge] = Informally Employed Workforce IEW/"WF[Age]"
UNITS: Dimensionless
IEW Aging[1] = -Informally Employed Workforce IEW[1]/Years Per Cohort
UNITS: People/Years
IEW Aging[2] = Informally Employed Workforce IEW[1]/Years Per Cohort-
Informally Employed Workforce IEW[2]/Years Per Cohort
UNITS: People/Years
IEW Aging[3] = Informally Employed Workforce IEW[2]/Years Per Cohort
UNITS: People/Years
IEW Deaths[WfAge] = WF DF by Age*Informally Employed Workforce IEW
UNIFLOW
OUTFLOW PRIORITY: 2
UNITS: People/Years
Informal Employment Rate = Informally Employed/Workforce
UNITS: Dimensionless
Informal Employments & Layoffs[WfAge] =
Unemployed Workforce in Job Market UW*Net Informal EL Fraction
OUTFLOW PRIORITY: 4
UNITS: People/Years
Informal Retirement[1] = 0 UNIFLOW
OUTFLOW PRIORITY: 1
UNITS: People/Years
Informal Retirement[2] = 0 UNIFLOW
OUTFLOW PRIORITY: 1
UNITS: People/Years
Informal Retirement[3] = Informally Employed Workforce IEW[3]/Years Per Cohort
UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: People/Years

Informally Employed = SUM(Informally Employed Workforce IEW[*]) SUMMING

CONVERTER

UNITS: People

Informally Employed Workforce IEW[WfAge](t) =

Informally Employed Workforce IEW[WfAge](t - dt) +

(Informal Employments & Layoffs[WfAge] + IEW Aging[WfAge] -

Informal Retirement[WfAge] - IEW Deaths[WfAge] - Net Formalization[WfAge]) * dt

NON-NEGATIVE

INIT Informally Employed Workforce IEW[WfAge] = "Initial IEW[Age]"

UNITS: People

"Initial Age Distribution [PopAge]"[1] = 0.288272

UNITS: Dimensionless

"Initial Age Distribution [PopAge]"[2] = 0.211446

UNITS: Dimensionless

"Initial Age Distribution [PopAge]"[3] = 0.195332

UNITS: Dimensionless

"Initial Age Distribution [PopAge]"[4] = 0.165957

UNITS: Dimensionless

"Initial Age Distribution [PopAge]"[5] = 0.139

UNITS: Dimensionless

Initial CE = Initial E*Initial Covered Fraction

UNITS: People

Initial Covered Fraction = 0.237

UNITS: Dimensionless

Initial E = "Initial Age Distribution [PopAge]"[5]*Initial Pop

UNITS: People

"Initial FER[Age]"[1] = 0.518

UNITS: Dimensionless

"Initial FER[Age]"[2] = 0.626

UNITS: Dimensionless

"Initial FER[Age"[3] = 0.53

UNITS: Dimensionless

"Initial FEW[Age]"[WfAge] = "Initial WF[Age]"*"Initial FER[Age]"

UNITS: People

"Initial IER[Age]"[1] = 0.322

UNITS: Dimensionless

"Initial IER[Age]"[2] = 0.289

UNITS: Dimensionless

"Initial IER[Age]"[3] = 0.23

UNITS: Dimensionless

"Initial IEW[Age]"[WfAge] = "Initial WF[Age]"*"Initial IER[Age]"

UNITS: People

Initial JN = "Initial Age Distribution [PopAge]"[1]*Initial Pop

UNITS: People

"Initial PF[Age]"[1] = 0.021

UNITS: Dimensionless

"Initial PF[Age]"[2] = 0.0643

UNITS: Dimensionless

"Initial PF[Age]"[3] = 0.237

UNITS: Dimensionless

Initial Pop = 10^7

UNITS: People

"Initial PS[Age]"[WfAge] = "Initial WF[Age]"*"Initial PF[Age]"

UNITS: People

Initial UE = Initial E*(1-Initial Covered Fraction)

UNITS: People

"Initial UR[Age]"[1] = 0.14

UNITS: Dimensionless

"Initial UR[Age]"[2] = 0.0205

UNITS: Dimensionless

"Initial UR[Age]"[3] = 0.00322

UNITS: Dimensionless

"Initial UW[Age]"[WfAge] = "Initial WF[Age]"*"Initial UR[Age]"

UNITS: People

"Initial WF[Age]"[1] = Initial Pop*"Initial Age Distribution [PopAge]"[2]

UNITS: People

"Initial WF[Age]"[2] = Initial Pop*"Initial Age Distribution [PopAge]"[3]

UNITS: People

"Initial WF[Age]"[3] = Initial Pop*"Initial Age Distribution [PopAge]"[4]

UNITS: People

Initial YoW[1] = $1.58*10^7$

UNITS: Years

Initial YoW[2] = $31.8*10^6$

UNITS: Years Initial YoW[3] = $1.17*10^8$

UNITS: Years

JN Deaths = Juveniles JN*Juvelines DF UNIFLOW

OUTFLOW PRIORITY: 4

UNITS: People/Years

Juvenile = Juveniles JN SUMMING CONVERTER

UNITS: People

Juvenile Deaths = JN Deaths SUMMING CONVERTER

UNITS: People/Years

Juveniles JN(t) = Juveniles JN(t - dt) + (Births - Enter WF[1] - Enter WF[2] - Enter WF[3] - JN Deaths) * dt NON-NEGATIVE

INIT Juveniles JN = Initial JN

UNITS: People

Labor Force Participation Rate = Workforce/Population

UNITS: Dimensionless

LE = SUM(Death Age Means)/SUM(Deaths by Age Group)

UNITS: Years

Migration Start Time = 10

UNITS: Years

Net Formal EL Fraction = 0.21

UNITS: Per year

Net Formalization[WfAge] = IF NF Fraction+Effect of CF on Formalization > 0
THEN
Informally Employed Workforce IEW*(NF Fraction+Effect of CF on Formalization)
ELSE
Formally Employed Workforce FEW*(NF Fraction+Effect of CF on Formalization)
OUTFLOW PRIORITY: 3
UNITS: People/Years
Net Informal EL Fraction = 0.21
UNITS: Per Year
NF Fraction = 0.023
UNITS: Per Year
Pensioners PS[WfAge](t) = Pensioners PS[WfAge](t - dt) + (Formal Retirement[WfAge]
+ PS Aging[WfAge] - Exit WF Covered[WfAge] - PS Deaths[WfAge]) * dt NONNEG-
ATIVE
INIT Pensioners PS[WfAge] = "Initial PS[Age]"
UNITS: People
"PF[Age]"[WfAge] = Pensioners PS/"WF[Age]"
UNITS: Dimensionless
Population = Elderly + Juvenile + Workforce SUMMING CONVERTER
UNITS: People
Population by Age Group[1] = Juvenile
UNITS: People
Population by Age Group[2] = "WF[Age]"[1]
UNITS: People
Population by Age Group[3] = "WF[Age]"[2]
UNITS: People
Population by Age Group[4] = "WF[Age]"[3]
UNITS: People
Population by Age Group[5] = Elderly
UNITS: People
PS Aging[1] = -Pensioners PS[1]/Years Per Cohort
UNITS: People/Years

PS Aging[2] = Pensioners PS[1]/Years Per Cohort-Pensioners PS[2]/Years Per Cohort

UNITS: People/Years

PS Aging[3] = Pensioners PS[2]/Years Per Cohort

UNITS: People/Years

PS Deaths[WfAge] = Pensioners PS*WF DF by Age UNIFLOW

OUTFLOW PRIORITY: 3

UNITS: People/Years

Reference CF = 0.15

UNITS: Dimensionless

Total Deaths = CE Deaths + SUM(FEW Deaths[*]) + SUM(IEW Deaths[*]) +

JN Deaths + SUM(PS Deaths[*]) + UE Deaths + SUM(UW Deaths[*]) SUMMING

CONVERTER

UNITS: People/Years

UE Deaths = Elderly DF*Uncovered Elderly UE UNIFLOW

UNITS: People/Years

Uncovered Elderly UE(t) = Uncovered Elderly UE(t - dt) + (Informal Retirement[1] +

Informal Retirement[2] + Informal Retirement[3] + Exit WF Uncovered[1] +

Exit WF Uncovered[2] + Exit WF Uncovered[3] + FEW Uncovered Exit[1] +

FEW Uncovered Exit[2] + FEW Uncovered Exit[3] - UE Deaths) * dt NONNEGATIVE

INIT Uncovered Elderly UE = Initial UE

UNITS: People

Unemployed = SUM(Unemployed Workforce in Job Market UW[*]) SUMMING

CONVERTER

UNITS: People

Unemployed Workforce in Job Market UW[WfAge](t) =

Unemployed Workforce in Job Market UW[WfAge](t - dt) + (Enter WF[WfAge] +

UW Aging[WfAge] + UW Immigration[WfAge] - UW Deaths[WfAge] -

Formal Employments & Layoffs[WfAge] - Informal Employments & Layoffs[WfAge]

