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ANALYSIS OF THE GROWTH AND GEOGRAPHICAL VARIATION OF STROKE CENTERS ACROSS THE UNITED STATES (2008–2017)

by

Gabriel Chen

December 2018

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ANALYSIS OF THE GROWTH AND GEOGRAPHICAL VARIATION OF STROKE CENTERS ACROSS THE UNITED STATES (2008–2017)

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Submitted in partial fulfillment of the
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LIST OF ACRONYMS AND ABBREVIATIONS

AHA	American Heart Association
ASA	American Stroke Association
BAC	Brain Attack Coalition
CDC	Centers for Disease Control and Prevention
CSC	Comprehensive Stroke Center
FPL	Federal Poverty Line
GDP	Gross Domestic Product
HSA	Hospital Service Area
TJC	Joint Commission
PCNASR	Paul Coverdell National Acute Stroke Registry
PSC	Primary Stroke Center
tPA	Tissue Plasminogen Activator

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My thesis journey has been an arduous nine months of whipping the data into shape, coding and re-coding, running endless regressions and translating number after number into a coherent story. I am very grateful to my advisors, Professor Shen and Professor Hsia, for their inputs; in particular, Professor Shen for her constant guidance and for spending hours bouncing ideas, discussing analysis results, and giving me clear direction.

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I. INTRODUCTION

> The care of human life and happiness, and not their destruction, is the first and only object of good government.
>
> —Thomas Jefferson

A. BACKGROUND

According to the Centers for Disease Control and Prevention (2017), "stroke is the fifth leading cause of death for Americans" and the leading cause of long-term disability. Over 795,000 people in the United States suffer from a stroke each year and annually, nearly 140,000 Americans die due to stroke; that is one American death every four minutes (Centers for Disease Control and Prevention [CDC], 2017).

Over the last 20 years, stroke care has become a healthcare priority in the United States as government agencies and practitioners alike seek to educate citizens on stroke prevention and early detection, raise the standards of stroke care; and improve patient outcomes for stroke victims. Since December 2003, the Joint Commission[1] (TJC) introduced the Primary Stroke Center (PSC) certification to achieve these ends (American Heart Association [AHA], n.d.). This certification program is a voluntary evaluation that assesses hospitals on their consistency in achieving clinical outcomes for stroke patients.

Organized stroke care has made progress. In the summary of PSC Policy in the United States, CDC reports that by mid-2009, each state and the District of Columbia had at least one stroke certified PSC (Centers for Disease Control and Prevention [CDC], 2011). A number of other studies, Ying Xian et al. (2011) and Lichtman et al. (2009) also find that PSC hospitals correlate with better stroke patient outcomes, as measured by lower mortality rates.

However, as stroke certification is a voluntary program undertaken by individual hospitals, a key concern is that the growth of stroke centers might be concentrated in certain

[1] The Joint Commission is an organization that sets quality standards for hospitals in the United States and serves as a certifying body for hospitals.

communities, namely, the affluent and urban neighborhoods. If this hypothesis is true, it might have an adverse effect on lower income and rural communities. These communities may be at-risk of not having adequate access to quality stroke care.

B. PURPOSE

The purpose of my study is to examine the hospital characteristics and the population characteristics of communities surrounding hospitals with/without stroke certification programs. The research questions that my study focuses on are:

1. Are there systematic differences in hospital and community characteristics between stroke certified and non-stroke certified hospitals?
2. What is the geographic variation in stroke centers?
3. Among hospitals with stroke certifications, are there systematic differences in hospital and community characteristics between early and late adopters of stroke certifications?

From my findings to these questions, I attempt to identify drivers of stroke certification, in particular, I explore whether economic pressures and market signaling influence a hospital's decision to achieve stroke certification. In addition, my study seeks to highlight at-risk communities that do not have adequate access to quality stroke care.

C. SCOPE AND METHODOLOGY

My research analyzes the growth of stroke certified hospitals over a period of 10 years, between 2008 quarter 1 and 2017 quarter 3. I compare the hospital characteristics of hospitals with and without stroke certifications, investigate the demographics and population characteristics of the communities that stroke-certified and non-stroke hospitals serve, and study the difference in hospital and community characteristics between early and late adopters of stroke certification.

I first consolidate the hospital and population characteristics for each of the 4,584 unique hospitals in my study. I also group these hospitals into five categories: All hospitals, Stroke-Certified (SC) hospitals, Non-Stroke Certified (non-SC) hospitals, Early Adopters and Late Adopters of the PSC program. In order to test for significant differences between categories (i.e., SC vs. non-SC, Early vs. Late adopters), I use a *t*-test for variables where there are sample means; and a *z*-test when testing across sample proportions.

Next, I use the Cox proportional hazard model to perform a survival analysis. I run a multivariate analysis including all hospital/population variables and the key event, stroke certification. This allows me to study characteristics such as income level and the demographics of the population surrounding stroke/non-stroke certified hospitals. This gives me an in-depth analysis of whether there are systemic differences between SC and non-SC; as well as Early and Late adopters. Synthesizing the findings, I identify and make recommendations for the communities that are at-risk and do not have adequate access to quality stroke care.

D. ORGANIZATION

Chapter I introduces my research topic, it describes the background, purpose, scope and methodology of my study. Chapter II is a literature review of previous research relating to stroke certification programs. I summarize how stroke care within the United States has transformed since the turn of the millennium, I also discuss the value of stroke certified hospitals, the need for Comprehensive Stroke Centers and how organized stroke care has progressed. In Chapter III, I describe the analysis software and the data used in my research. I detail how my data has been put together, the computations as well as the key assumptions made during the course of my research. I further detail the methodology used in my data analysis and discuss my hypothesis. Chapter IV discusses my results from the survival analysis I run between the hospital/population characteristics and my key event, stroke certification. In Chapter V I conclude my thesis write-up by summarizing key findings and making my recommendations with regards to my findings.

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II. LITERATURE REVIEW

A review of the existing literature facilitates understanding of (a) how stroke care has transformed across the years in the United States; (b) the value of stroke certification programs; (c) patient access to stroke certified hospitals; and (d) factors influencing stroke certification.

A. STROKE CARE TRANSFORMATION

I discuss the progress of stroke care in the United States and how it has transformed from initiatives to prevent stroke and document stroke data to organized stroke care, to having comprehensive stroke care centers ready to deal with complicated stroke cases and to having different stroke programs now where hospitals can choose to take-up base on their service area's needs and requirements.

1. Initiatives and Recommendations that Launch Organized Stroke Care

Since the turn of the millennium, the U.S. Center for Disease Control and Prevention launched an initiative called "Healthy People 2010" to promote healthy living, combat disease prevention, and design a framework to improve the health of all people in the United States over 10 years (Centers for Disease Control and Prevention [CDC], 2015). Healthy People 2010 identified health threats to citizens and organizes their objectives into 28 focus areas (CDC, 2015). Heart disease and stroke were among these focus areas. Among the goals for this particular focus area were early identification and treatment of heart attacks and strokes (CDC, 2015).

