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Understanding temporal change of spatial accessibility to healthcare: An analytic framework for local factor impacts

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ABSTRACT

Population demand, health service supply, and the linkages between them (e.g., transport infrastructure) are important factors that determine spatial accessibility to healthcare at a place. These three factors vary differently over time and location, leading to temporal changes and spatial disparities in access to healthcare. Few analytic methods have been developed to measure local impacts of these factors on healthcare accessibility over time, which are essential to alleviating health disparities and evaluating intervention programs. We propose a spatially explicit analytic framework to measure local factor impacts over time by adopting a chain substitution method from economics. The analysis is illustrated by a case study of spatial accessibility to physicians in Florida, USA, from 1990 to 2010. For each census block group, the results show the impact of local population change, physician relocation, and road-network expansion on the loss and gain of healthcare accessibility over time. The leading impact factor are identified for each census block group through comparison, and spatial clusters of factor impacts are discovered. To the literature of healthcare accessibility, this article presents a promising start of factor impact analysis and offers new perspectives in exploring spatial processes underlying people's access to healthcare.

1. Introduction

Accessibility to healthcare refers to the ease with which people of a given area can reach medical services and facilities (BTS, 1997). The degree of accessibility varies dramatically across communities, which have long been considered as a health disparity issue in the United States, as they can cause poor health outcomes, low quality of life, and excessive medical expenditures (LaVeist et al., 2011). Since the 1960s, health agencies have attempted to improve access to healthcare through various intervention programs, such as designating medically underserved areas (Jones et al., 2008; NIH, 2002) and training young physicians to practice in designated areas (Rieselbach et al., 2010). To evaluate the effectiveness of these programs, it is essential to understand 1) the pattern of changes: how does accessibility to healthcare change over time? and 2) the processes underlying changes: which factor(s) has the most or least impact on such temporal changes? While many studies answer the question of pattern changes (Cooper et al., 2009; Hine and Kamruzzaman, 2012; Luo et al., 2004), few have addressed the question about underlying processes.

In a spatial context, three factors are commonly considered as contributors to spatial accessibility to healthcare, including: 1) the geographical distribution of populations who need health services (demand), 2) the geographical distribution of health services (supply), and 3) the spatial linkages/barriers between demand and supply via transportation infrastructure (Khan, 1992). These three factors are temporally dynamic and thus lead to loss or gain of spatial accessibility over time, for instance, the growth of population, the relocation of health services, and the expansion of road network. Furthermore, each factor can vary at different rates between communities, such as faster population growth in urban than rural communities. Hence, they impact spatial accessibility at different extents over locations, resulting in spatial disparities. Measuring these factor impacts is thus critical to thorough understanding of local disparities in healthcare accessibility and an in-depth evaluation of the spatial effectiveness of intervention programs. For instance, health policy makers may be interested in: to what degree does the population growth in a county or the physician relocation in a ZIP code area influence the local healthcare accessibility? Which factor(s) was the most important in improving or worsening accessibility at a given location? Where has the current intervention program been most or least effective in improving accessibility? In the current literature, there is a lack of analytic tools to address these practical questions, particularly at a local scale.

To fill this research gap, we propose a spatially explicit analytic framework to measure and map local impacts of factors on the

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healthcare accessibility over time. Briefly, the spatial accessibility to healthcare is measured as a mathematical function of three spatio-temporally varying factors: 1) the population demand, 2) the health service supply, and 3) the transport infrastructure that links the demand and supply. A chain substitution method is applied to this function by substituting factors one after another with their values at next time period. The difference in accessibility values before and after the substitution indicates the local impact of the substituted factor. For illustration, we applied this framework to identify where spatial accessibility to physicians improved or worsened from 1990 to 2010 in Florida, USA, and most importantly, to measure how much the three factors impacted the local change of spatial accessibility. The next section reviews related literature on accessibility to healthcare and its temporal change. The section that follows describes the proposed framework for localized factor impact analysis. The fourth section articulates a case study of our method in Florida. The fifth section presents and discusses the results.

2. Literature on accessibility to healthcare and its temporal change

Accessibility is one dimension in a broad concept of 'access to healthcare'. Penchansky and Thomas (1981) defined access to healthcare as the degree of 'fit' between the demand and the supply, and identified five dimensions of it, namely availability, accessibility, accommodation, affordability, and acceptability. *Availability* defines the supply of services in relation to demand: are the capacity and types of services adequate to meet healthcare demands? *Accessibility* highlights the geographical location of services in relation to population in demand. Geographical barriers, including distance, transportation, and travel time, are often considered in this dimension. *Accommodation* identifies the degree to which services are organized to meet demand, including hours of operation, application procedures, and waiting times. *Affordability* refers to the price of service in regard to people's ability to pay, e.g., their income levels and insurance coverage. Lastly, *acceptability* describes clients' views of health services and how service providers interact with demand, such as barriers linked to gender, culture, ethnicity, and sexual orientation (Cromley and McLafferty, 2011).

