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Towards Public Health Policy Formulation

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Abstract. Typical market is a heterogeneous and decentralized structure with natural occurrence of individual or group subjectivity and irrationality, authors propose heterogeneous system dynamics and agent based models capable of coping with centralized aspects of markets, such as institutions and regulation, as well as decentralized components of the markets, such as patients. Such market characteristics cannot be fully expressed with one-shot rigorous formal models based on, e.g. mathematics, statistics or empirical formulas. An innovative solution is being presented extending the domain of agent based computational economics towards the concept of heterogeneous models in service provider and consumer market such as health care. The behavior of the market is described by a variety of agent classes – mainly the consumer and service provider agents - whose internal dynamics are fundamentally different. Customers are rather free multi-state structures, adjusting behavior and preferences quickly in accordance with time, changing environment and available information. Service providers, on the contrary, are traditionally structured companies or institutions with well-defined internal processes and specific managerial policies. Their operational momentum is higher and immediate reaction possibilities limited. The aim of this paper is to present the heterogeneous model as a viable tool for analysis of emergent market behavior enabling evaluation of different public health policies. The value of the presented research methods relies in application of heterogeneous paradigm in multiple perspectives – not only by combining the agent-based models with system dynamics approach, but also by combining and evaluating alternative approaches to representing agent state and knowledge. The outcomes of this research would contribute to the expert discussion in public health sector and would ideally enable the government agencies to optimize their policy formulation process with respect to the expected behavior of key elements of the public health environment and would allow for making well informed and future-proof decisions.

Keywords: Policy, Agent-Based Computational Economics, Heterogeneous Models and Simulation.

1. Introduction

Just as the business environment today is becoming ever more competitive and ever more complex, the public health sector represents extremely complex environment as well. Governments today face numerous challenges from aging population to ever growing expenses of medical treatment. New methods and tools are being searched for to help businesses take better strategic decisions or to help policy makers make better-optimized decisions even in the public sector. In majority of cases such critical strategic decisions can only be made as one-time decisions with no chance to step back later to change and pursue alternative path. The key stakeholders thus require solid analysis or evidence to base their decisions on. In the past markets or health sector would have been analysed by various mathematical, analytical and statistical tools that would typically apply to a specific sub-segment of the studied market or specific limited time period and conditions only. Is there however a tooling available to analyse the entire complex environment and predict its behaviour at different phases in time? The system modelling addressing these exact requirements has been gaining traction since the second half of the 20th century. The modelling and subsequent simulation provides for a risk-free evaluation of alternatives (what-if analysis), predicts the future evolution of the modelled system and facilitates communication and common understanding between the key decision makers.

2. Related Work

The initial research on system modelling and simulation goes back to Forrester [1], who has introduced the system dynamics, a system science methodology first studied within supply chain management, later seeing wealth of applications in economics and also in management. System dynamics works with stocks

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and flows of model variables capturing the overall cumulative behaviour of the studied system. This is suitable framework for cases where aggregate statistics exist and where the system is centralized and well structured. System dynamics is often referred to as top-down modelling approach working with overall cumulative behaviour of the entire system. In contrary to that systems science and fields of artificial intelligence have given rise to agent based modelling methodology, a bottom-up modelling technique focusing on the micro behaviour and construction of the overall aggregate system behaviour through interaction of agents as atomic parts of the studied environment. Specifically, agent based models have been used extending the traditional field of computational economics Amman [2] and Tesfatsion[3] by generative and evolutionary approach to the study of economic systems and markets. In that case we talk about agent based computational economics (ACE) as introduced by Tesfatsion[4]. While both system dynamics and agent based modelling have received enormous attention each on its own, so far only limited attention has been paid to combined heterogeneous models blending the centralized top-down modelling approach of system dynamics with decentralized constructive bottom-up approach to modelling via agents. Early discussions on hybrid modelling have been started by e.g. Akkermans [5] and have recently been extended with also some applications by Lättilä[6]. The past limited attention to hybrid modelling may have partly accounted to low maturity of the computational tools, which is however about to change with hybrid modelling toolboxes such as AnyLogic, as introduced by Borshchevet al [7].