In 2001, the CDC received congressional funding to establish the Paul Coverdell National Acute Stroke Registry (PCNASR) (Centers for Disease Control and Prevention [CDC], 2016). The registry is named after the late U.S. Senator, Paul Coverdell, who suffered a fatal stroke while serving in Congress, the PCNASR identifies, measures, and tracks stroke care outcomes (CDC, 2016). Between 2001 and 2004, the PCNASR set-up prototype registries, identified data elements to be collected, and collected data on the quality of care provided to stroke patients. According to the CDC, results from this phase of the PCNASR highlights that many acute stroke patients did not receive the appropriate stroke care treatments (CDC, 2016).

In between the two initiatives, in June 2000, the Brain Attack Coalition (BAC), a multidisciplinary group of representatives involved with preventing stroke and delivering stroke care, put forth a consensus statement recommending the establishment of Primary Stroke Centers (PSC) (Alberts et al., 2000). In Alberts et al. (2000), the BAC's recommendations centered on 11 aspects: (1) acute stroke teams to deliver care; (2) written care protocols; (3) emergency medical services to ensure rapid evaluation and transport; (4) trained Emergency Department personnel with the ability to diagnose and treat acute stroke patients; (5) stroke units; (6) neurological services; (7) commitment of the medical organization in terms of its support for its people and administration of stroke care; (8) neuroimaging capabilities; (9) availability of laboratory services; (10) tracking of patient outcomes and quality improvements; and (11) educational programs for the stroke center's professional staff, along with annual programs to educate the public on prevention and recognition of stroke.

2. Need for Organized Stroke Care

Findings from Healthy People 2010, PCNASR and the recommendation from the BAC point towards a need for organized stroke care. In December 2003, the Joint Commission[2] with the American Heart Association (AHA) and American Stroke Association (ASA) put in place the PSC certification program (AHA, n.d.). Since then, organizations such as Healthcare Facilities Accreditation Program and Det Norske Veritas have developed stroke certification programs; some states have also put in place their own certification programs. In my study, I focus on whether hospitals are JC stroke certified and do not segregate the certified hospitals by the agency that certifies them. I detail this in Chapter III.

The introduction of the PSC certification serves to increase standards of care for stroke victims by providing a framework for the identification and treatment of stroke

[2] The Joint Commission is the organization that sets quality standards for hospitals in the United States and serves as a certifying body for hospitals.

patients (AHA, n.d.). The certification program is a voluntary evaluation that assesses hospitals on their consistency in reaching clinical outcome measurements for stroke patients, which are in turn based on certain minimum standards for stroke care. Stroke certified centers undergo an onsite review every two years and report on quality measures quarterly. In their summary of PSC Policy in the U.S., CDC reports that by mid-2009, each state and the District of Columbia had at least one stroke-certified PSC (CDC, 2011).

3. Need for Comprehensive Stroke Centers

The focus of the PSC is primarily on improving standards, ensuring necessary staffing/resourcing in appropriate capabilities, training stroke internationalists and public education. In the recommendations for Comprehensive Stroke Centers, the BAC noted that when treating patients with complex stroke types, there is a need for more specialized care and technological resources (Alberts et al., 2005). These patients are likely to need more advanced diagnostics and treatment done by specialists. The BAC thus recommended that Comprehensive Stroke Centers (CSC) be established to handle the full range of stroke patients (Alberts et al., 2005).

In 2012, the Joint Commission, again, collaborating with the AHA and ASA, launched the Advanced Certification for CSCs, distinguished by increased stroke resources, staffing and training necessary for treatment of complex stroke cases (Joint Commission, n.d.a). The Joint Commission also anticipates that overtime, referral networks would be in place so that patients with complex cases are sent to CSC certified hospitals (Joint Commission, n.d.b).

4. Progress of Organized Stroke Care

To date, The Joint Commission's stroke certification program has continued to evolved, and as of this moment, it includes four core certifications based on diagnostic testing, neurosurgical services, and clinical performance standards. The four stroke care certifications, ranking from highest to lowest, are CSC, Thrombectomy-Capable Stroke Center, PSC, and Acute Stroke Ready Hospital. The different levels of certifications reflect differences in the level of resource intensity and highlight the individual hospital's capability to achieve quality results based on the needs of the population it serves. As of

2016, stroke certification data from the JC and Hospital data from AHA show that 1,271 hospitals in the United States are stroke certified (representing 30% of all acute general short-state hospitals in the continental United States).

Govan, Weir and Langhorne (2008), in their paper on organized inpatient (stroke unit) care for stroke, examine if improving inpatient stroke care organization can bring about improvements in stroke patients' survival and recovery. The authors examine trials conducted by various hospitals and stroke centers, comparing stroke unit care vis-à-vis general wards. The authors find that organized stroke unit care is beneficial and compared to non-stroke unit care, stroke unit care reduces the risk of death of stroke patients by 14%, reduces the risk of death or institutionalized care of stroke patients by 18%, and reduces the risk of death or dependency of stroke patients by 18%. A couple of other studies, Ying Xian et al. (2011) and Lichtman et al. (2009), also find that organized stroke care correlates with better patient outcomes, as measured by lower mortality rates. The next section of the literature review discusses these two studies and the value of PSCs in further detail.

B. VALUE OF PRIMARY STROKE CENTERS

In this section, I discuss the value of PSCs in terms of the better patient outcomes achieved by stroke-certified hospitals and how stroke certification may indicate hospital quality.

1. Better Patient Outcomes

Ying Xian et al. (2011) examine the association between admission to stroke centers for acute stroke and mortality. The authors use patient data from admissions to New York State hospitals and identify patients with a principal diagnosis of acute ischemic stroke.[3] Ying Xian et al. (2011) find that admissions to stroke centers are associated with a lower 30-day mortality (2.5% lower mortality rates compared to non-stroke certified

[3] CDC defines three main types of strokes: (a) Ischemic stroke occurs as a result of an obstruction within a blood vessel supplying blood to the brain. This accounts for 87% of all stroke cases; and this is the type of stroke Ying Xian et al. (2011) discusses (b) Hemorrhagic stroke occurs when a weakened blood vessel rupture. the most common cause of hemorrhagic stroke is uncontrolled hypertension (high blood pressure). (c) Transient Ischemic Attack is caused by a temporary clot; often called a "mini stroke".

hospitals). The authors also find that admissions to stroke centers are associated with a greater use of thrombolytic therapy[4] (2.2% higher usage compared to non-stroke certified hospitals).

In another study, Lichtman et al. (2009) examine whether stroke certified centers have better patient outcomes vis-à-vis non-stroke certified hospitals, prior to the establishment of the Joint Commission's (JC) stroke certification program. The authors' hypothesis is that hospitals that are JC certified in the early stages of the JC stroke certification program, outperform the non-JC certified hospitals (i.e., those who were not certified in the early stages of the JC stroke certification program) in terms of stroke patient outcomes, prior to the introduction of the stroke certification program. The study looks at a sample of 5070 hospitals, 317 of which are JC certified in the early stages of the stroke certification program.

Lichtman et al. (2009) finds that JC certified hospitals perform better than their counterparts even before the introduction of PSC certification. Compared to non-JC certified hospitals, the 317 JC certified hospitals have a lower risk of in-hospital mortality, lower risk of 30-day mortality after treatment, and lower risk of readmission 30 days after discharge. The authors highlight that any research that attempts to evaluate the impact of PSCs on patient outcomes should discuss these pre-existing differences. This will prevent studies from incorrectly attributing the benefits of patient outcomes to the PSC certification. The authors also find that hospitals that are JC certified in the early stages of the stroke certification program tend to be larger in terms of bed size, and a substantial proportion (a third) of the 317 hospitals are teaching hospitals.