The access of a population to healthcare changes over time because it is determined by a range of aspatial and spatial factors that also vary over time. Aspatial factors (from the dimensions of accommodation, acceptability and affordability) involve disparities among people in term of ethnicity, income, language, culture, age, etc. Many longitudinal studies exist on the role of aspatial factors in access to healthcare. For example, Weinick et al. (2000) investigated racial and ethnic differences in access and use of health care services from1977 to1996. Green and Pope (1999) analyzed the role of gender difference in the use of medical services from 1970 to 1971. Choi (2010) and Setia et al. (2011) examined the impacts of immigrant status on the longitudinal changes in access to health care in the USA and Canada, respectively.

Spatial factors (from the dimension of availability and accessibility) considers geographic distributions of demand and supply, and the linkages between them. Compared to the literature on aspatial factors, little is known on how spatially dependent factors impact the temporal variation of healthcare accessibility. To the best of our knowledge, a very small number of studies paid attention to this question. For instance, Luo et al. (2004) examined temporal changes of access to primary physicians in Illinois between 1990 and 2000 in a Geographic Information System (GIS) environment. Cooper et al. (2009) compared spatial access to pharmacies that sell OTC syringes in New York City from 2001 to 2006. Hine and Kamruzzaman (2012) studied the changing patterns in the utilization and geographic access to health services in Great Britain using National Travel Survey data for 1985–2006. All these studies, however, are limited to only mapping the patterns of change in spatial accessibility to healthcare over time, but none of them moved further to examine the respective impacts of the three contributing factors (demand, supply, and transportation linkages) on temporal changes.

3. Methodologies

3.1. A framework for localized factor impact analysis

We here propose a chain substitution method to measure the local impact of factors on healthcare accessibility over time. This method is widely used in financial and economic analysis to estimate the impacts of different factors on regional economic growth or decline (Balakrishnan, 2010; Vaninsky, 1984), but has not been adapted to healthcare accessibility studies yet. Since both healthcare accessibility and regional economies are impacted by interplays between supply and demand, it is appropriate to adopt this method from regional economic analysis to study healthcare accessibility. Specifically, the healthcare accessibility of a location L at time T, denoted as $A_{L,T}$, is formulated as a generic function of three variables (factors) around location L:

$$A_{L,T} = F(P_{L,T}, S_{L,T}, R_{L,T}) \tag{1}$$

where $P_{L,T}$, $S_{L,T}$, $R_{L,T}$ represent the population demands, health service supply, and transport infrastructure around location L at time T, respectively. The function F can have various operational forms that exist in the current literature, for example, the floating catchment area model (Luo and Wang, 2003), the gravity model (Schuurman et al., 2010), the kernel density model (Jones et al., 2008), as well as their combinations.

To examine the impact of each factor on accessibility, the chain substitution method substitutes factors in Eq. (1) one after another with their values at time $T+1$. Specifically, let $Sub_{L,P}$ denote the outcome of function F at location L as a result of substituting the population factor $P_{L,T}$ with $P_{L,T+1}$, while keeping the other two factors constant:

$$Sub_{L,P} = F(P_{L,T+1}, S_{L,T}, R_{L,T})$$

Next, $Sub_{L,S}$ is the outcome of function F at location L by further substituting the supply factor $S_{L,T}$ with $S_{L,T+1}$:

$$Sub_{L,S} = F(P_{L,T+1}, S_{L,T+1}, R_{L,T})$$

Last, $Sub_{L,R}$ represents the outcome of function F at location L by replacing the transport infrastructure factor $R_{L,T}$ with $R_{L,T+1}$. Since all three factors are substituted for time $T+1$ by this step, $Sub_{L,R}$ equals the accessibility at location L at time $T+1$, i.e., $A_{L,T+1}$:

$$Sub_{L,R} = F(P_{L,T+1}, S_{L,T+1}, R_{L,T+1}) = A_{L,T+1}$$

After a chain of substitutions, the impact of each factor on the temporal change of accessibility can be measured in the same order. The impact of population from time T to $T+1$, denoted as $I(\Delta P_L)$, is the difference between $Sub_{L,P}$ and $A_{L,T}$ (the accessibility before any substitution):

$$I(\Delta P_L) = Sub_{L,P} - A_{L,T} = F(P_{L,T+1}, S_{L,T}, R_{L,T}) - F(P_{L,T}, S_{L,T}, R_{L,T}) \tag{2}$$

Subsequently, the impact of health service supply from time T to $T+1$, $I(\Delta S_L)$, can be calculated as $Sub_{L,S}$ subtracting $Sub_{L,P}$:

$$I(\Delta S_L) = Sub_{L,S} - Sub_{L,P} = F(P_{L,T+1}, S_{L,T+1}, R_{L,T}) - F(P_{L,T+1}, S_{L,T}, R_{L,T}) \tag{3}$$

Likewise, the impact of transport infrastructure from time T to $T+1$, $I(\Delta R_L)$, can be calculated as $Sub_{L,R}$ subtracting $Sub_{L,S}$:

$$I(\Delta R_L) = Sub_{L,R} - Sub_{L,S} = A_{L,T+1} - F(P_{L,T+1}, S_{L,T+1}, R_{L,T}) \tag{4}$$

Overall, the sum of the three impact measures, $I(\Delta P_L)$,$I(\Delta S_L)$, and $I(\Delta R_L)$ is the total change of accessibility between