3. Health Capital Analytical Model

Authors present a method for modelling of public health as capital goods using the method of iterative non-linear optimization through heterogeneous simulation. The model is inspired by Michael Grossman's model of demand for the commodity "good health". Grossman [8] presents health as durable capital stock that produces an output of healthy time. The health capital is not purely exogenous it has its general form that is given for any patient, but can be cultivated through proper treatment or on the other hand deteriorates without proper care and over time with increasing age. In other words, individuals inherit initial stock of health that can be increased through investment and depreciates over time and at increasing rate. The death occurs once the stock falls under certain given limit. With this definition individuals have at least some power for influencing their life duration expectancy. Similarly, the government or public sector can also use such model to better understand and predict the best policies for increasing population life expectancy, while optimizing the public health policy costs. Grossman suggests health being demanded by consumers for two reasons: as a consumption commodity and as an investment commodity that positively determines the total time available for an individual for their market and nonmarket activities.

From mathematical point of view, Grossman's model represents a classical optimization problem. There is a utility function that combines the demand for health capital and other commodities increasing individual utility. Health capital is an abstract term expressed as a complex mathematical formula or as a combination of direct and subjective factors. Parameters of the utility function can be defined using their own production function. Finally, the optimization exercise seeks for such values of parameters that given specified constraints maximize the utility function. With respect to such model, Economists and econometricians will often employ their standard empirical functions and will follow by inspecting the functional properties of analytical scheme. An alternative engineering approach that is suggested by the authors is an iterative parametric optimization through rapid prototyping of the proposed model. The proposed model is based on hybrid paradigm blending between system dynamics view and an agent based model and subsequent simulation. The engineering formulation of the problem consists of a) definition of the utility function, b) enumeration of the substantial parameters of the utility function, c) selection of empirical or statistical forms (models) to individual parameters of the utility function, and d) definition of appropriate initial parameters, bounding conditions and environment constraints.

4. Health Capital Simulation Model

The real life management challenges are full of examples from complex environments in which there are parts (sub-systems) of the problem (system) that behave as independent units with distributed decision behaviour and actions that add up into the cumulative behaviour of the sub-system, and other parts of the problem that behave in a centralized fashion where the cumulative behaviour of the sub-system is rather straight-forward to observe and describe. The earlier sub-systems would be typically modelled using a bottom-up approach and often represented with the agent based modelling approach, while the latter would typically be modelled in a top-down fashion and often implemented by means of the system dynamics modelling paradigm. A classical example of such environment would be a market for selling and buying of services or goods, which is typically represented by three key actors – 1) the producers or service providers on one hand, 2) customers or consumers on the other hand and finally 3) environment policies or market regulation providing the constraints and overall conditions imposed by the environment. Models investigated by the authors in the past have focused on the case of service provider and consumer markets, with a specific example of mobile telecommunications operators in mind and their comparison to stiffer health care provider market.

Suggested model and related simulation framework shall serve as management and decision support tool to better evaluate conditions and outcomes of different public health policies aiming at maximizing the average expected duration of life across the population(Life Expectancy) and parallel optimization of other key performance indicators (KPI's). The simulation model is loosely inspired by Grossman's concept of demand for health capital. The model considers the government's ability to subsidize or regulate the available capacity of given types of health providing institutions (hospitals or clinics), and also the government's ability to regulate the structure and amount of insurance plans. The model considers three types of agents – patients, hospitals and insurances – and has been implemented using the AnyLogic multi-paradigm modelling and simulation environment.

While Grossman's original concept represents a classical dynamic optimization problem, based on utility function optimization, deriving an analytical form of the health capital function as its result. Our approach is going to take the concept of a health capital function as an input into a simulation model whose goal is to seek experimental and iterative solution to complex optimization problems defined within the model framework. Authors believe that applying simulations as an extension of the original Grossman's framework is an innovative method to approach policy formulation problems in the health economy.