The results from Lichtman et al. (2009) highlight that it may not be the act of certification, per se, that improves patient outcomes. However, the findings from both Ying Xian et al. (2011) and Lichtman et al. (2009) do suggest that larger hospitals—which typically have a larger staff, bigger administrative team and better resources—as well as

[4] "Most strokes are caused when blood clots move to a blood vessel in the brain and block blood flow to that area. For Ischemic strokes, thrombolytics can be used to help dissolve the clot quickly. Giving thrombolytics within 3 hours of the first stroke symptoms can help limit stroke damage and disability." MedlinePlus (2018).

teaching hospitals that typically have better laid out processes and technical capabilities achieve better stroke patient outcomes. This supports the primary aim of implementing the PSC certification program and highlights how well-organized stroke care, sufficient resourcing, and appropriate capabilities do raise stroke care standards and in turn, patient outcomes.

2. Indication of Quality

Lichtman et al.'s (2009) discussion suggests that the 317 JC certified hospitals were quality stroke centers even before the JC introduced the stroke certification program. This raises an interesting and plausible issue of market signaling at work. The incentive to differentiate their quality from other hospitals within their Hospital Service Area (HSA) could motivate the same 317 hospitals, who are early adopters of the certification program, to take-up stroke certification. I discuss the theory that relates to this thought later in Section D, where I distil insights from existing literature to understand why some hospitals take-up stroke certification and others shy away from the program.

C. TIMELY ACCESS TO STROKE CERTIFIED HOSPITALS

In addition to raising the standards of stroke care and improving patient outcomes, timely access to stroke certified hospitals is also important to reduce the risk of death and disability in stroke patients. Acute ischemic stroke is a time sensitive medical condition and during a stroke, blood flow is cut-off to the brain. The disruption of blood flow is due to a blood clot, and if the clot does not clear and blood circulation to the brain discontinues, this deprives brain cells of oxygen. Where left untreated, this quickly leads to brain death.

Tissue Plasminogen Activator (tPA) is a treatment that works to dissolve blood clots and restores blood circulation to the brain. The treatment needs to be given within 3 hours from the onset of acute ischemic stroke,[5] after which the risks of using this treatment may outweigh the benefits. Hacke et al. (2008) suggests that there may be some evidence that the time window can be up to 4.5 hours from the onset of acute ischemic stroke

[5] The Food and Drug Administration approves the use of tPA within 3 hours from the onset of acute ischemic stroke symptom.

symptoms. However, many academic studies emphasize that the sooner the stroke patient gets the tPA treatment, the greater the benefit of the treatment.

Adeoye et al. (2014) finds that ~66% of the United States population have timely access to a PSC; this number goes up to 91% if air ambulances are used. Compared to an earlier study (i.e., Albright et al, 2010) this represents an increase in the percentage of the United States population that has timely access to a PSC. Timely access is defined as having access to a PSC within 60 minutes[6] and the authors compute this by considering time from the telephone call to the 911 center, time from ambulance dispatch until scene arrival, time spent on-scene with the patient and travel time to the hospital.

D. FACTORS THAT INFLUENCE STROKE CERTIFICATION

One reason for the increase in percentage of United States population having timely PSC access is the growth in the number of stroke certified hospitals. To that end, some research has gone into identifying the characteristics that correlates with stroke certified hospitals. This gives insight on why some hospitals choose to take-up stroke certification and the barriers facing other hospitals from achieving stroke certification.

McDonald et al. (2014) use 2011 American Hospital Association survey data and the 2010 national census data to uncover hospital characteristics and demographic factors influencing PSC certification. The authors perform a univariate analysis, to determine individual factors' association with PSCs. The authors find that PSCs are typically larger (based on number of beds) than their non-stroke certified counterparts, have busier Emergency Departments (56,000 visits versus 24,000 visits annually), utilize inpatient neurological services, correlate with a higher number of households per zip code; and correlate with higher income per household. PSCs also tend not to be government-run health care facilities, they are also not likely to be sole healthcare providers within their community.

[6] While different institutions have varied standards for timeliness, the Military Health System and the California State Department of Managed Health Care developed benchmarks for access and included 60-minute drive time for specialty care.

1. Resourcing and Administration

A lack of resources and complex administration are barriers that hinder stroke certification. In McDonald et al. (2014), the authors discuss how factors such as financial constraints, a lack of medical expertise, administrative constraints and poor coordination work against hospitals achieving stroke certification. The authors also find that hospitals run by government related organizations are significantly less likely to be PSC certified. The same authors note that this phenomenon is especially stark in county hospitals *who play an important role as a safety net for the indigent and the under-served*.

The challenges McDonald et al. (2014) lists are consistent with the findings of O'Toole, Slade, Brewer, and Gase (2011) who perform an in-depth analysis of four states[7] to understand the barriers and facilitators towards implementing a PSC policy within a state. In O'Toole et al. (2011), the study documents the experiences of PSC policy implementations at the state-level and sheds light on factors that impact the certification of stroke centers. Semi-structured interviews were conducted and participants (including state health officials, representatives from AHA and ASA, state stroke advisory committee members) were asked to identify barriers to implementing PSC policy, among other things.

In both McDonald et al. (2014) and O'Toole et al. (2011), the common barriers to stroke certification include (a) a lack of coordination between medical dispatch, emergency medical services and health care delivery systems, (b) insufficient medical expertise, (c) insufficient human and financial resources for the acute stroke team and (d) complexity of public administration and government entity coordination of healthcare delivery. Anecdotally, these four common threads point towards certain hospital types that are less likely to be stroke certified: government run, smaller sized hospitals in rural locations, hospitals in poorer districts. This translates into certain communities (rural, lower income, communities with only government run hospitals, communities with only one health service provider) having no PSCs within a 60-minute drive away. Given the time-sensitivity of stroke treatment, this puts the mention communities in an unfavorable

[7] The authors did a study of the experiences of a sample of four states (Florida, Massachusetts, New Mexico, and New York) that have put in place PSC policies.

position with a higher risk of death and disability should citizens in these populations experience acute ischemic stroke.

2. Market Signaling

Market signaling is another factor that contributes to the growth of stroke certified centers; and explains the geographical variation of PSCs. The unraveling theory under quality disclosures and certification provides further insight on why certain hospital types are early adopters and others stay away from the stroke certification. The theory states that the best quality firm in a certain market would be the first to disclose its quality (i.e., get stroke certified). Once that happens, the second-best firm in the market has an incentive to disclose its quality, and this goes on until the worst firm discloses.

Dranove and Zhe (2010) in their paper on quality disclosure and certification, suggests that top-quality firms (in this case: hospitals) are driven by the incentive to differentiate themselves from their competitors. This is particularly true for hospitals that operate in highly competitive markets (typically urban areas, higher households per zip code and a higher number of hospitals within the same HSA). This can spur an “arms race” for stroke certification and is a possible explanation why urban hospitals have a higher probability of being stroke certified. Consumers, or patients in this case, will infer that hospitals who do not voluntarily achieve stroke certification have inferior standards.