- Exit WF Uncovered[WfAge]) * dt NON-NEGATIVE

INIT Unemployed Workforce in Job Market UW[WfAge] = "Initial UW[Age]"

UNITS: People

Unemployment Rate = Unemployed/Workforce

UNITS: Dimensionless

"UR[Age"[WfAge] = Unemployed Workforce in Job Market UW/"WF[Age]"

UNITS: Dimensionless

UW Aging[1] = -Unemployed Workforce in Job Market UW[1]/Years Per Cohort

UNITS: People/Years

UW Aging[2] =

Unemployed Workforce in Job Market UW[1]/Years Per CohortUnemployed Workforce in Job Market UW[2]/Years Per Cohort

UNITS: People/Years

UW Aging[3] = Unemployed Workforce in Job Market UW[2]/Years Per Cohort

UNITS: People/Years

UW Deaths[WfAge] = WF DF by Age*Unemployed Workforce in Job Market UW

UNIFLOW

OUTFLOW PRIORITY: 1

UNITS: People/Years

UW Immigration[WfAge] = PULSE(UWM Volume/3, Migration Start Time,

UWM Frequency) UNIFLOW

UNITS: People/Years

UWM Frequency = 5

UNITS: Years

UWM Volume = 0

UNITS: People

WF Cohort 1 = Pensioners PS[1] + Unemployed Workforce in Job Market UW[1] +

Formally Employed Workforce FEW[1] + Informally Employed Workforce IEW[1]

SUMMING CONVERTER

UNITS: People

WF Cohort 2 = Pensioners PS[2] + Unemployed Workforce in Job Market UW[2] +

Formally Employed Workforce FEW[2] + Informally Employed Workforce IEW[2]

SUMMING CONVERTER

UNITS: People

WF Cohort 3 = Pensioners PS[3] + Unemployed Workforce in Job Market UW[3] +

Formally Employed Workforce FEW[3] + Informally Employed Workforce IEW[3]

SUMMING CONVERTER

UNITS: People

WF1 Deaths = FEW Deaths[1] + IEW Deaths[1] + PS Deaths[1] + UW Deaths[1]

SUMMING CONVERTER

UNITS: People/Years

WF2 Deaths = FEW Deaths[2] + IEW Deaths[2] + PS Deaths[2] + UW Deaths[2]

SUMMING CONVERTER

UNITS: People/Years

WF3 Deaths = FEW Deaths[3] + IEW Deaths[3] + PS Deaths[3] + UW Deaths[3]

SUMMING CONVERTER

UNITS: People/Years

"WF[Age]"[1] = WF Cohort 1

UNITS: People

"WF[Age]"[2] = WF Cohort 2

UNITS: People

"WF[Age]"[3] = WF Cohort 3

UNITS: People

Withdrawal from WF[WfAge] = Formal Retirement*YoW per FWE UNIFLOW

UNITS: Dimensionless

Workforce = SUM(Pensioners PS[*]) +

SUM(Unemployed Workforce in Job Market UW[*]) +

SUM(Formally Employed Workforce FEW[*]) +

SUM(Informally Employed Workforce IEW[*]) SUMMING CONVERTER

UNITS: People

Year per Person = 1

UNITS: 1/People

Years of Work YoW[WfAge](t) = Years of Work YoW[WfAge](t - dt) +

(Active Workyears[WfAge] + YoW Aging[WfAge] - Withdrawal from WF[WfAge]) *

dt NON-NEGATIVE

INIT Years of Work YoW[WfAge] = Initial YoW

UNITS: Years

Years Per Cohort = 15

UNITS: Years

YoW Aging[1] = -Years of Work YoW[1]/Years Per Cohort

UNITS: Dimensionless

YoW Aging[2] =

Years of Work YoW[1]/Years Per CohortYears of Work YoW[2]/Years Per Cohort

UNITS: Dimensionless

YoW Aging[3] = Years of Work YoW[2]/Years Per Cohort

UNITS: Dimensionless

YoW Distribution[WfAge] = YoW per FWE/SUM(YoW per FWE)

UNITS: Dimensionless

YoW per FWE[WfAge] = Years of Work YoW/Formally Employed Workforce FEW

UNITS: Years/People

********** Private Insurance: **********

Affordability Index[Plan] = GRAPH("Premium PR [Plan]"/Reference Premium)

Points: (0.000, 1.98661429815), (0.100, 1.97802611474), (0.200, 1.96402758008), (0.300, 1.9413755385), (0.400, 1.90514825364), (0.500, 1.84828363996), (0.600, 1.76159415596), (0.700, 1.63514895239), (0.800, 1.46211715726), (0.900, 1.2449186624), (1.000, 1.000), (1.100, 0.755081337596), (1.200, 0.53788284274), (1.300, 0.364851047613), (1.400, 0.238405844044), (1.500, 0.151716360042), (1.600, 0.0948517463551), (1.700, 0.0586244615027), (1.800, 0.0359724199242), (1.900, 0.0219738852612), (2.000, 0.0133857018486)

UNITS: Dimensionless

Attractiveness Index[Plan] = GRAPH("Price Distortion [Plan]"/Normal PD)

Points: (0.000, 0.260039276386), (0.0666666666667, 0.263973939018), (0.133333333333, 0.269430591296), (0.200, 0.276979314943), (0.266666666667, 0.287386639971), (0.333333333333, 0.301667793499), (0.400, 0.321138809766), (0.466666666667, 0.347453753693), (0.533333333333, 0.382599515811), (0.600, 0.428804383033), (0.666666666667, 0.488303657321), (0.733333333333, 0.562912790989), (0.800, 0.653412132055), (0.866666666667, 0.758865446851), (0.933333333333, 0.876144690307), (1.000, 1.000), (1.06666666667, 1.12385530969), (1.13333333333, 1.24113455315), (1.200, 1.34658786795), (1.26666666667, 1.43708720901), (1.33333333333, 1.51169634268), (1.400, 1.57119561697),

(1.46666666667, 1.61740048419), (1.53333333333, 1.65254624631), (1.600, 1.67886119023), (1.66666666667, 1.6983322065), (1.73333333333, 1.71261336003), (1.800, 1.72302068506), (1.86666666667, 1.7305694087), (1.93333333333, 1.73602606098), (2.000, 1.73996072361)
UNITS: Dimensionless
"Copayment Level CP [Plan]"[Generous](t) =
"Copayment Level CP [Plan]"[Generous](t - dt) + (CP Adjustment[Generous]) * dt
INIT "Copayment Level CP [Plan]"[Generous] = 0.5
UNITS: Dimensionless
"Copayment Level CP [Plan]"[Modest](t) = "Copayment Level CP [Plan]"[Modest](t - dt) + (CP Adjustment[Modest]) * dt
INIT "Copayment Level CP [Plan]"[Modest] = 0.5
UNITS: Dimensionless
"Coverage Level CL [Plan]"[Generous](t) = "Coverage Level CL [Plan]"[Generous](t - dt) + (CV Adjustment[Generous]) * dt
INIT "Coverage Level CL [Plan]"[Generous] = 0.8
UNITS: Dimensionless
"Coverage Level CL [Plan]"[Modest](t) = "Coverage Level CL [Plan]"[Modest](t - dt) + (CV Adjustment[Modest]) * dt
INIT "Coverage Level CL [Plan]"[Modest] = 0.4
UNITS: Dimensionless
CP Adjustment[Plan] = 0
UNITS: Per Year
CV Adjustment[Plan] = 0
UNITS: Per Year
Desired Crude Profit[Plan] = INIT("Payer Profit [Plan]")
UNITS: US Dollar Per Year
"Economic Stress on [Plan]"[Plan] =
GRAPH(SMTH1("Payer Profit [Plan]"/Desired Crude Profit, Smoothing Factor))
Points: (0.000, 1.9413755385), (0.0666666666667, 1.92653481866), (0.133333333333, 1.9081150005), (0.200, 1.8853516482), (0.266666666667, 1.85737049587), (0.333333333333, 1.82320064559), (0.400, 1.78180635761), (0.466666666667,

