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Combining econometric analysis and simulation modeling to evaluate Population-Based health policies for chronic disease prevention and control

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ABSTRACT

Objectives: Population-based health policies play an important role in preventing and controlling chronic disease. Policymakers need to understand both the short- and long-term impacts of different policies to optimize resource allocation. The objective of this study is to develop a framework that combines econometric analysis and simulation modeling for a comprehensive evaluation of population-based health policies.
Study design: Both econometric analysis and simulation modeling were used to evaluate the impact of a population-based health policy.
Methods: We identified a cohort of hypertensive patients from the 2011–2013 China Health and Retirement Longitudinal Study and fitted the data into our framework to evaluate the effectiveness of a community-based hypertension-screening program under the Essential Public Health Services (EPHS) policy on the future burden of cardiovascular disease in China.
Results: Using an econometric approach, we identified that the community-based hypertension screening program would lead to a 7.9% improvement in the rate of hypertension control. Using a validated simulation model, we further estimated that if the policy was fully implemented nationwide, it could avert 97,100 cases of myocardial infarction and 215,600 cases of stroke. The policy would cost $2131 on average to save 1 quality-adjusted life year over 10 years.
Conclusions: This study proposed a framework integrating two different methods and assessing both short- and long-term impact of a population-based health policy. Through a case study, we demonstrated that combining econometric analysis and simulation modeling could provide policymakers with a more powerful tool to evaluate health policies for controlling chronic disease.

1. Introduction

Over the past few decades, many countries around the world have been facing a growing burden of chronic diseases including heart disease, stroke, diabetes, and obesity (Ng et al., 2014). For example, in 2013 nearly half of the adult population in the United States (US) had at least one chronic condition; and approximately 70 percent of deaths were caused by chronic diseases (Centers for Disease Control and Prevention, 2014; Xu et al., 2016). It was estimated that the total impact of chronic disease on the US economy was $1.3 trillion annually (DeVol et al., 2008). Globally, chronic diseases are leading causes of death. In 2013, the top five causes of deaths were ischemic heart disease, lower respiratory infections, cerebrovascular disease, low back and neck pain, and road injuries (Murray et al., 2015). As the epidemic of chronic diseases continues to grow unabated around the world, there is an urgent need for public health leaders, health care providers, and policymakers to make evidence-based decisions to reduce the burden of chronic disease and improve population health.

A new paradigm in chronic disease prevention and management has evolved, whereby individual-level approaches are complemented with population-level and policy changes to mitigate the burden (Zimmerman, 2013). While methods for formal evaluation of these broad changes are community-based randomized controlled trials, these designs are costly and often not feasible to implement in conjunction with

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policy advances. In this context, analytic approaches such as simulation modeling and econometric analysis provide important insights into changes in risk factors across target populations amidst policy changes (Kopec et al., 2010; Krueger and Friedman, 2009). These analytic approaches have also provided policymakers with high-quality evidence on both the short- and long-term impact of different policies on health and economic outcomes.

Although simulation modeling and econometric analysis are frequently used for program evaluation, there is no formal framework for the integration of both approaches for chronic disease prevention and control. In this study, we developed a framework to combine econometric analysis and simulation modeling for a comprehensive policy impact evaluation. We demonstrated the application of this framework through a case study that evaluated the short-term impact and long-term cost-effectiveness of the hypertension-screening program under the Essential Public Health Services (EPHS) policy in China.

2. Methods

2.1. Overview

Econometric analysis and simulation modeling has been used separately to assess the effectiveness and cost-effectiveness of a population-based health policy (Dimick and Ryan, 2014; Hoerger et al., 2015; Jian et al., 2015; Moran et al., 2015; Pandya et al., 2015; Rosenthal et al., 2016; Brownson et al., 2018). However, few studies have combined the two methods to assess both the short- and long-term impact of a policy. Policy impact analysis using natural experiment design and empirical econometric models have long been favored by economists and other social scientists (Wing et al., 2018); while simulation modeling has been applied largely by systems engineers, computer scientists, ecologists and a smaller number of social scientists (Homer and Hirsch, 2006). Although there has been a lack of communications and understanding between the two schools of science, the growing demand for evidence in medicine and public health calls for the integration of both methods that are rather complementary to each other (Brownson et al., 2009; Anderson et al., 2005).