Conversely, the unraveling theory suggests that smaller-sized hospitals, which are typically less well-resourced and have smaller staff numbers, shy away from stroke certification. Given their resourcing challenges, these hospitals may not be top-quality stroke care hospitals and these “average” and “lower quality” hospitals possibly choose not to put themselves up for stroke certification as consumers may not consider non-disclosure as a signal of the lowest quality.

Competition and market signaling also provides insight on why hospitals in rural areas may be less likely to be stroke-certified. Rural hospitals are often located in less competitive markets where there are fewer hospitals and in some cases, only 1 (i.e., monopoly). In these instances, consumers have less choice(s) in terms of healthcare providers, and hospitals have little need to signal their stroke care quality given that they have a “captive-pool” of patients.

3. State Legislation

State legislation is another factor with strong association with the number of stroke certified centers. Uchino, Man, Schold, and Katzan (2015) also looks into factors that correlates with PSC certifications, these authors give weight to how stroke legislation affects the proliferation of certified centers in the United States. The authors use a logistic regression and find that in both univariate and multivariate analysis, PSC certification correlates with state stroke legislation, number of hospital beds, urbanization and state gross domestic product (GDP).

The primary conclusion Uchino et al. (2015) makes is that “state stroke legislation increased the number of stroke certified centers in the United States, potentially improving the accessibility of standardize stroke care for patients with acute ischemic stroke” (p. 1903). The authors further find that larger hospitals are more likely to have more resources and staff to achieve stroke certification. The authors also bring up the issue of market signaling. They discuss the possibility that hospitals in urban areas are more likely to be stroke-certified and this could be due to competition from other hospitals and thus see a need to raise their own care standards upwards. Uchino et al. (2015) also highlight that “the availability of specialize physicians and prioritization of certifying bodies to more populous areas so as to maximize impact” (p. 1906) may also explain why there is a higher probability that urban hospitals are stroke-certified vis-à-vis hospitals in rural areas.

While state stroke legislation may have a positive effect on PSC certification, there lies the possibility of reverse causality. When the number of PSC certified hospitals within a state increases, that might compel the state to impose state legislation or their own certification so as to govern and ensure consistent standards across the hospitals within that state. This suggests that the coefficient of the odds ratio for state stroke legislation may be positively biased.

4. Possible Economic Pressures and Incentives

In Uchino et al. (2015), the unspoken elephant in the room, is state GDP. It is not discussed in detail even though the univariate logistic regression shows that the state GDP correlates with a higher likelihood of having a stroke certified center in that state. This gives some insight that hospitals do face economic pressures and incentives; and this in turn could influence hospitals decision on whether or not to strive for stroke certification.

E. VALUE ADDED TO THIS STUDY

I begin Section D discussing how more hospitals taking up stroke certification can lead to timely access to PSCs for citizens and reduce the risk of death and disability in stroke patients. At the same time, having too many stroke certified hospitals could mean that each PSC does not get sufficient stroke patient volume and stroke certified hospitals may not be truly specialized in treating stroke cases. Going through the existing literature, it is obvious that further proliferation of PSCs may not necessarily achieve better patient outcomes or standards of stroke care across the United States. Instead, having a detailed understanding of the factors that influence stroke certification will enable policy-makers to re-look the stroke care system and consider how they can take stroke care forward.

I study factors influencing stroke certification that previous studies have not deeply investigated. My study adds to the existing literature by examining the association between stroke center certifications and whether there are systematic differences in economic and geographical (urban/rural) characteristics between stroke certified and non-stroke certified hospitals.

I examine how the probability of having a stroke certified hospital in an area increase as the average income of an area increases. I also analyze the geographic variation in stroke center growth and study if there are systematic differences in hospital, in particular, community and geographical characteristics between early and late adopters of stroke certifications. From my analysis, I detail how economic pressures and incentives as well as geographical variation influence hospitals' decision-making when it comes to attaining stroke certification. I also identify at-risk communities, relating to the economic and geographical characteristics, that do not have good access to PSCs.

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III. DATA AND METHODOLOGY

The data for my analysis spans over a 10-year period, from the first quarter of 2008 to the third quarter of 2017. It comprises of hospital characteristics of 4,584 unique hospitals and the population characteristics of the Hospital Service Area (HSA) that each hospital serves.

A. DATA OVERVIEW

My data comes from four sources. The first is from the Joint Commission, which comprises a listing of hospitals that are stroke certified under the JC's PSC certification program. While 2008 is the first year of data availability, the PSC certification program began in 2003. As such, while it appears that 627 hospitals were stroke certified in 2008, they were really first certified over a five-year period from 2003 to 2008. The dataset I obtained from the JC has quarterly stroke certification data beginning 2010; this is the impetus for the timeline in my study to be quarter-year. The JC's dataset includes Comprehensive Stroke Center certification information, however for the purposes of my study, I do not differentiate between the types of stroke certified hospitals; I elaborate on this further under Section B of this chapter.

The second data source is the AHA hospital annual survey which comprises organizational information of the hospitals, such as ownership types, available medical capabilities and number of hospital beds. Given that the AHA annual survey does not include hospital financial information, there is a need to merge the AHA survey information with information from the Healthcare Cost Report Information System (HCRIS). The HCRIS data is taken from my third data source: Centers for Medicare & Medicaid Services (CMS).

My fourth and final data source is the Census Bureau's 2010 Census dataset. This allows me to identify economic and demographic factors of the population surrounding the hospitals in my study. Where certain economic or demographic fields are unpopulated in the 2010 census data, I augment this information with the 2000 census data. The Census Bureau's data lists the economic and demographic factors by zip codes, in order to identify the population characteristics surrounding each hospital, I have to group the census data at the HSA level. An HSA is the region that a hospital serves; and there can be more than one hospital serving an HSA. An HSA is made-up of a number of zip codes whose residents receive their hospitalizations from the hospitals within that HSA. I then aggregate my zip code level population characteristics to an HSA level by using a crosswalk from the Dartmouth Atlas of Health Care which is a crosslink between HSA and zip codes as well as HSA and hospitals.

To arrive at my panel dataset, I merge the quarterly stroke certification information and the AHA hospital annual surveys using the AHA identification number, which is a unique key given to each hospital. Next, I combine that dataset with the HCRIS data using each hospital's Medicare provider identification number. Finally, to add the census data of the population surrounding each hospital, I merge the 2010 census data, aggregated to the HSA level as described earlier, to the existing hospital characteristics dataset using a crosswalk between the HSA number and Medicare provider ID. My study will focus on continental United States, as such, the hospitals of Alaska, Hawaii and Puerto Rico are excluded. The final data set includes a total of 159,345 hospital-quarter observations, representing 4,584 unique hospitals.

My study analyzes the growth of stroke certified hospitals and the variation in hospital and area characteristics between stroke and non-stroke certified hospitals; it also studies how the characteristics between early and late adopters of stroke certification differ. In order to facilitate the analysis, I summarize the number of observations by the following categories in Table 1: All hospitals, Hospitals that never received stroke certification during study period, Hospitals that were stroke certified sometime during the study period, Early adopters of stroke certification; and Late adopters of stroke certification. I define Early adopters to be hospitals that took up stroke certification within the first 5 years of the PSC program implementation (2003-2008); all other hospitals stroke certified after 2008 are classified as Late adopters.