1.73214422335), (0.533333333333, 1.67325152097), (0.600, 1.60436777712), (0.666666666667, 1.52508394331), (0.733333333333, 1.43550211392), (0.800, 1.33637554434), (0.866666666667, 1.22918899654), (0.933333333333, 1.11614021175), (1.000, 1.000), (1.06666666667, 0.883859788252), (1.13333333333, 0.770811003465), (1.200, 0.663624455664), (1.26666666667, 0.564497886085), (1.33333333333, 0.474916056688), (1.400, 0.395632222883), (1.46666666667, 0.326748479027), (1.53333333333, 0.267855776648), (1.600, 0.218193642391), (1.66666666667, 0.176799354414), (1.73333333333, 0.14262950413), (1.800, 0.114648351798), (1.86666666667, 0.0918849994957), (1.93333333333, 0.0734651813441), (2.000, 0.0586244615027)

UNITS: Dimensionless

"Effect of ES on Premium [Plan]"[Plan] = GRAPH("Economic Stress on [Plan]")

Points: (0.000, 0.950669285092), (0.100, 0.951098694263), (0.200, 0.951798620996), (0.300, 0.952931223075), (0.400, 0.954742587318), (0.500, 0.957585818002), (0.600, 0.961920292202), (0.700, 0.968242552381), (0.800, 0.976894142137), (0.900, 0.98775406688), (1.000, 1.0000), (1.100, 1.01224593312), (1.200, 1.02310585786), (1.300, 1.03175744762), (1.400, 1.0380797078), (1.500, 1.042414182), (1.600, 1.04525741268), (1.700, 1.04706877692), (1.800, 1.048201379), (1.900, 1.04890130574), (2.000, 1.04933071491)

UNITS: Dimensionless

Eligible Population = Elderly + Workforce SUMMING CONVERTER

UNITS: People

Expected PH Distribution[Plan] =

Attractiveness Index*Affordability Index/SUM(Attractiveness Index*Affordability Index) UNITS: Dimensionless

"Expected Policy Holders [Plan]"[Plan] =

Expected PH Distribution*Eligible Population

UNITS: People

"Indicated Premium [Plan]"[Plan] =

"Effect of ES on Premium [Plan]"*"Premium PR [Plan]"

UNITS: US Dollars/Years/People

"OOP [Plan]"[Plan] = (1-"Price Distortion [Plan]")*"Total Visit Cost [Plan]"

UNITS: US Dollars/Years

"Payer Expenditure [Plan"[Plan] = "Total Visit Cost [Plan]"*"Price Distortion [Plan]"

UNITS: US Dollar Per Year

"Payer Profit [Plan]"[Plan] = "Payer Revenue [Plan]"-"Payer Expenditure [Plan]"

UNITS: US Dollar Per Year

"Payer Revenue [Plan]"[Plan] =

"Premium PR [Plan]"*SUM("Policy Holders PH [Plan]")

UNITS: US Dollars/Year

PH Distribution[Plan] = "Policy Holders PH [Plan]"/Eligible Population

UNITS: Dimensionless

Plan Change[Plan] = ("Policy Holders PH [Plan]"-

"Expected Policy Holders [Plan]")/Plan Change Delay

UNITS: People/Years

Plan Change Delay = 2

UNITS: Years

"Policy Holders PH [Plan]"[Generous](t) = "Policy Holders PH [Plan]"[Generous](t - dt) + (- Plan Change[Generous]) * dt NON-NEGATIVE

INIT "Policy Holders PH [Plan]"[Generous] = Eligible Population*0.35

UNITS: People

"Policy Holders PH [Plan]"[Modest](t) = "Policy Holders PH [Plan]"[Modest](t - dt) + (- Plan Change[Modest]) * dt NON-NEGATIVE

INIT "Policy Holders PH [Plan]"[Modest] = Eligible Population*0.65

UNITS: People

PR Adjustment[Plan] = ("Indicated Premium [Plan]"-

"Premium PR [Plan]")/PR Adjustment Delay

UNITS: US Dollars/Years/People/Years

PR Adjustment Delay = 1

UNITS: Years

"Premium PR [Plan]"[Generous](t) = "Premium PR [Plan]"[Generous](t - dt) + (PR Adjustment[Generous]) * dt

INIT "Premium PR [Plan]"[Generous] = 2000

UNITS: US Dollars/Years/People

"Premium PR [Plan]"[Modest](t) = "Premium PR [Plan]"[Modest](t - dt) +
(PR Adjustment[Modest]) * dt
INIT "Premium PR [Plan]"[Modest] = 1000
UNITS: US Dollars/Years/People
"Price Distortion [Plan]"[Plan] = "Coverage Level CL [Plan]"*(1-
"Copayment Level CP [Plan]")
UNITS: Dimensionless
Reference Premium = 1500
UNITS: US Dollars/Years/People
Smoothing Factor = 1
UNITS: Years
"Total Visit Cost [Plan]"[Plan] = "Estimated Visits [Plan]"*Unit Visit Cost
UNITS: US Dollar Per Year
Weighted Price Distortion =
("Price Distortion [Plan]"[1]*"Policy Holders PH [Plan]"[1]+"Price Distortion [Plan]"[
2]*"Policy Holders PH [Plan]"[2])/SUM("Policy Holders PH [Plan]")
UNITS: Dimensionless
********** Public Scheme: **********
Base Scenario UVC = 40.2904825336
UNITS: US Dollars/Visits
Budget Shortfall = Desired Fund Level-Healthcare Fund HF
UNITS: US Dollars
CF Adjustment = (Indicated CF-Contribution Fraction CF)/Policy Adjustment Delay
UNITS: Per Year
CL Adjustment = (Indicated CL-Coverage Level CL)/Micro PAD
UNITS: Per Year
Contribution Fraction CF(t) = Contribution Fraction CF(t - dt) + (CF Adjustment) *
dt
NON-NEGATIVE
INIT Contribution Fraction CF = Initial CF
UNITS: Dimensionless
Contributions = Total Taxable Income*Contribution Fraction CF UNIFLOW

UNITS: US Dollars Per Year

"Cost-sharing Level CS"(t) = "Cost-sharing Level CS"(t - dt) + (CS Adjustment) * dt NON-NEGATIVE

INIT "Cost-sharing Level CS" = Initial CS

UNITS: Dimensionless

Coverage Level CL(t) = Coverage Level CL(t - dt) + (CL Adjustment) * dt NONNEGATIVE

INIT Coverage Level CL = Initial CL

UNITS: Dimensionless

CS Adjustment = (Indicated CS-"Cost-sharing Level CS")/Micro PAD

UNITS: Per Year

Desired Fund Level = Initial HF

UNITS: US Dollars

"Economic stress on Public Scheme (ES)" =

GRAPH(Budget Shortfall/Desired Fund Level)

Points: (-1.000, 0.109362634432), (-0.933333333333, 0.130750666851), (-0.866666666667, 0.155976470259), (-0.800, 0.185585906234), (-0.733333333333, 0.220145148725), (-0.666666666667, 0.260216948726), (-0.600, 0.30632743153), (-0.533333333333, 0.358923038815), (-0.466666666667, 0.418318730426), (-0.400, 0.484640721993), (-0.333333333333, 0.557769643954), (-0.266666666667, 0.637292532422), (-0.200, 0.722473649702), (-0.133333333333, 0.812253794132), (-0.0666666666667, 0.905284763714), (0.000, 1.000), (0.0666666666667, 1.09471523629), (0.133333333333, 1.18774620587), (0.200, 1.2775263503), (0.266666666667, 1.36270746758), (0.333333333333, 1.44223035605), (0.400, 1.51535927801), (0.466666666667, 1.58168126957), (0.533333333333, 1.64107696119), (0.600, 1.69367256847), (0.666666666667, 1.73978305127), (0.733333333333, 1.77985485127), (0.800, 1.81441409377), (0.866666666667, 1.84402352974), (0.933333333333, 1.86924933315), (1.000, 1.89063736557)

UNITS: Dimensionless

Effect of ES on CF = GRAPH("Economic stress on Public Scheme (ES)")

Points: (0.000, 0.901338570185), (0.050, 0.901715497083), (0.100, 0.902197388526), (0.150, 0.902812725409), (0.200, 0.903597241992), (0.250, 0.904595473982), (0.300,