As shown in Fig. 1, we developed a framework to combine both econometric analysis and simulation modeling. It shows how the two approaches could be combined to provide high-quality evidence for health policy decision-making.

2.2. Framework stages

Common econometric approaches for policy impact analysis include the difference-in-difference (DID) approach, the instrumental-variables (IVs) approach, and the regression discontinuity (RD) approach (Smith and Sweetman, 2016). These approaches utilize a quasi-experimental design (DID and RD) or a pseudo-randomization (IVs) to create the counterfactual scenario for estimation of the causal effect of a population-based policy (Heckman and Vytlacil, 2007); because a randomized controlled experiment – the gold standard for causal inference – is often infeasible for evaluating population-based policies that are already in place (Victora et al., 2004).

For econometric analysis, cross-sectional or panel data are often used to estimate the effect of an intervention or policy using a DID model (Heckman and Vytlacil, 2007). DID integrates the advances of the fixed effects estimators by controlling for unobserved characteristics and combining it with observed or complementary information (Athey and Imbens, 2017). Additionally, DID is a flexible form of causal inference as it can be combined with other statistical procedures to improve the robustness of findings, such as the propensity score and the IV methods (Athey and Imbens, 2017; D'Agostino, 2007). The results from the analysis could then help inform which policies should be recommended and implemented.

Econometric analysis can provide evidence on the effectiveness of health policies within the duration of the study period. However, it cannot assess the a policy's long-term impact, which is relevant particularly regarding policies for chronic disease prevention because the impact of a policy may not be observed in the short-term (D'Agostino, 2007). Simulation modeling, instead, is useful in predicting the long-term health and economic outcomes of a policy. By adopting simulation models, we create a synthetic population that captures the distribution of characteristics and disease progression of the actual population. We can then simulate a policy intervention by modifying certain parameters in the model and observe the projected outcomes due to the policy implementation. The model needs to be validated and calibrated against real-world data to make sure the simulation results