Table 1. Summary of Hospital-Quarter Observations

Categories	Unique hospitals	Hospital-quarter observations
All hospitals	4,584	159,345
Hospitals that never received stroke certification during study period	3,166	105,462
Hospitals that were stroke certified sometime during the study period	1,418	53,883
Early adopters	627	24,082
Late adopters	791	29,801

B. VARIABLE DESCRIPTION

This section provides a detailed explanation of the variables in my analysis. The variables are classified into three broad categories: Event variable, Hospital characteristics and Population characteristics within each HSA.

1. Event Variable

Stroke Certification is the key event in my survival analysis, this event is coded as a binary variable that assigns a value of 1 to hospitals that are stroke certified by the Joint Commission, and 0 otherwise. Of the four stroke-certification program that JC has introduced, a hospital is coded as stroke certified if it received either the PSC or the ACSC (the other stroke certification levels were implemented after the end of the study period). As discussed in Chapter II, PSC program was the first of four programs to be introduced by JC. This event definition allows me to identify and analyze hospitals who are early adopters (certified in 2008 or before) versus late adopters of the stroke certification program; it also allows me to perform a meaningful duration analysis.

2. Hospital Characteristics

Ownership types. There are three hospital ownership type variables that I use in my analysis, they are all binary variables. In the US, hospitals can be organized either as not-for-profit, for-profit or government run hospitals. Based on the American Hospital Association survey, a hospital is coded as for-profit if it is investor-owned hospitals where profits go to shareholders, and 0 otherwise (American Hospital Association, 2014). A hospital is coded as *Not-for-Profit* if it is private hospital controlled by not-for-profit organizations and it is allowed to make a profit, but surplus monies must be reinvested into the hospitals (American Hospital Association, 2014). Finally, *Government hospitals* are operated by the State or Federal government (American Hospital Association, 2014). Where there is no information with regards to the three hospital type variables, a 0 was assigned to that observation. In the multivariate analysis, I use not-for-profit hospitals as the reference group, since they represent the largest type of ownership at over 60% of hospitals in the United States (American Hospital Association, 2018).

Teaching hospitals. I examine two proxies for teaching hospitals. *Teaching* is a stricter variable and assigns a 1 to hospitals that have a resident-to-bed ratio that is greater than 0.25, and 0 otherwise (American Hospital Association, 2014). *Medical school affiliation* assigns a 1 to hospitals that have a resident program affiliated with a medical school (American Hospital Association, 2014). Where there is no information with regards to the two teaching hospital variables, a 0 was assigned to that observation.

Hospital systems and capabilities. I use six hospital system and capability variables in my analysis, they are all binary coded variables. *Member of a System* variable assigns a 1 to a hospital that is either part of a multihospital or a single hospital system, and 0 otherwise (American Hospital Association, 2018). A multihospital system is grouped with at least one other hospital as well as their satellite medical facilities; the hospitals are owned, leased, sponsored or managed by a central organization (American Hospital Association, 2018). A single hospital system is an individual hospital that has several separate specialized facilities. The single hospital meets the system guideline when it brings into membership three or more, or at least 25%, of their owned, or leased non-hospital healthcare organizations (American Hospital Association, 2018). *Critical access* *hospital* variable assigns a 1 to hospitals with this status, and 0 otherwise. Some key critical access hospitals criteria are that the hospital must be located in a State that has an established rural health plan, be located in a rural area, provide 24-hour emergency care services 7 days a week, maintains no more than 25 inpatient beds; and have an annual average length of stay of 96 hours or less per patient for acute care (Centers for Medicare and Medicaid Services, 2017). *Emergency Department* (ED) variable assigns a 1 to hospitals that operate an ED, and 0 otherwise. *Trauma center* variable assigns a 1 to hospitals that operates a trauma center, and 0 otherwise. *Percutaneous Coronary Intervention* (PCI) variable assigns a 1 to hospitals that have the capacity to perform PCI, and 0 otherwise. Finally, a *Coronary Artery Bypass Graft* (CABG) variable that assigns a 1 to hospitals that have the capacity to perform CABG surgery, and 0 otherwise. Where there is no information with regards to the six-hospital system and capability variables, a 0 was assigned to that observation.

Hospital financials. There are two types hospital financial variables I use in my analysis. The first is *Negative net income*, which is a binary variable that assigns 1 to hospitals that have a negative net income, and 0 otherwise. Where there is no information with regards to the net income for that particular year, I back-fill the blanks using the latest available year's net income. My assumption is that financial status tends to correlate highly over time within the same hospital, the net income of a particular hospital is unlikely to change significantly between two consecutive years. Post back-filling, where blanks remain, I filled the blanks with the mean net income ($8,521,260) of all non-blank observations.

The second type of hospital financials I use are the profit margin variables. *Profit margin* is a continuous variable that is computed using the formula: (net revenue – total operating expenditure) / total operating expenditure. I further identify the four quartiles for the profit margin variable and classify each hospital into one of three categories. *Profit margin lower quartile* which is a binary variable that assigns 1 to hospitals with profit margins <= -0.072, and 0 otherwise. *Profit margin inter-quartile* which is a binary variable that assigns 1 to hospitals with profit margins between -0.072 and 0.045, and 0 otherwise.

Profit margin upper quartile which is a binary variable that assigns 1 to hospitals with profit margins above 0.045, and 0 otherwise.

Hospital beds. I make use of the continuous variable, *hospital beds*, which states the number of beds each hospital has. For computation of my descriptive statistics, I categorize the hospitals into five categories: *fewer than 50 beds*, *50 to 99 beds*, *100 to 199 beds*, *200 to 399 beds*; and *400 beds or more*. The variables are self-explanatory and are assigned a value of 1 if they fall within that particular category, and 0 otherwise. Where a hospital has no information with regards to its number of hospital beds, it is grouped in the category *less than 50 beds*.

In my bivariate and multivariate analysis, I further reduce the number of categories to three for ease of analysis and clarity when depicting visualizations: *fewer than 100 beds*, *100 to 399 beds*; and *400 beds or more*. Again, the variables are self-explanatory and binary. Where a hospital has no information with regards to its number of hospital beds, it is grouped in the category *less than 100 beds*.

Case complexity. In my analysis, I make use of the continuous variable, *case-mix*, which refers to the transfer adjusted case mix index score.[8] In general, the higher the index score, the higher the clinical complexity of the cases. In other words, this serves as a proxy of the underlying patient population's sickness in a given hospital. Where a hospital has no information with regards to the case-mix for that particular year, I back-fill the blanks using the latest available year's case-mix. Similar to net income, my assumption is that year-on-year, the case-mix of a particular hospital is unlikely to vary significantly. Post back-filling, where blanks remain, I fill those blanks with the mean case-mix score (1.430) of all non-blank observations. Using *case-mix*, I identify three thirds for the case-mix score and I classify the hospitals into three categories. *Low case-mix* which is a binary variable that assigns a value of 1 to hospitals with a case-mix <= 1.383, and 0 otherwise. *Medium case-mix* which is a binary variable that assigns a value of 1 to hospitals with case-mix scores

[8] The case mix index reflects a hospital's diversity, clinical complexity as well as the needs for resources of the patient population that the hospital treats (HealthData.gov, 2018).

between 1.383 and 1.448, and 0 otherwise. *High case-mix* which is a binary variable that assigns a value of 1 to hospitals with case-mix scores greater than 1.448, and 0 otherwise.