0.90586244615), (0.350, 0.907465377469), (0.400, 0.909485174636), (0.450, 0.912017330035), (0.500, 0.915171636004), (0.550, 0.91906989298), (0.600, 0.923840584404), (0.650, 0.929609439606), (0.700, 0.936485104761), (0.750, 0.944540027765), (0.800, 0.953788284274), (0.850, 0.964164260165), (0.900, 0.97550813376), (0.950, 0.987564699823), (1.000, 1.0000), (1.050, 1.01243530018), (1.100, 1.02449186624), (1.150, 1.03583573984), (1.200, 1.04621171573), (1.250, 1.05545997223), (1.300, 1.06351489524), (1.350, 1.07039056039), (1.400, 1.0761594156), (1.450, 1.08093010702), (1.500, 1.084828364), (1.550, 1.08798266997), (1.600, 1.09051482536), (1.650, 1.09253462253), (1.700, 1.09413755385), (1.750, 1.09540452602), (1.800, 1.09640275801), (1.850, 1.09718727459), (1.900, 1.09780261147), (1.950, 1.09828450292), (2.000, 1.09866142982)

UNITS: Dimensionless

Effect of ES on CL = GRAPH("Economic stress on Public Scheme (ES)")

Points: (0.000, 1.09866142982), (0.050, 1.09828450292), (0.100, 1.09780261147), (0.150, 1.09718727459), (0.200, 1.09640275801), (0.250, 1.09540452602), (0.300, 1.09413755385), (0.350, 1.09253462253), (0.400, 1.09051482536), (0.450, 1.08798266997), (0.500, 1.084828364), (0.550, 1.08093010702), (0.600, 1.0761594156), (0.650, 1.07039056039), (0.700, 1.06351489524), (0.750, 1.05545997223), (0.800, 1.04621171573), (0.850, 1.03583573984), (0.900, 1.02449186624), (0.950, 1.01243530018), (1.000, 1.0000), (1.050, 0.987564699823), (1.100, 0.97550813376), (1.150, 0.964164260165), (1.200, 0.953788284274), (1.250, 0.944540027765), (1.300, 0.936485104761), (1.350, 0.929609439606), (1.400, 0.923840584404), (1.450, 0.91906989298), (1.500, 0.915171636004), (1.550, 0.912017330035), (1.600, 0.909485174636), (1.650, 0.907465377469), (1.700, 0.90586244615), (1.750, 0.904595473982), (1.800, 0.903597241992), (1.850, 0.902812725409), (1.900, 0.902197388526), (1.950, 0.901715497083), (2.000, 0.901338570185)

UNITS: Dimensionless

Effect of ES on CS = GRAPH("Economic stress on Public Scheme (ES)")

Points: (0.000, 0.901338570185), (0.050, 0.901715497083), (0.100, 0.902197388526), (0.150, 0.902812725409), (0.200, 0.903597241992), (0.250, 0.904595473982), (0.300, 0.90586244615), (0.350, 0.907465377469), (0.400, 0.909485174636), (0.450, 0.912017330035), (0.500, 0.915171636004), (0.550, 0.91906989298), (0.600,

0.923840584404), (0.650, 0.929609439606), (0.700, 0.936485104761), (0.750, 0.944540027765), (0.800, 0.953788284274), (0.850, 0.964164260165), (0.900, 0.97550813376), (0.950, 0.987564699823), (1.000, 1.0000), (1.050, 1.01243530018), (1.100, 1.02449186624), (1.150, 1.03583573984), (1.200, 1.04621171573), (1.250, 1.05545997223), (1.300, 1.06351489524), (1.350, 1.07039056039), (1.400, 1.0761594156), (1.450, 1.08093010702), (1.500, 1.084828364), (1.550, 1.08798266997), (1.600, 1.09051482536), (1.650, 1.09253462253), (1.700, 1.09413755385), (1.750, 1.09540452602), (1.800, 1.09640275801), (1.850, 1.09718727459), (1.900, 1.09780261147), (1.950, 1.09828450292), (2.000, 1.09866142982)

UNITS: Dimensionless

Effect of ES on RA = GRAPH("Economic stress on Public Scheme (ES)")

Points: (0.000, 0.901338570185), (0.050, 0.901903238137), (0.100, 0.902467906089), (0.150, 0.903032574041), (0.200, 0.903597241992), (0.250, 0.905069225153), (0.300, 0.906541208314), (0.350, 0.908013191475), (0.400, 0.909485174636), (0.450, 0.913074027078), (0.500, 0.91666287952), (0.550, 0.920251731962), (0.600, 0.923840584404), (0.650, 0.931327509372), (0.700, 0.938814434339), (0.750, 0.946301359307), (0.800, 0.953788284274), (0.850, 0.965341213205), (0.900, 0.976894142137), (0.950, 0.988447071069), (1.000, 1.0000), (1.050, 1.01155292893), (1.100, 1.02310585786), (1.150, 1.03465878679), (1.200, 1.04621171573), (1.250, 1.05369864069), (1.300, 1.06118556566), (1.350, 1.06867249063), (1.400, 1.0761594156), (1.450, 1.07974826804), (1.500, 1.08333712048), (1.550, 1.08692597292), (1.600, 1.09051482536), (1.650, 1.09198680853), (1.700, 1.09345879169), (1.750, 1.09493077485), (1.800, 1.09640275801), (1.850, 1.09696742596), (1.900, 1.09753209391), (1.950, 1.09809676186), (2.000, 1.09866142982)

UNITS: Dimensionless

GC = 10^9 UNIFLOW

GC Discrete Switch = 1

UNITS: Dimensionless

GC Initial = 0

UNITS: Years

GC Interval = 1

UNITS: Years

GC Volume = 0

UNITS: USD

Government Contributions = PULSE(GC Volume, GC Initial,

GC Interval)*GC Discrete Switch+HF Boost UNIFLOW

UNITS: US Dollars/Years

Healthcare Fund HF(t) = Healthcare Fund HF(t - dt) + (Contributions +

Government Contributions - PS Expenditure) * dt

INIT Healthcare Fund HF = Initial HF

UNITS: US Dollars

HF Boost = HF Buffer*0 UNIFLOW

HF Buffer(t) = HF Buffer(t - dt) + (GC - HF Boost) * dt NON-NEGATIVE

INIT HF Buffer = $2*10^9$

Indicated CF = MIN(Contribution Fraction CF*Effect of ES on CF, 1)

UNITS: Dimensionless

Indicated CL = MIN(Coverage Level CL*Effect of ES on CL, 1)

UNITS: Dimensionless

Indicated CS = MIN("Cost-sharing Level CS"*Effect of ES on CS, 1)

UNITS: Dimensionless

Indicated RA = MIN(Retirement YoW Requirement RA*Effect of ES on RA, 60)

UNITS: Years

Initial CF = 0.15

UNITS: Dimensionless

Initial CL = 0.50

UNITS: Dimensionless

Initial CS = 0.30

UNITS: Dimensionless

Initial HF = $2*5.4*10^9$ UNITS: US Dollars

Initial RA = 30

UNITS: Years

Micro PAD = Policy Adjustment Delay

UNITS: Years

OOP Payments = (1-Price Distortion)*Total Visit Cost

UNITS: US Dollars/Years

Policy Adjustment Delay = 3

UNITS: Years

Price Distortion = Coverage Level CL*(1-"Cost-sharing Level CS")

UNITS: Dimensionless

PS Expenditure = Price Distortion*Total Visit Cost UNIFLOW

UNITS: US Dollars Per Year

RA Adjustment = (Indicated RARetirement YoW Requirement RA)/Policy Adjustment Delay

UNITS: Dimensionless

Retirement YoW Requirement RA(t) = Retirement YoW Requirement RA(t - dt) + (RA Adjustment) * dt NON-NEGATIVE

INIT Retirement YoW Requirement RA = Initial RA

UNITS: Years

Total Taxable Income =

Household income HI*SUM(Formally Employed Workforce FEW)

UNITS: US Dollars/Years

Total Visit Cost = Visits Served*Unit Visit Cost

UNITS: US Dollars/Years

Unit Visit Cost = 40.2904825336

UNITS: US Dollars/Visits

********** Socioeconomics: **********

Disability Adjusted Life Years =

"YLL (Years of Life Lost)"+"YLD (Years Lived with Disability/Disease)"

UNITS: Years

Disturbance = PULSE(0, 20, 100)

UNITS: US Dollars/Years/People/Years

"Earn/Loss per Day" = 5

UNITS: US Dollars / Days / People

Effect of NI on IED = GRAPH(Net Income/Reference NI)

Points: (0.000, 1.98105791284), (0.200, 1.95267884369), (0.400, 1.88426608945), (0.600,