4.1. Patient Population

Initial population of individuals is generated with the given age structure AGE(i) and distribution of income SALARY(i) or RENT(i) and their associated utility function UTIL(i). Only the population of individuals older than 18 years is being considered as children and underage represent a very specific category from the perspective of health capital build-up. Each modelled individual is going to use their utility UTIL(i) and will choose the highest quality and affordable insurance plan INSUR(i) that they are able to finance from their income in the give year of simulation. For the sake of simplicity, it is assumed that the categories of attributes SALARY and UTIL remain constant for the entire life of the individual; however their value will vary with age (these are non-stationary parameters).

Besides that, each individual is characterized by their stock of health capital that naturally depreciates with age, but will appreciate through investment in an insurance plan and if capacity is available in the system of hospitals that accommodates the given insurance standard and provides the agreed care. In case of injuries, which occur as random events across the population the level of health capital can deteriorate step-wise (e.g. by 5% or other random factor), even multiple times during individual's lifetime. An individual dies once their health capital stock decreases under certain limit. In order to maintain the population and to reflect varying population dynamics each individual after the age of 40 or latest by the time they die will span one new young 18 years old adult. All these parameters are subject to further tuning to adapt to realistic population dynamics for selected region or country. The parameters have been experimentally adjusted to relate to actual situation in the Czech Republic.

4.2. Hospital Facilities

The service provider function of the market and the model is characterized by health facilities consisting of four types of hospitals: HOSPITAL(1), HOSPITAL(2), HOSPITAL(3) and specialized luxury care providing CLINIC. Each hospital type is capable of providing care for specific set of insurance plans.

4.3. Insurance Plans

The function of insurance companies in the model is represented by the insurance plans INSUR(1), INSUR(2), and INSUR(3).

4.4. Government Policy

The role of government regulation is represented by the ability to change initial parameters of the experiment: private and public pricing per insurance plan, structure of insurance, structure of hospitals and their capacity, and costs per hospital capacity unit.

5. Experiments & Evaluation

Default experiment shows population in three salary groups distributed across three age groups and defines three types of insurance with sample costs for the private and public sector and an estimated effect on the individual health capital (additive factor). The resulting simulation graph in Figure 1 shows bubbles representing the modelled individuals with their age on the horizontal axis and their stock of health capital on the vertical axis. Colour notation is used to distinguish and present in real time what insurance plan the individuals can afford and are enrolling to and how that affects their resulting health capital. The simulation demonstrates visually any collision cases when downgrades in insurance plan are required due to drop in individual's budget (typically this happens at the age of 65 when individuals enter retirement) or in case there is insufficient capacity in the hospital facilities that would be able to accommodate for the required health care guaranteed by the given insurance plan. The default experiment allows re-configuration of the hospital facilities capacity during the simulation run and as a result the experiment will always return the sample mean and variance of the life expectancy (LE) for the given parameters and the total population and separately for the three salary groups. As additional output, the model execution will return the estimated public and private costs. The public costs are based on the public share of the insurance costs and on the maintenance costs for keeping available hospital capacity. Private costs are determined by the private part of each insurance plan costs. Standard 100 years simulation run results are shown in Figure 1.The resulting life expectancy reaches 76 years of age on average and then 70 years, 76 years, and 81 years for the three respective age groups.