Hospital location. In my analysis, I identify whether each the hospital is situated in an urban or rural locality using the *Urban* variable, which is a binary variable and assigns a value of 1 to hospitals in urban locations, and 0 otherwise.

3. Population Characteristics within HSA

Population demographics. In my analysis, I use a *total population* variable. This is a continuous variable that identifies the total population number within each HSA. This number is also the potential patient base for each hospital.

All else constant, there is a higher chance for older person to suffer from a stroke attack compared to younger one as such I include variables that consider the elderly population within each HSA. In my analysis, I use the variable *elderly* which is a continuous variable that identifies the percentage of over 65 years old population living within an HSA. Using *elderly*, I identify three thirds for *elderly* and classify the hospitals into three categories. *Low share of elderly population* which is a binary variable that assigns a value of 1 to hospitals in an HSA that have a proportion of elderly population of less than or equal to 12.7%, and 0 otherwise. *Medium share of elderly population* which is a binary variable that assigns a value of 1 to hospitals in an HSA that has a proportion of elderly population between 12.7% and equal to 15.9%, and 0 otherwise. *High share of elderly population* which is a binary variable that assigns a value of 1 to hospitals in an HSA that has a proportion of elderly population above 15.9%, and 0 otherwise. The share of elderly population variables will allow me to test whether hospitals located in an HSA with high elderly population have a higher/lower likelihood of being stroke-certified.

Population economic indicators. I study two types of economic indicators, the *mean income* and the *poverty proportions* of the population living in the HSA.

An HSA is made-up of a number of zip codes and the data from the census 2010 survey that is available to me is median income per zip code. The *mean income* variable I use for my analysis is a continuous variable and it is computed by averaging the median income of all the zip codes within each HSA. Using *mean income*, I classify the hospitals into three categories: located in a low-income HSA, a middle-income HSA and a high-income HSA. The categories are then converted in to 3 variables. *Low income* is a binary variable that assigns a value of 1 to hospitals located in an HSA that has a mean income of less than or equal to $52,170, and 0 otherwise. *Middle income* is a binary variable that assigns a value of 1 to hospitals located in an HSA that has a mean income of between $52,170 to $64,216, and 0 otherwise. *High income* is a binary variable that assigns a value of 1 to hospitals located in an HSA that has a mean income of above $64,216, and 0 otherwise.

The *poverty* variable I use for my analysis is a continuous variable that details the percentage of the population in each HSA that is living below the Federal Poverty Line. *Poverty* is computed by dividing the poverty population within an HSA by the total population within the HSA. Using *poverty*, I classify the hospitals into three categories again, located in an HSA with: low share of poverty population, medium share of poverty population and high share of poverty population. The categories are then converted in to 3 variables. *Low share of poverty population* is a binary variable that assigns a value of 1 to hospitals located in an HSA where the proportion of poverty population is less than or equal to 12.1% of the population, and 0 otherwise. *Medium share of poverty population* is a binary variable that assigns a value of 1 to hospitals located in an HSA where the proportion of poverty population is between 12.1% to 16.6% of the population, and 0 otherwise. *High share of poverty population* is a binary variable that assigns a value of 1 to hospitals located in an HSA where the proportion of poverty population is greater than 16.6% of the population, and 0 otherwise.

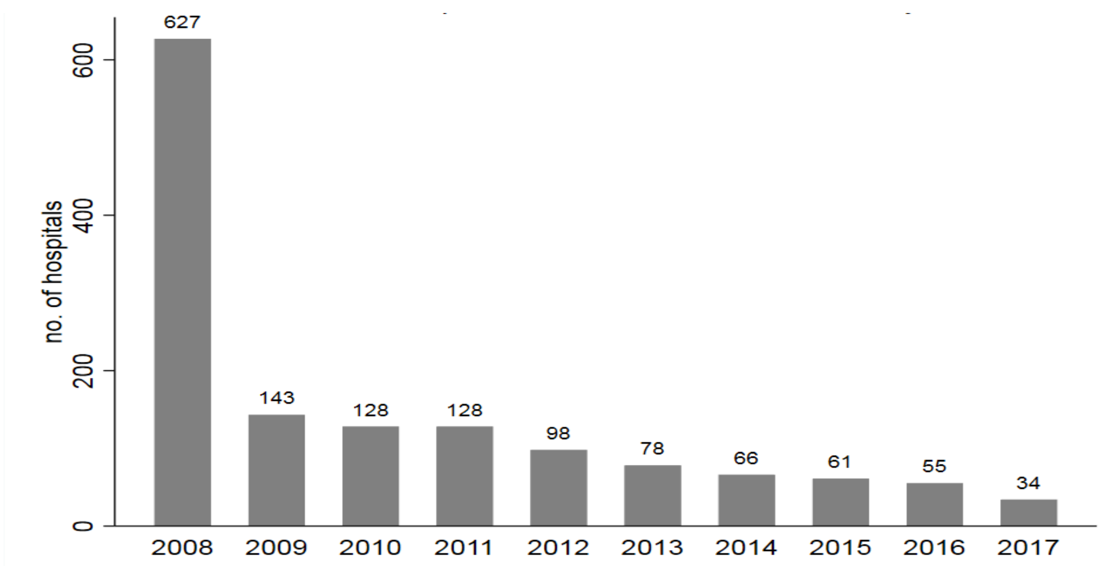
C. DESCRIPTIVE STATISTICS

My descriptive statistics section is further broken down into three segments, the overall summary statistics, comparisons between the characteristics of stroke-certified and non-stroke certified hospitals as well as a comparison between the characteristics of early versus late adopters of stroke certification.

1. Summary Statistics

The summary statistics for hospital and population characteristics are shown in Table 2 and Table 3, respectively. The tables represent one-time snapshot of the hospitals in my sample, and captures the 4,584 hospitals' statistics based on the first quarter-year that each hospital appears in my records. In order to test for significant differences between categories (i.e., SC vs. non-SC, Early vs. Late adopters), I use a t-test for variables where there are sample means; and a z-test when testing across sample proportions.

Across the 10-year span of my study, 1,418 or 31% of the hospitals were stroke certified. In 2008, my sample includes 4,393 hospitals, 627 of which were stroke certified. These 627 hospitals are considered to be early adopters as they took up stroke certification within the first 5 years of the PSC program implementation; all hospitals stroke certified after 2008 are classified as late adopters. By 2017, the number of stroke certified hospitals across the United States swelled to 1,286. This represents a 105% increase in the number of stroke certified hospitals since 2008. Referencing Figure 1, there is a large increase in the number of PSC certifications between 2009 to 2011, before the growth started to taper downwards in 2012; and reduce to only 34 hospitals taking up the PSC program in 2017.