1.7305938961), (0.800, 1.43415057099), (1.000, 1.000), (1.200, 0.565849429014), (1.400, 0.269406103904), (1.600, 0.115733910553), (1.800, 0.0473211563109), (2.000, 0.0189420871639)
UNITS: Dimensionless
Health Spending = IF MultiPayer Switch THEN SUM("Payer Revenue [Plan]") ELSE Contributions+OOP Payments
UNITS: US Dollars/Years
Health Spending Health Spending per capita = Health Spending/Population
UNITS: US Dollars/People/Years
Household income HI(t) = Household income HI(t - dt) + (Income Production - Disturbance) * dt NON-NEGATIVE
INIT Household income HI = Reference HI
UNITS: US Dollars/Years/People
Income Elasticity of Demand = Initial PED*Effect of NI on IED
UNITS: Dimensionless
Income Production =
(Productive Time PTProductive Time Stagnancy Cutoff)*"Earn/Loss per Day"/IP Delay
UNITS: US Dollars/Years/People/Years
"Indicated Illness-Avoidance" = GRAPH(Population Health Status PHS)
Points: (0.000, 1.000), (0.200, 0.726149037074), (0.400, 0.527292424043), (0.600, 0.382892885975), (0.800, 0.278037300453), (1.000, 0.200), (1.200, 0.14660696213), (1.400, 0.106458504379), (1.600, 0.0773047404433), (1.800, 0.0561347628341), (2.000, 0.0407622039784)
UNITS: Dimensionless
Indicated ST = "Indicated Illness-Avoidance"*Sigma
UNITS: Days/Years
Initial PED = -0.17
UNITS: Dimensionless
DOCUMENT:
https://www.rand.org/content/dam/rand/pubs/monograph reports/2005/MR1355.pdf
IP Delay = 10
UNITS: Years

MAX LE = 100

UNITS: Years

Net Income = Household income HI-Taxes-Health Spending per capita

UNITS: US Dollars/People/Years

Other Tax Percentage = 0.25

UNITS: Dimensionless

Productive Time PT(t) = Productive Time PT(t - dt) + (- Timing) * dt NONNEGATIVE

INIT Productive Time PT = 365*0.8

UNITS: Days/Years

Productive Time Stagnancy Cutoff = SMTH3(Productive Time PT, 50,

Reference Productive Time)

UNITS: Days/Years

Reference HI = 10000

UNITS: US Dollars/Years/People

Reference NI = INIT(Net Income)

UNITS: US Dollars/Years/People

Reference Productive Time = 365*0.8

UNITS: Days/Years

Sick Time ST(t) = Sick Time ST(t - dt) + (Timing) * dt NON-NEGATIVE

INIT Sick Time ST = 365*0.2

UNITS: Days/Years

Sigma = 365

UNITS: Days/Years

Taxes = Household income HI*Other Tax Percentage

UNITS: US Dollars/People/Years

Timing = (Indicated ST-Sick Time ST)/Timing Adjustment Delay

UNITS: Days/Years/Years

Timing Adjustment Delay = 1

UNITS: Years

"YLD (Years Lived with Disability/Disease)" =

(Sick Time ST/Sigma)*Life Expectancy

UNITS: Years

"YLL (Years of Life Lost)" = MAX LE-Life Expectancy

UNITS: Years

The model has 292 (460) variables (array expansion in parens). In root model and 0 additional modules with 6 sectors. Stocks: 27 (41) Flows: 54 (102) Converters: 211 (317) Constants: 77 (109) Equations: 188 (310) Graphicals: 26 (31). There are also 26 expanded macro variables.

APPENDIX B: GRAPHICAL EFFECT FUNCTIONS

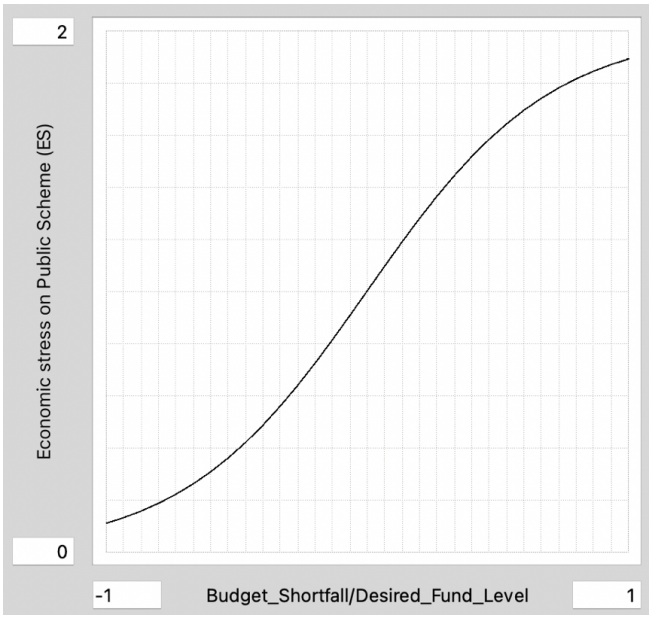

Figure B.1. Economic Stress on Public Scheme graphical function (dimensionless).

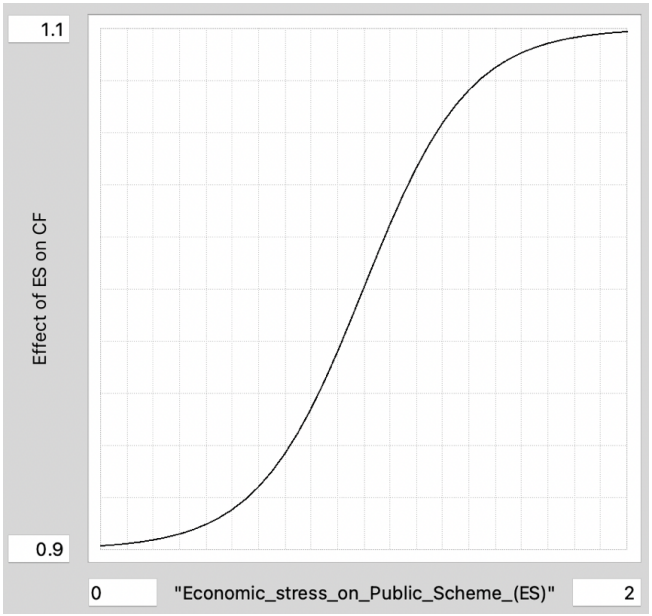

Figure B.2. Effect of Economic Stress on Contribution Fraction graphical function (dimensionless).

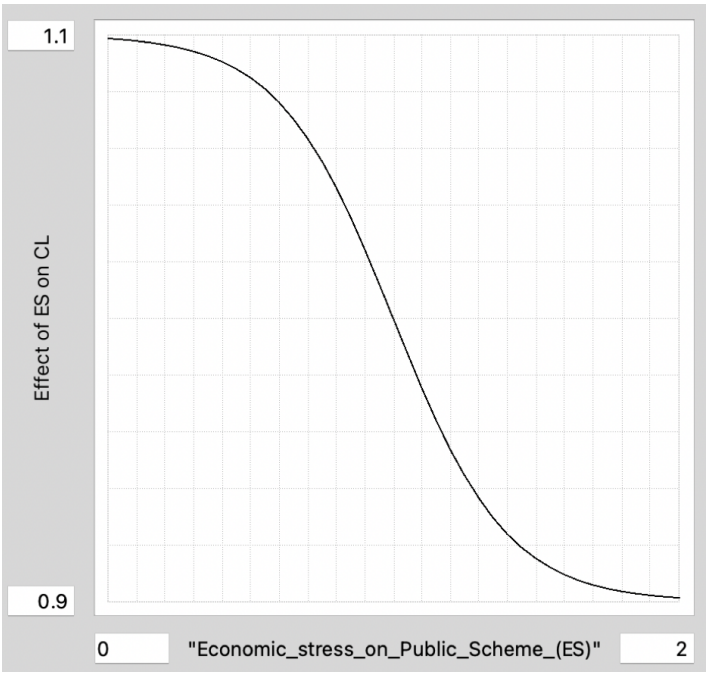

Figure B.3. Effect of Economic Stress on Coverage Level graphical function (dimensionless).