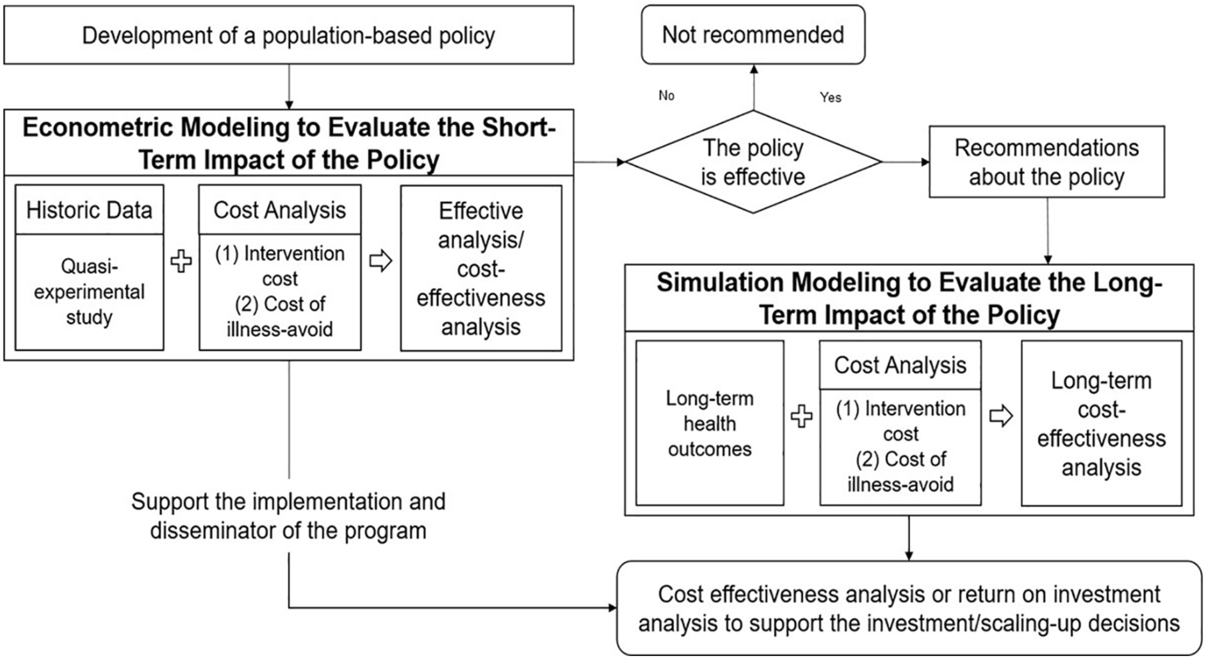

Fig. 1. The conceptual framework for a comprehensive health policy evaluation.

are meaningful to policymakers. Outcome measures such as the incidence of a disease, healthcare costs, and quality-adjusted life years (QALY) can be calculated and reported through model simulation. The modelling approach is often used for comparative effectiveness analysis and cost-effectiveness analysis.

2.3. *Relationship between the two stages*

As the framework suggests, the two approaches can work coherently in policy evaluation. In particular, we first perform econometric analysis and assess empirically the short-term health and economic outcomes affected by policy implementation. Short-term evaluation using econometric modeling is to determine if a national, state or local policy is effective or achieves its goal. If the econometric analysis shows promising short-term effectiveness, simulation modeling is conducted to assess the long-term impact of the health policy. Under certain circumstances, if the short-term evaluation does not show favorable results, long-term evaluation may be conducted anyway if policymakers are wanting to know the long-term impact of a health policy (not shown in Fig. 1). Finally, the output from both approaches will contribute to the realm of evidence to inform the decision regarding scaling-up of a policy and future investment.

2.4. *A case study*

In the following case study, we applied this framework by evaluating the short-term and long-term impacts of the hypertension-screening program under the National Essential Public Health Services (EPHS) policy in China (Zhang et al., 2017). The EPHS policy was implemented in 2009 aiming to provide essential public health services equally to all Chinese citizens. Financing through taxes, the EPHS policy guaranteed to pay 15 Renminbi (RMB) per capita in 2009 to 74 RMB per capita in 2020 (The State Council of the People's Republic of China, 2020). Since its initiation, the EPHS program has progressively implemented in more places across the country and covered an increased number of services such as maternal and child health care, annual health check-up services, chronic disease screening and management in the communities. Since the awareness, treatment, and control rates of hypertensive patients in China were very low, especially in the rural places (Xing et al., 2008), the EPHS program providing free community-based screening could increase awareness rate of hypertension, and improve medication use and follow-up hypertension management in the community, a potentially cost-effective population health policy strategy that was demonstrated in many developed and developing countries (Zhang et al., 2017). Our purpose is to evaluate the impact of the EPHS policy on hypertension control following its three years of implementation and further determine the long-term impact of the free hypertension screening and management services in the communities.

The mechanism by which the intervention leads to better hypertension control is not defined, so it is hard to assess the face validity of the estimated effect on hypertension control; more importantly for policymakers, this doesn't provide much guidance on how to design a similar intervention.

We used data from a cohort of hypertensive patients from the 2011–2013 China Health and Retirement Longitudinal Study (CHARLS), a high quality nationally representative sample of Chinese residents ages 45 and older and modeled after the Health and Retirement Study in the US (Sonnega et al., 2014). The baseline survey was conducted in 2011 and the participants were followed up every two years (Zhao et al., 2012). We selected the respondents with complete biomarker information (e.g., blood pressure measures) in both 2011 and 2013 as our study sample. The de-identified database was publicly available and had been analyzed in our published study (Wang et al., 2016).

