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Calibration of a stochastic health evolution model using NHIS data

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ABSTRACT

This paper presents and calibrates an individual's stochastic health evolution model. In this health evolution model, the uncertainty of health incidents is described by a stochastic process with a finite number of possible outcomes. We construct a comprehensive health status index (HSI) to describe an individual's health status, as well as a health risk factor system (RFS) to classify individuals into different risk groups. Based on the maximum likelihood estimation (MLE) method and the method of nonlinear least squares fitting, model calibration is formulated in terms of two mixed-integer nonlinear optimization problems. Using the National Health Interview Survey (NHIS) data, the model is calibrated for specific risk groups. Longitudinal data from the Health and Retirement Study (HRS) is used to validate the calibrated model, which displays good validation properties. The end goal of this paper is to provide a model and methodology, whose output can serve as a crucial component of decision support for strategic planning of health related financing and risk management.

1. Introduction

Due to improved living conditions and advanced medical technology, life expectancy of Americans has almost doubled in the past century to 78.1 years in 2009, and is steadily increasing. Along with the longevity comes an increasing living cost and health care expenditures. In response to these new trends, there is a vast body of work addressing the financial issues underlying human health and health evolution, which includes retirement planning, annuity and insurance purchase decisions, and healthcare management.

Strategic planning for health related financing is important, but not easy, since significant uncertainty is associated with an individual's health evolution over time. Firstly, it is generally difficult to concisely assess and quantify the health status of an individual, since health status is a multi-faceted and complex quantity. Secondly, the occurrence of health incidents and effect of healthcare services received in the future are tough to predict. Thirdly, living and healthcare expenses will change significantly over a long planning period. A typical individual, however, is not sophisticated enough on his own to comprehend these uncertainties and manage his health and healthcare financing risks. A decision support system is needed to help individuals do better planning so as to guarantee their long-term wellbeing. In order to create such a decision support framework, it is essential to comprehend and quantify the uncertainties related with an individual's health evolution over time.

The objective of this paper is to develop and demonstrate a framework for the calibration of a reduced-form model for health evolution. The rest of the paper is organized as follows. Section 2 provides an overview of related literature. Section 3 outlines a specific health evolution model. In Section 4, we provide a detailed description of the NHIS data, while Section 5

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describes the approach adopted for using the NHIS data and the methods for model calibration. We demonstrate the results of the calibration in Section 6, and perform a validation of the calibrated model in Section 7. Our conclusions are summarized in Section 8.

2. Health modeling literature

In this section, we set the stage for the calibration goal of this paper by providing an overview of the related literature and concepts. We begin with a summary of how health risk and health status are described in the literature, followed by a discussion about the existing models of health.

2.1. The concept of health

In modern literature, health is commonly related to one or both of two distinct dimensions: good health and ill health [1, 2]. Good health includes qualitative aspects of human life, and is commonly related with the concept of well being, or mental and physical fitness. Ill health is associated with morbidity and in the extreme, mortality, which is determined by the presence or absence of diseases, injury, disability, and functional limitations.

Health status can constitute measuring a single or a group of indices used to systematically assess the overall health of an individual or a well-defined group. The commonly available measures used in health related research include self-reported health status, physical diseases, mental and emotional health, and functional limitations. Results of prior research suggest that the subjective self-reported health status is a valid indicator and can be used in cohort studies and population health monitoring [3–5]. Functional status is the second health status measure that has been widely used in recent studies. The most widely used functional status measures include the activities of daily living (ADL) scale developed by Katz et al. [6], the instrumental activities of daily living (IADL) developed by Lawton and Brody [7], and the Nagi's disability scale [8]. These three scales play an important role in modern health promotion research, and are available in many survey data. Whitelaw and Liang proposed and evaluated two models for integrating self-reported health status measures for the elderly, each of which includes three dimensions of physical health: chronic illness, functional limitation, and self-rated health [9]. Johnson and Wolinsky discussed the shortcomings of functional status measures and proposed a more complex model of the structure of health status, which includes self-reports of disease, disability, functional limitations, and perceived health [10].

Health status and health evolution can be very much influenced by many risk factors. Health risk factors are any observable quantities that possess a predictive capacity for an individual's likelihood of experiencing a health event or incident. Belloc found that individual health practices, such as smoking, alcohol consumption, hours of sleep, regularity of meals, and physical activity were strongly related to morbidity and mortality [11]. Mokdad et al. showed that the leading risk contributors to mortality in United States were tobacco, poor diet, inactivity, and alcohol consumption [12]. Meng et al. developed a chronic disease risk index (CDRI), which includes five components: smoking, alcohol use, BMI, fat intake, and fruit and vegetable consumption [13]. They investigated CDRI's relation with chronic diseases in a multi-ethnic cohort and found that individuals with higher CDRI to have a significantly higher risk of cancer, heart diseases, and stroke. Some scholars also demonstrate that health promotion programs which encourage physical activity, weight loss, smoking cessation, and health education, can greatly enhance health and avoid chronic diseases [14,15].

2.2. Modeling health

In the past decades, a wide variety of models have been used to describe the dynamic evolution of human diseases and health. These methods have proved to be very useful in health promotion and epidemiology, both for exploring the underlying nature of the evolution processes from the analysis of observed data [16–18], and for predicting the future behavior and (or) status of the processes [19].

In his pioneering work on human capital, Becker outlined a household production framework, where households were viewed as a special kind of entity instead of solely consumers of goods and services [20]. Households were assumed to derive utility from the basic commodities they produce and their consumption activities in the market. Based on Becker's model, Grossman is the first to investigate health as a form of durable stock of capital and medical care as an investment towards enhancing that capital [21,22].

Since Grossman's work, the model of health capital has been extremely influential in this field and has become a basis for much research in health promotion. Cropper constructed two life cycle models of investment in health which explicitly recognize the random nature of illness and death [23]. Muurinen extended Grossman's model by including the effects of behavioral, lifestyle, and environmental factors in the model [24]. Picone et al. modified Grossman's model by introducing an uncertainty of incidence of illness, and developed a simplified version of a dynamic Grossman household production model to characterize patterns of individual's precautionary behaviors [25]. Gupta and Li adapted Picone et al.'s model by distinguishing restorable illness from non-restorable illness, where only medical investments for restorable illness contribute to improving an individual's health [26].

Based on the prior research on the concept of health capital, models of health risk and health evolution, we introduce a stochastic health evolution model in the next section.