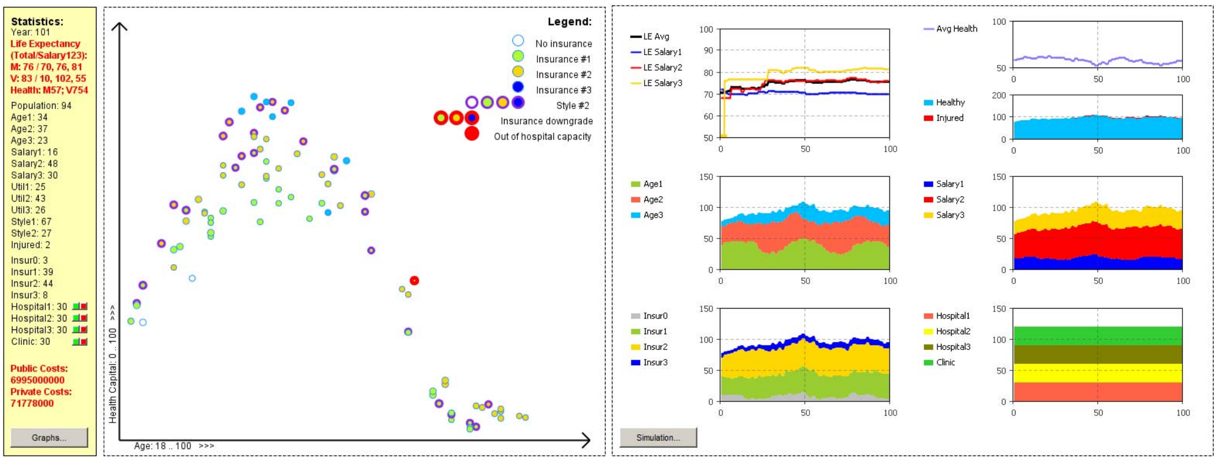

Fig. 1: Default experiment visualization and statistics, default initial parameters

6. Conclusion

Presented results demonstrate the default experiment and together with extreme experiments (e.g. no insurance in the population or on the other hand availability of the top insurance plan for everybody) would outline the area of practically achievable results for different public policies. Immediate optimization task would be the tuning of the hospital facility capacities. Another task would be the setting of private portion of the costs of insurance plans– in order to balance between the public and private costs of healthcare. All these experiments are easy to define and execute with the described model. The aim of this work and the model is to develop a simulation framework that could be calibrated to real situations and used for active government policy making.

7. Future Work

The government has its specific utility functions – one of the suggested utilities is the life expectancy optimization. However there are also other utilities and government regulatory targets as well that are worth considering in the future simulation experiments. As an example, Milstein [9] talks about *HealthBound* policy simulation game and government regulatory targets as diverse as – availability of health care, its quality, minimum costs, minimum morbidity and mortality. *HealthBound* policy simulation game is System Dynamics model, which is a top down modelling approach. Our future aim is to apply a bottom up approach to simulating the elementary components of the distributed health care environment of the *HealthBound* policy simulation game, thereby hopefully obtaining a better representation of the modelled reality.

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9. References

[1] J. W. Forrester. Industrial Dynamics. Productivity Press, Cambridge, Mass, 1961.

[2] H. M. Amman, D. A. Kendrick, and J. Rust. Handbook of Computational Economics. North Holland, 1st ed., June, 1996.

[3] L. Tesfatsion, and K. L. Judd. Handbook of Computational Economics, Volume 2: Agent-Based Computational Economics. North Holland, 1 ed., July, 2006.

[4] L. Tesfatsion. "Chapter 16 Agent-Based Computational Economics: A Constructive Approach to Economic Theory," Handbook of Computational Economics, vol. 2, pp. 831–880, 2006.

[5] H. Akkermans. "Emergent supply networks: System dynamics simulation of adaptive supply agents", Proceedings of the Hawaii International Conference on System Sciences, p. 63, 2001.

[6] L. Lättilä, P. Hilletofth, and B. Lin. "Hybrid simulation models - when, why, how?", Expert Systems with Applications, vol. 37, no. 12, pp. 7969–7975, 2010.

[7] A. Borshchev, Y.Karpov, and V. Kharitonov. "Distributed simulation of hybrid systems with AnyLogic and HLA", Future Generation Computer Systems, vol. 18, pp. 829–839, 2002.

[8] M. Grossman. "On the Concept of Health Capital and the Demand for Health", The Journal of Political Economy, Vol. 80, No. 2, pp 223-255, 1972.

[9] B. Milstein. "The "HealthBound" Policy Simulation Game: An Adventure in US Health Reform", International System Dynamics Conference, July 26-30, 2009, Albuquerque, New Mexico, USA, 2009. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1157.pdf