We assessed the policy in the following two steps. First, we conducted an econometric analysis by applying a DID approach to assess the impact of the EPHS policy on hypertension control. We defined the treatment group as the respondents who attended the EPHS-covered hypertension screening in 2011–2013, and the control group as those who did not receive an EPHS-covered hypertension screening. We used a time dummy to demonstrate the fixed secular time trend in the two groups. In addition, the net effect of the influence of the policy on patient outcomes was represented by an interaction term between the intervention and the time dummy. Probit regressions were implemented to adjust the socio-demographic characteristics (Wang et al., 2016).

We used the hypertension control rate as the main outcome. If one hypertensive patient had his/her average systolic blood pressure below 140 mm Hg and average diastolic blood pressure below 90 mm Hg, we considered his/her blood pressure were under control. The hypertension control rates were then defined as the percentage of hypertensive patients whose hypertension was controlled.

Next, we built an individual-based state-transition model to simulate the population of hypertension in China and evaluate the cost-effectiveness of the policy in the long term. Fig. 2 shows the basic structure of the simulation model.

The hypertensive patients would occupy the "Hypertension" state and move to other states related to the hypertension state. The events causing the transition was the CVD events, including coronary heart disease (CHD) and stroke, in which the CHD states include arrest, angina, myocardial infarction (MI). We also took into consideration the adverse events happened on the patient due to the use of anti-hypertensive medication. Besides, there were absorbing states included - Fatal Events state and Natural Death state, and patients would be considered dead when they transit to this state. An annual cost and quality-of-life utility were assigned for each health state and would be accumulated as the simulation runs. The model output measures were health outcomes, costs, and QALYs. The transition between two different states was based on the transition probabilities. The policy will increase the proportion of hypertensive patients who are under control. In the model, more specifically, the transition probabilities from the hypertension state to CVD states will be lower with the implementation of the policy, and the reduced transition probabilities are captured by the relative risks derived in the econometric analysis. All of the input parameters mentioned above as well as their sources are present in the Supplementary Appendix (Table SA1) (Lewington et al., 2016; Law et al., 2009; Liu et al., 2004; Gu et al., 2015; Gu et al., 2008; Xie et al.,

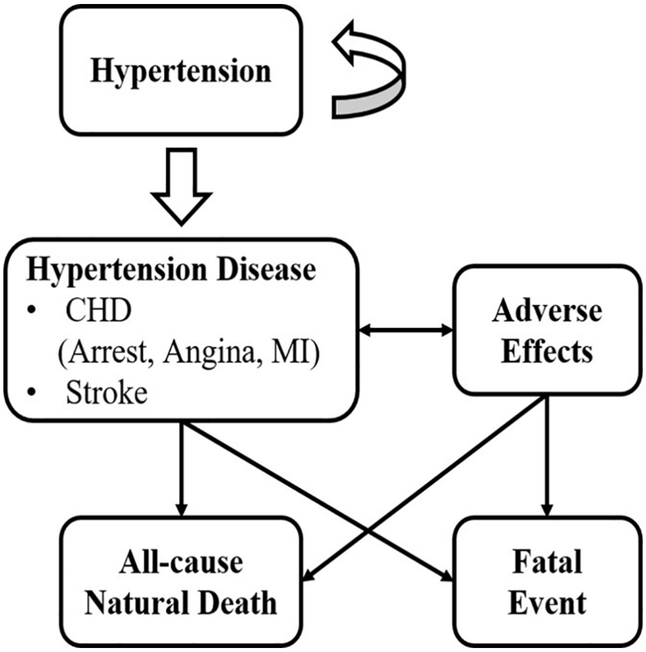

Fig. 2. Conceptual structure of the simulation model.