(2008 numbers include all new certifications from 2003–2008)

Figure 1. Number of Stroke Certifications Annually

Across all the 4,584 hospitals in our study, 60% of the hospitals are not-for-profit, 17% are for-profit, and the remaining 22% are government-operated hospitals (either federal or state-operated). In terms of hospital financials, the mean profit margin across all hospitals stands at -0.02 with 1,073 of the hospitals falling in the lowest quartile; and turning in a profit margin of less than -0.07. Separately, 57% of all hospitals in my sample are situated in an urban location.

The descriptive statistics of the population characteristics are shown in Table 3. The statistics are computed based on the population living within the HSA of the hospitals in my study. The average population size in an HSA is 314,046 people and within an HSA, the average share of elderly population stands at 15%. In terms of economic indicators, the mean income across all the HSAs stands at $61,100; and the average share of people living below the federal poverty line is 15%.

2. Stroke-Certified (SC) Versus Non-Stroke Certified (NSC) Hospitals

I find significant differences in the hospital and population characteristics between SC and NSC hospitals. 10% of SC hospitals are government-operated compared to 28% of SC hospitals ($P<0.001$). SC hospitals have a higher likelihood of running a resident program that is affiliated to a medical school compared to NSC hospitals ($P<.001$). In terms of hospital financials, 15% of SC hospitals lie in the lowest quartile of the profit margin distribution as compared to 28% of NSC hospitals ($P<0.001$).

SC hospitals are more likely than NSC hospitals to be part of a system, and more likely to have better hospital resources and capabilities (i.e., ED, trauma center, PCI and CABG capacity). SC hospitals are also more likely than NSC hospitals to manage complex cases (1.53 case-mix vs. 1.32 case-mix, $P<0.001$), and more likely to have a larger number of hospital beds as compared to NSC hospitals (mean of 322 beds vs. 100 beds, $P<0.001$). SC hospitals are also more likely than NSC hospitals to be situated in an urban locality (93% vs. 41%, $P<0.001$).

Significant differences are also observed in the population characteristics surrounding SC hospitals vis-à-vis that of NSC hospitals. Compared to NSC hospitals, I note that SC hospitals tend to be located in HSAs that have a smaller share of low-income population (14% vs. 42%, P<0.001). SC hospitals also tend to be located in HSAs that have a lower share of population living under the federal poverty line (13% vs. 16%, P<0.001). Finally, SC hospitals are more likely to be located in an HSA that has a low share of elderly population (50% vs. 27%, P<0.001).

Table 2. Descriptive Statistics of Hospital Characteristics by Stroke Certification Status

Characteristics	All Hospitals		Non-Stroke Certified Hospitals		All Certified Hospitals		*P* value	Early Adopters		Late Adopters		*P* Value
N	4,584[a]		3,166		1418[b]			627		791		
HOSPITAL CHARACTERISTICS: No. (%), unless otherwise stated												
Not-for-profit hospital	2,748	(60%)	1,726	(55%)	1022	(72%)	0.000	483	(77%)	539	(68%)	0.000
For-profit hospital	799	(17%)	551	(17%)	248	(17%)	0.944	82	(13%)	166	(21%)	0.000
Government hospital	1,018	(22%)	871	(28%)	147	(10%)	0.000	62	(10%)	85	(11%)	0.599
Teaching hospital	309	(7%)	94	(3%)	215	(15%)	0.000	141	(22%)	74	(9%)	0.000
Medical school affiliation	1,038	(23%)	395	(12%)	643	(45%)	0.000	363	(58%)	280	(35%)	0.000
Negative net income	1,881	(41%)	1,324	(42%)	557	(39%)	0.106	244	(39%)	313	(40%)	0.802
Profit margin[c], mean (s.d.)	-0.02	(0.39)	-0.03	(0.17)	0.00	(0.66)	0.054	0.01	(0.12)	-0.02	(0.88)	0.433
Lower quartile	1,073	(23%)	857	(27%)	216	(15%)	0.000	84	(13%)	132	(17%)	0.087
Inter-quartile	2,445	(53%)	1,678	(53%)	767	(54%)	0.494	357	(57%)	410	(53%)	0.055
Upper quartile	1,066	(23%)	631	(20%)	435	(31%)	0.000	186	(30%)	249	(34%)	0.462
Member of a system	2,531	(55%)	1,498	(47%)	1033	(73%)	0.000	452	(72%)	581	(73%)	0.567
Critical access hospital	1,143	(25%)	1,140	(36%)	3	(0%)	0.000	1	(0%)	2	(0%)	0.704
Operates an ED	4,198	(92%)	2,827	(89%)	1371	(97%)	0.000	609	(97%)	762	(96%)	0.406
Operates a trauma center	1,610	(35%)	934	(30%)	676	(48%)	0.000	367	(59%)	309	(39%)	0.000
Has PCI capacity	1,938	(42%)	733	(23%)	1205	(85%)	0.000	571	(91%)	634	(80%)	0.000
Has CABG surgery capacity	1,161	(25%)	278	(9%)	883	(62%)	0.000	458	(73%)	425	(54%)	0.000
Case-mix[d], mean (s.d.)	1.39	(0.24)	1.32	(0.21)	1.53	(0.23)	0.000	1.60	(0.22)	1.47	(0.22)	0.000
Low	1,850	(40%)	1,456	(46%)	394	(28%)	0.000	110	(18%)	284	(36%)	0.000
Medium	1,618	(35%)	1,429	(45%)	189	(13%)	0.000	61	(10%)	128	(16%)	0.000
High	1,116	(24%)	281	(9%)	835	(59%)	0.000	456	(73%)	379	(48%)	0.000

Characteristics	All Hospitals		Non-Stroke Certified Hospitals		All Certified Hospitals		*P* value	Early Adopters		Late Adopters		*P* Value
N	4,584		3,166		1418			627		791		
Hospital beds, mean (s.d.)	169	(189)	100	(119)	322	(222)	0.000	400	(241)	262	(185)	0.000
less than 50 beds	1,377	(30%)	1,358	(43%)	19	(1%)	0.000	1	(0%)	18	(2%)	0.001
50 to 99 beds	824	(18%)	729	(23%)	95	(7%)	0.000	15	(2%)	80	(10%)	0.000
100 to 199 beds	1,015	(22%)	693	(22%)	322	(23%)	0.537	80	(13%)	242	(31%)	0.000
200 to 399 beds	916	(20%)	307	(10%)	609	(43%)	0.000	285	(45%)	324	(41%)	0.090
more than 400 beds	452	(10%)	79	(3%)	373	(26%)	0.000	246	(39%)	127	(16%)	0.000
Urban locality	2,631	(57%)	1,306	(41%)	1325	(93%)	0.000	608	(97%)	717	(91%)	0.000

Abbreviation: ED, emergency department; PCI, percutaneous coronary intervention; CABG, coronary artery bypass graft

[a] Refers to the total number of unique hospitals studied over the 10-year period, between 2008 to 2017. Depending on the availability of records and the individual hospital's time of inception, the number of years tracked may differ from hospital to hospital.

[b] Includes all hospitals that have been stroke certified before 2008 or at some point during the study.

[c] Profit margin is computed based on: (Net revenue – Total operating expenditure) / Total operating expenditure

[d] Hospitals are grouped into 3 categories (low, medium and high case-mix) based on the tertiles of the case-mix distribution across all hospitals.