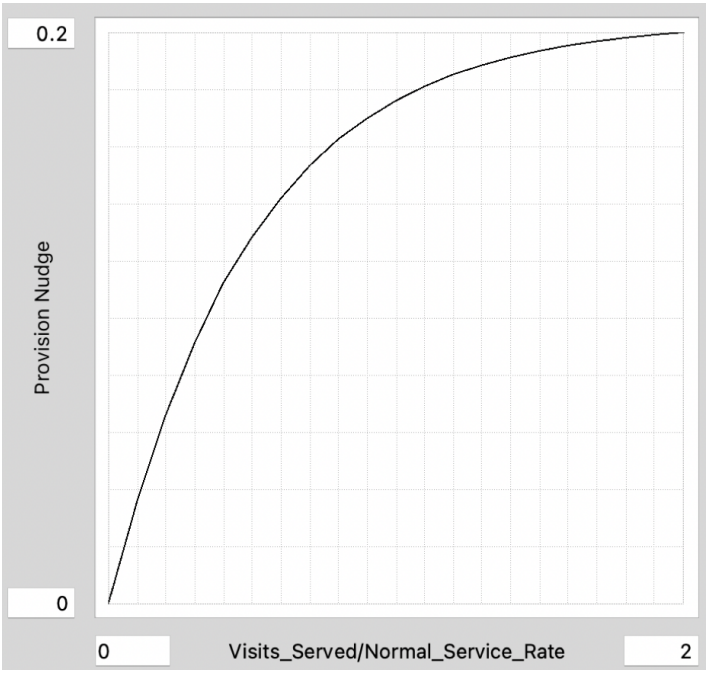

Figure B.4. Effect of Economic Stress on Cost-Sharing Level graphical function (dimensionless).

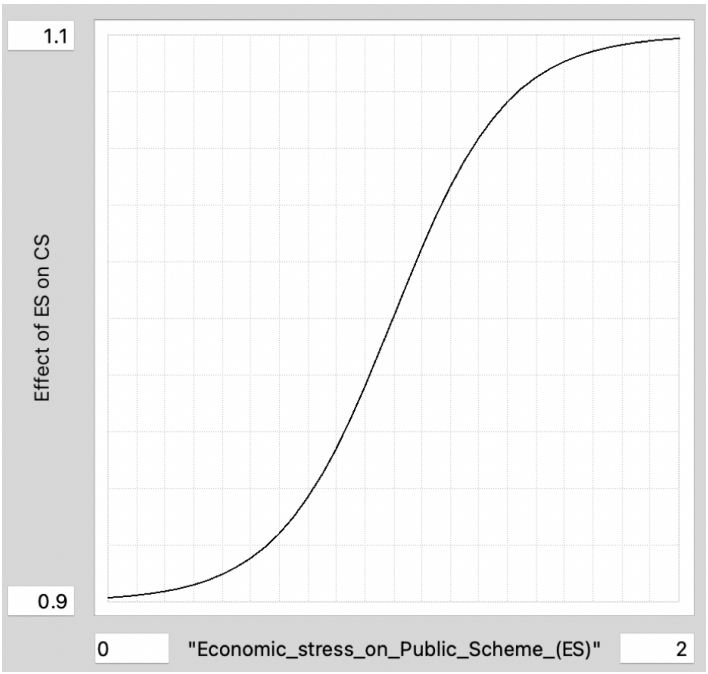

Figure B.5. Effect of Economic Stress on Retirement YoW Requirement graphical function (dimensionless).

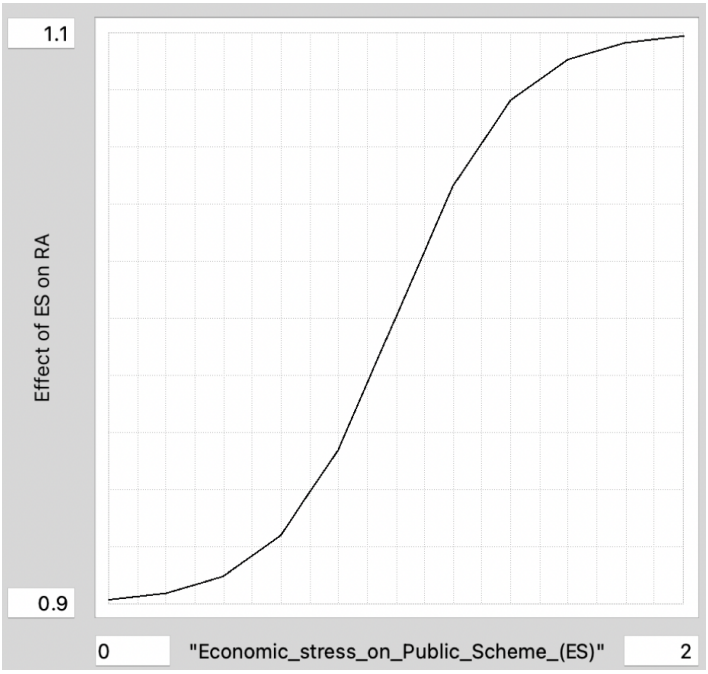

Figure B.6. Effect of Price Distortion on Demand Expression graphical function (dimensionless).

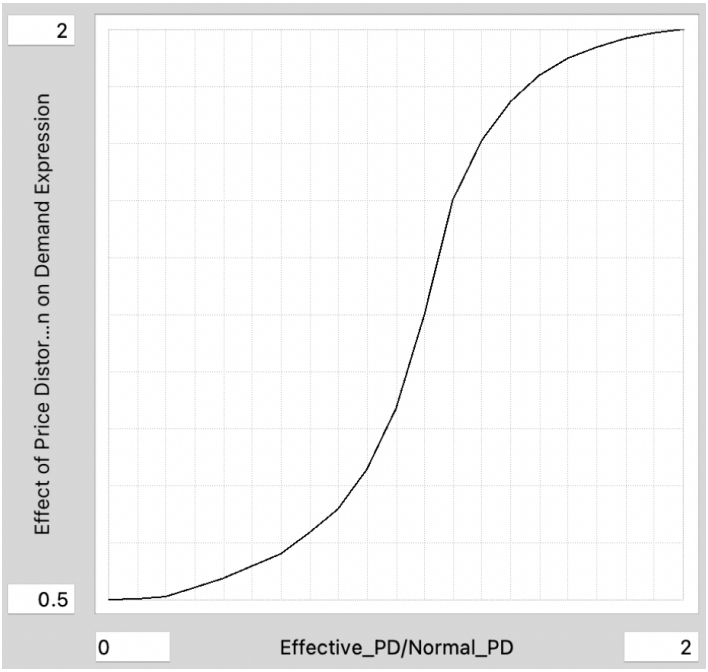

Figure B.7. Effect of Income Elasticity of Demand on Demand Expression graphical function (dimensionless).

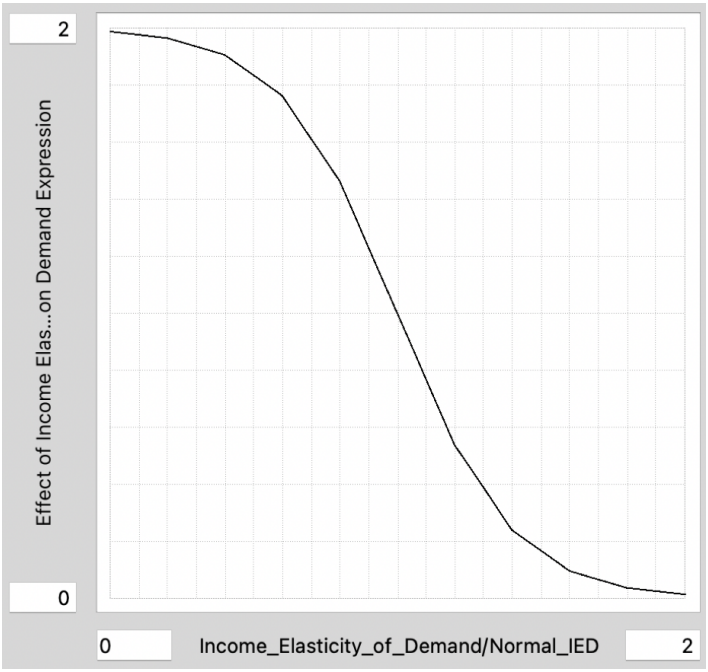

Figure B.8. Effect of Population Health Status on Death Fraction graphical function (dimensionless).

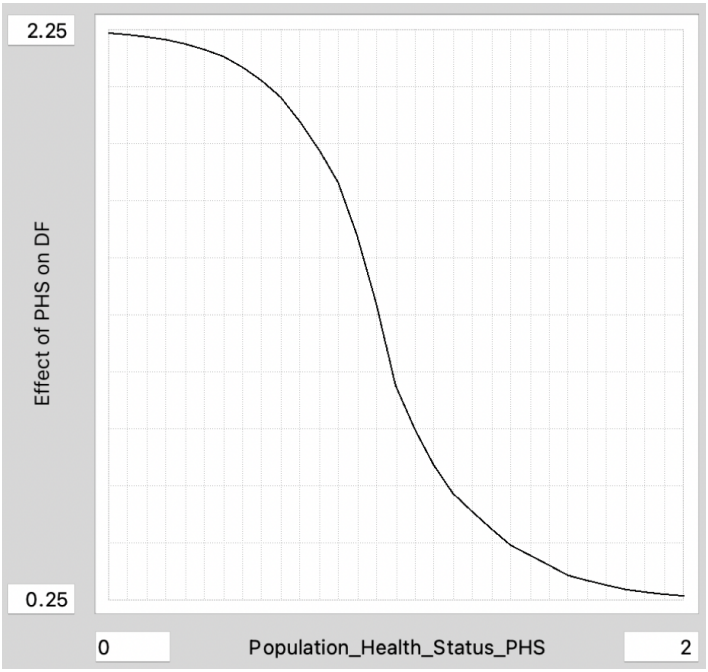

Figure B.9. CiD Nudge graphical function (dimensionless).