2016; Salomon et al., 2012; Weinstein et al., 1996; The Ministry of Health of the People's Republic of China, 2013). The model was programmed in TreeAge Pro software (TreeAge Software, Inc., Williamstown, MA, USA) linked with Microsoft Excel (Microsoft Corporation, Redmond, WA).

Two scenarios of simulation were conducted, including the one with the coverage of the EPHS policy and the one without coverage. The parameter that reflected the difference in hypertension control rate from the two scenarios was obtained from the previous econometric analysis (Zhang et al., 2017).

3. Results

Table 1 shows the regression results from the DID analysis (Zhang et al., 2017). The results showed that the control rate had improved, and particularly, the improvement was larger in the treatment group than it was in the control group. Coverage by the EPHS policy was associated with an increase of 7.9% on average in hypertension control rate. The EPHS program had a significant impact on improving the rate of hypertension control, which indicated that the policy was effective at the population level.

Table 2 presents simulation results of the 10-year incidence of CVD in both scenarios. Under the EPHS policy, the control of CVD improves, and it would eventually result in 97,100 reductions in MI and 2155,600 reductions in stroke cases over 10 years. Table 3 demonstrates the costs and QALY outputs from the simulation model. It indicates that it would cost $2131.11 to save 1 QALY over 10 years, while the Gross Domestic Product (GDP) per capita in China in 2014 was about $7568.34. Given the cost-effectiveness threshold is generally set at the cost of less than three times the national annual GDP per capita (Marseille et al., 2014), the nationwide EPHS program was considered cost effective and should be recommended to expand to cover the entire adult population aged 45 and older in the country. We provided one-way sensitivity analyses on key variables to present the robustness of our results (see Table SA2 in supplement). We also added the probabilistic sensitivity analysis and the cost-effectiveness acceptance curve with respect to the willingness-to-pay thresholds. Both sensitivity analyses showed that our main finding was robust. The results of the econometric analysis above also supported the implementation and dissemination of this program (Zhang et al., 2017).

4. Discussion

In this study, we developed a conceptual framework combining the econometric analysis and simulation modeling. The framework was applied in the evaluation of a national public health policy in China. The conclusion of the evaluation was that the EPHS policy in China was cost-effective and worth further investment.

The concepts of evidence-based public health attracted much attention along with the growing complexities of the health care system (Brownson et al., 2009; Anderson et al., 2005). The strong demand exists on assessing the effectiveness of one intervention and deciding its potential values using existing data. In many cases, policymakers need evidence on the impact of the existing population-based policy and then predict the future burden of the targeted chronic disease as well as its economic impact. The econometric analysis is often considered an important analytical tool accelerating evidence-based public health (Brownson et al., 2009). However, the main limitation of this tool is that it depends very much on the availability and quality of the relevant data.

Table 1
Results from the Econometric Analysis (N = 4958).

	Treat n = 402	Control n = 4556	Marginal difference
2011	18.5 (2.0)	17.7 (0.8)	0.7 (2.0)
2013	36.0 (2.4)	27.2 (0.9)	8.7* (2.4)
DID Estimate			7.9* (2.9)

Standard errors in the presentences; * P < 0.05.

Table 2
Number of CVD cases prevented over 10 years in both scenarios (*1000).

	Arrest	Angina	Myocardial infarction	Stroke	Fatal events
EPHS[1]	2369.24	5845.42	2563.44	409.85.91	1874.03
Non-EPHS	2437.21	6020.2	2660.54	43141.53	1980.84
Reduction	67.97	174.78	97.1	2155.62	106.81

Attended the hypertension screening under the Essential Public Health Services policy.

Table 3
Cost-effectiveness analysis for expanding the hypertension screening program under the essential public health services policy over 10 years.

	Cost ($)		QALY[2] (year)		ICER [3] ($/year)
	Mean	S.E.	Mean	S.E.	
EHPS [1]	465.82	4.73	6.73	0.02	2131.11
Non-EHPS	444.51	4.83	6.72	0.02	

Attended the hypertension screening under the Essential Public Health Services policy.
QALY: Quality-adjusted life year.
ICER: incremental cost-effectiveness ratio.

Our two-stage framework can be used to evaluate population-based health policies in a more comprehensive way. The econometric models are empirically driven, which allows for empirical assessment of the short-term impact of a policy. As a complement, simulation models can predict longer-term outcomes. The combination allows policymakers to make more informed decisions that are based on both empirical data and scientifically sound projections. The integrated framework provides a holistic view of the data generated in a complex health care system in a systematic way to promote evidence-based public health. While each model is not in itself unique, we present the inclusion of both approaches as a distinctive framework to assess health policies for chronic disease control. Very few studies, if any, have been published that combine short-term policy impact analysis with longer-term policy simulation, and thus we believe this framework adds value to the current paradigm of health policy research.

As shown in the case study, the econometric analysis can handle the panel data well and evaluate the impact of hypertension screening program under the EPHS policy from 2011 to 2013. We should be cautious that the sample was relatively small because we assessed the impact of EPHS policy during its early stage of implementation. Since its inception in 2009, the EPHS policy has gradually expanded the scope of services to include chronic disease screening and management in 2011. We included only respondents who were identified as having hypertension in 2011 for the longitudinal analysis, and thus most patients were not screened at that time. Based on the cross-sectional data of CHARLS 2015, the prevalence of EPHS-funded community-based blood pressure monitoring was 32.1% among 2487 hypertensive persons and improved blood pressure control (odds ratio = 1.246, 95% CI = 1.035–1.499), suggesting that the EPHS policy had been implemented rapidly (Song et al., 2019). Our study used a well-designed econometrical model that boosted causal inference and showed the policy was effective at the initial stage, when evidence for further investment was in a critical need. In addition, our case study combining two different approaches provided us with a consistent set of results that supported the implementation and expansion of the policy. The burden of hypertension, as well as most other chronic diseases, would vary significantly in the near future. For instance, as the population aging becomes a national and global trend, dramatical changes will happen on the incidence of certain chronic diseases, assuming the rate of changing remains the same within each age group. The econometric models can only analyze the data for the current situation, while simulation modeling performs well in predicting health and economic outcomes when long-term data are not yet available and technological breakthroughs are not readily foreseeable. But on the other hand, the econometric analysis is indispensable before the simulation setting, because simulation modeling is most useful when utilizing data with real-world policy impact. Compared with the previous single approach framework where we apply only econometric analysis or simulation modeling, this comprehensive framework is more thorough and robust in supporting decision making.

A limitation of this framework is that it assumed that only when econometric analyses generated favorable results, simulation models will be needed. The underlying assumption is that a policy that does not demonstrate short-term effectiveness is unlikely to be effective or does not worth further investment. However, for some programs aiming to prevent long-term health outcomes and mortality, the impact may not be shown in a short time period (i.e. weight-reduction interventions), whereas it may be effective or cost-effective in a longer time period. In addition, spillover benefits or unintended consequences may not be observed during the initial stage of policy implementation, thus policy simulation with a systems perspective might fill these gaps. Policy makers may want to know the long-term impact of a policy even in situations where its short-term impact is ineffective. This process may need to be modified when applying the framework to a real-world setting.

5. Conclusions

This study proposed a framework combining econometrics analysis and simulation modeling. It integrated two different methods and assessed both short- and long-term impact of a population-based health policy, which would enable policymakers to evaluate health policies with a more powerful tool that ultimately improve population health with limited public health resources.

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CRediT authorship contribution statement

Xiaolei Xie: Conceptualization, Methodology, Writing – original draft. **Zhenghao Fan:** . **Yan Li:** . **Jian Kang:** . **Donglan Zhang:** .

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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