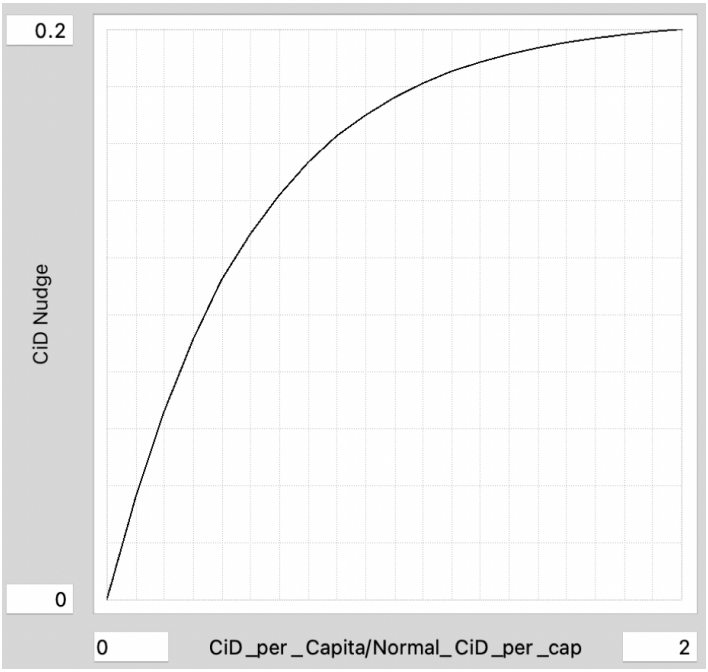

Figure B.10. Provision Nudge graphical function (dimensionless).

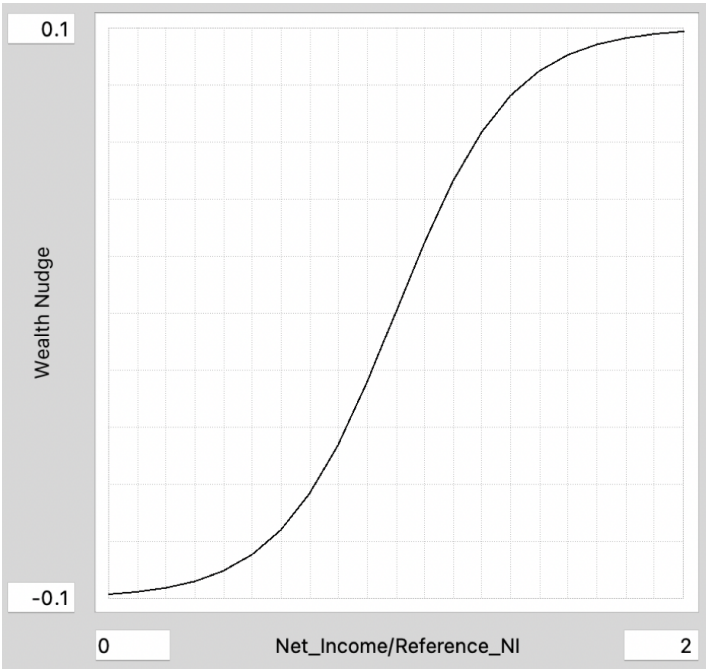

Figure B.11. Wealth Nudge graphical function (dimensionless).

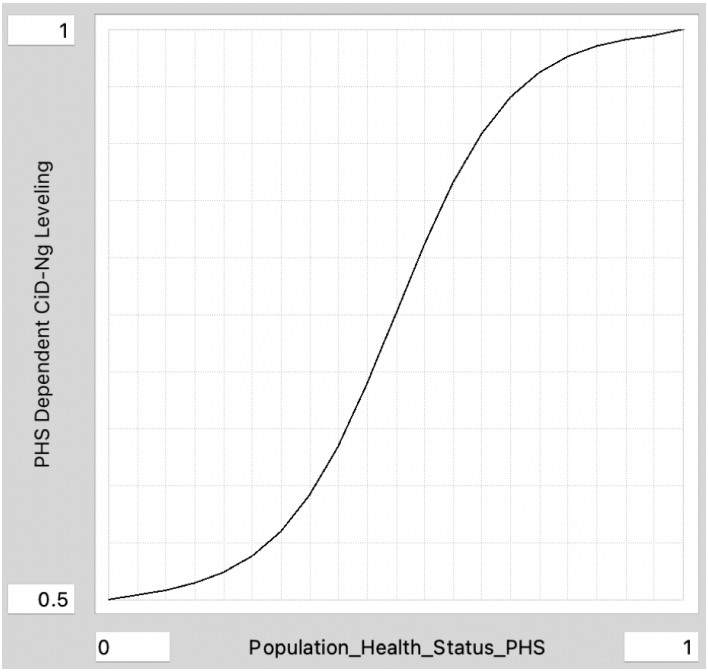

Figure B.12. PHS Dependent CiD-Ng Leveling graphical function (dimensionless).

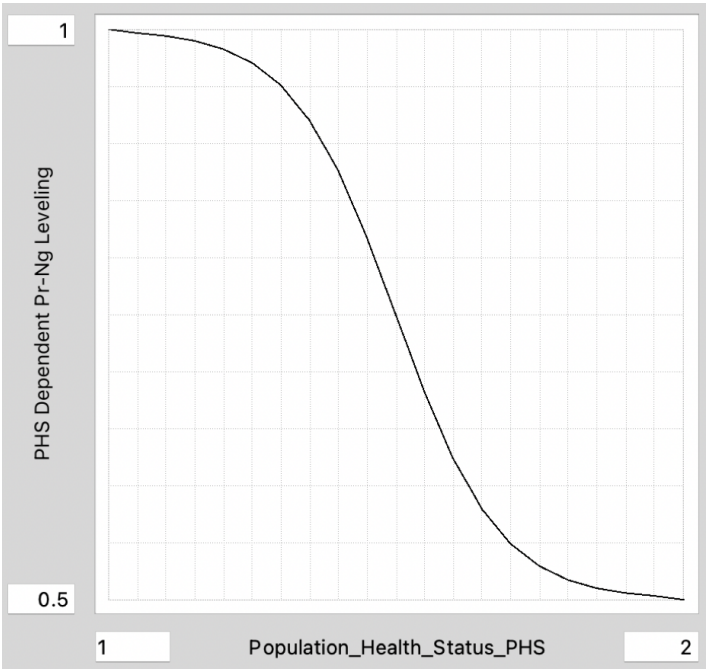

Figure B.13. PHS Dependent Pr-Ng Leveling graphical function (dimensionless).

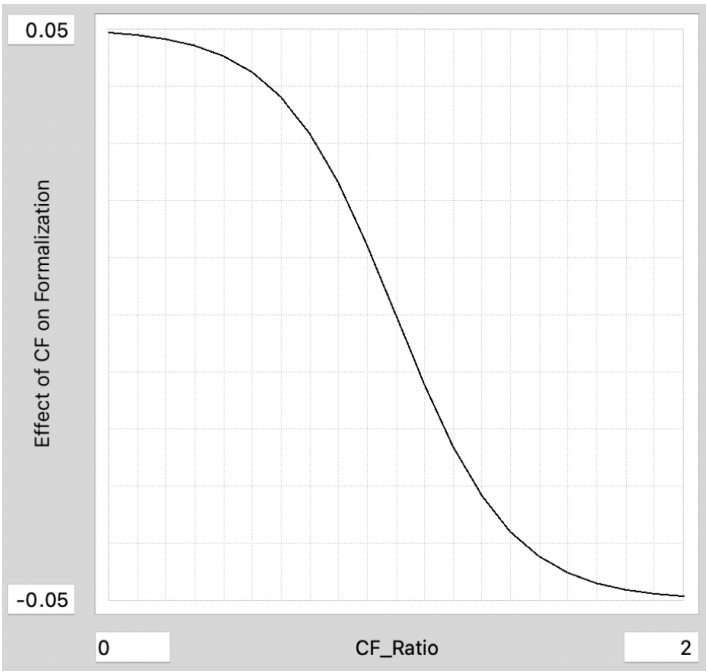

Figure B.14. Effect of Contribution Fraction on Formalization graphical function (dimensionless).

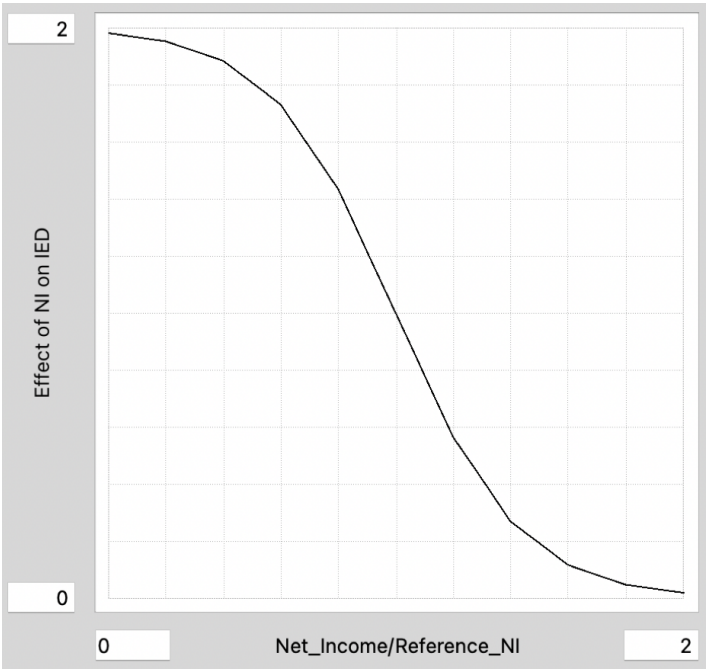

Figure B.15. Effect of Net Income on Income Elasticity of Demand graphical function (dimensionless).

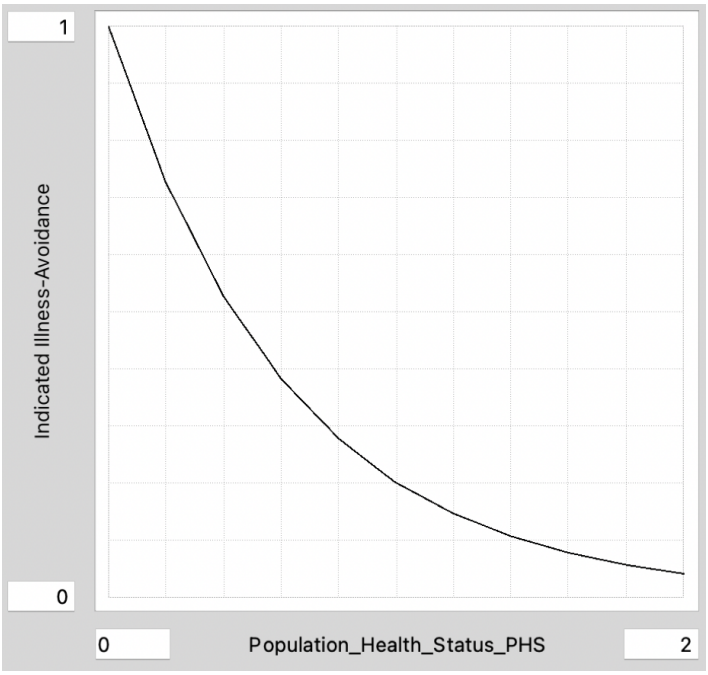

Figure B.16. Indicated Illness-Avoidance graphical function (dimensionless).

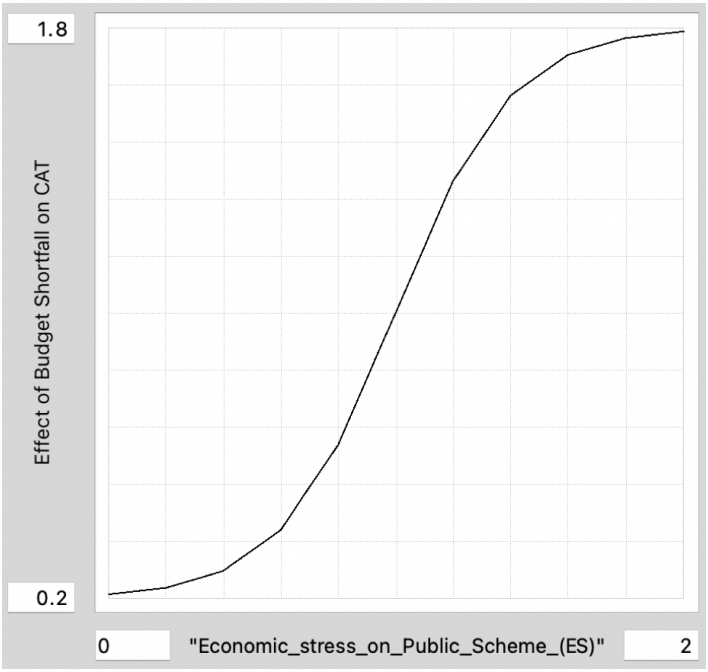

Figure B.17. Effect of Budget Shortfall on Capacity Adjustment Time graphical function (dimensionless).

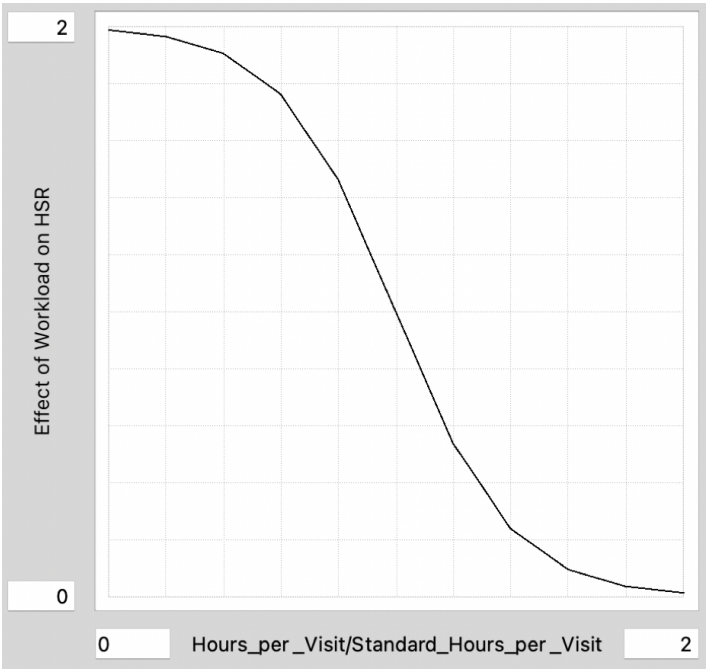

Figure B.18. Effect of Workload on Health Service Rate graphical function (dimensionless).

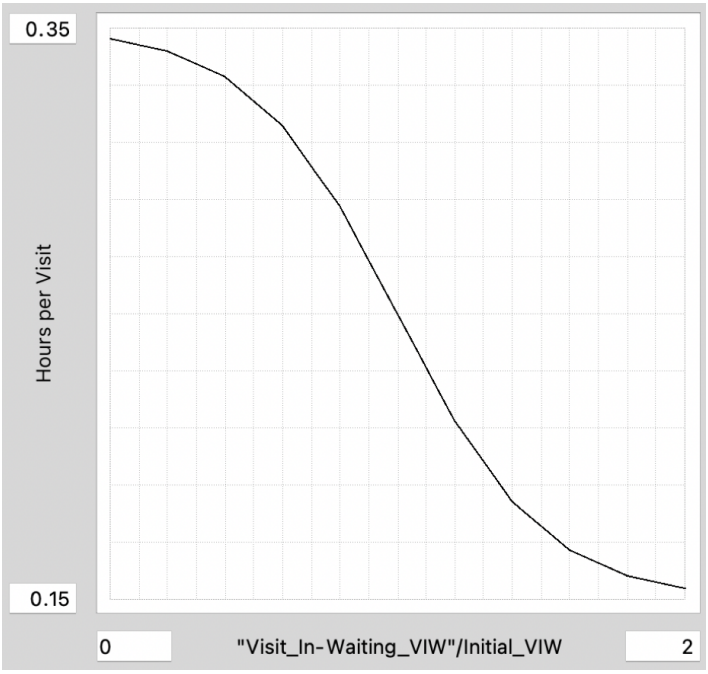

Figure B.19. Hours per Visit graphical function (dimensionless).