3. Early Versus Late Adopters

While early and late adopters of the PSC certification program share some common characteristics, there also exists significant differences. While there are no significant differences in hospital financials, early adopters do have a higher likelihood of running a resident program that is affiliated to a medical school compared to late adopters ($P<.001$).

Where hospital capabilities are concerned, early adopters are more likely than late adopters to operate a trauma center; and have PCI as well as CABG capacity. Compared to late adopters, early adopters are also more likely to manage more complex cases (1.60 case-mix vs. 1.47 case-mix, $P<0.001$), and more likely to have a larger number of hospital beds (mean of 400 beds vs. 262 beds, $P<0.001$). Rounding up the hospital characteristics, while early adopters are more likely than late adopters to be situated in an urban locality, I note that over 90% of both early and late adopters are situated in an urban locality (97% vs. 91%, $P<0.001$).

When analyzing the population characteristics surrounding early adopters vis-à-vis late adopters, early adopters tend to be located in HSAs that have a smaller share of low-income population as compared to late adopters (10% vs. 17%, $P<0.001$). Early adopters are also less likely to be located in HSAs considered to have a high share of population living under the federal poverty line (20% vs. 26%, $P<0.01$). Overall, while early and late adopters of the PSC program are similar across numerous hospital and population characteristics, the statistics tell us that the early adopters are better equipped, turn in a higher profit margin; and are located in more affluent neighborhoods.

Table 3. Descriptive Statistics of Population Characteristics

Characteristics	All Hospitals		Non-Stroke Certified Hospitals		All Certified Hospitals		*P* value	Early Adopters		Late Adopters		*P* Value
N	4,584		3,166		1418			627		791		
POPULATION CHARACTERISTICS (HSA) – No. (%), unless otherwise stated												
Population size, mean (s.d.)	314,046	(589,249)	215,583	(512,980)	533,886	(682,057)	0.000	578,152	(662,974)	498,797	(695,228)	0.030
Income, mean (s.d.)	61,100	(17,915)	57,082	(15,476)	70,071	(19,657)	0.000	72,881	(21,159)	67,843	(18,085)	0.000
Low	1,533	33%	1,335	(42%)	198	(14%)	0.000	61	(10%)	137	(17%)	0.000
Middle	1,521	33%	1,111	(35%)	410	(29%)	0.000	181	(29%)	229	(29%)	0.973
High	1,530	33%	720	(23%)	810	(57%)	0.000	385	(61%)	425	(54%)	0.004
Share of poverty population, mean (s.d.)	15%	(6%)	16%	(6%)	13%	(5%)	0.000	13%	(5%)	14%	(5%)	0.045
Low	1,509	33%	933	(29%)	576	(41%)	0.000	263	(42%)	313	(40%)	0.366
Medium	1,536	34%	1,026	(32%)	510	(36%)	0.018	241	(38%)	269	(33%)	0.084
High	1,539	34%	1,207	(38%)	332	(23%)	0.000	123	(20%)	209	(26%)	0.003
Share of elderly population, mean (s.d.)	15%	(4%)	15%	(4%)	13%	(4%)	0.000	14%	(4%)	13%	(4%)	0.004
Low	1,556	34%	853	(27%)	703	(50%)	0.000	293	(47%)	410	(52%)	0.056
Medium	1,521	33%	1,041	(33%)	480	(34%)	0.519	228	(36%)	252	(32%)	0.075
High	1,507	33%	1,272	(40%)	235	(17%)	0.000	106	(17%)	129	(16%)	0.764

[a] Each of the categorical variables (Income, Share of poverty population, Share of elderly population) is divided into low, medium/middle and high based on the tertiles of the distribution of the respective characteristic.

D. METHODOLOGY

Using Stata version 15, I perform a survival analysis of stroke certified hospitals in continental United States, between first quarter of 2008 to last quarter of 2016.[9] The analysis includes hospitals that receive stroke certification prior to the start of the study or at any point during the 35 quarter-year study period.

Using Cox proportional hazards model, I study the number of quarter-years (i.e., duration) from the start of the observation period of each hospital, until the hospital is stroke certified (i.e., exits the "risk window"), or until the end of my study period in 2016 quarter 4 (i.e., right-censored). The hazard function, $h(t)$, which analyzes the probability of a hospital obtaining stroke certification in quarter t, conditional on the hospital NOT being stroke certified up to the start of that time period, t, is given in the following equation:

$$h(t) = \lim_{\Delta t \to 0} \frac{\Pr(t < T < t + \Delta t \mid t < T)}{\Delta t}$$

where T is the time to stroke certification.

I start with a set of simple bivariate models, where I implemented the Cox proportional hazard model between individual hospital/population characteristics and stroke certification. The significance level provides me with an understanding of the net or overall effect (not the partial effect) of each individual characteristic (e.g., low, middle and high income) on stroke certification. In the second set of analysis, I run a multivariate analysis including all hospital/population variables. This allows me to study the partial effect of each characteristic in the full model. I also run four stratified models that allow me to remove the variation in certain variables (i.e., Locality and Hospital size) and study the partial effect of the remaining variables.

My hypothesis is that the decision to seek stroke certification is highly influenced by economic factors; and accordingly, stroke certified hospitals are more likely to be located in affluent communities where patients have a higher likelihood of affording the

[9] 2017 data is dropped for the survival analysis as there is not hospital characteristics information aside from whether the hospital is stroke certified or not.

treatment. Given the focus of my study, I plot cumulative hazard curves by mean income of the surrounding population, share of population living under the federal poverty line, hospital ownership status and profit margins of hospitals. In Chapter IV, I investigate the findings of the survival analysis, this allows me to highlight one slice of the systemic differences across stroke certified versus non-stroke certified hospitals.

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IV. RESULTS AND FINDINGS

I discuss the findings of my analysis in four sections, namely the effect of *economic variables*, *geography related variables*, *hospital characteristics* and *demographics* on achieving stroke certification. Under each section, I discuss the results of the cumulative hazard curve, the hazard ratio of the bivariate model (Table 4) and the hazard ratio of the multivariate models (Tables 5 and 6).

Table 4. Bivariate Hazard Ratios of Hospitals Achieving Stroke Certification, 2008 to 2016

		Bivariate	
		HR	[95%CI]
	Economic[a]		
Income level			
	High	1.0	[reference]
	Middle	0.4***	[0.4,0.5]
	Low	0.2***	[0.2,0.2]
Share of poverty population			
	Low	1.0	[reference]
	Medium	0.8***	[0.8,1.0]
	High	0.5***	[0.4,0.6]
Hospital ownership			
	Not-for-profit	1.0	[reference]
	For-profit	0.8**	[0.7,0.9)]
	Government	0.3***	[0.3,0.4]
Profit margin			
	Inter-quartile	1.0	[reference]
	Lower-quartile	0.5***	[0.4,0.6]
	Upper-quartile	1.5***	[1.3,1.7]
	Geographical Variation		
Rural locality		1.0	[reference]
Urban locality		15.2***	[12.1,19.0]
Non-critical access hospital		1.0	[reference]
Critical access hospital		0.0***	[0.0,0.0]
Non-stroke belt states		1.0	[reference]
Stroke belt states[b]		0.7***	[0.6,0.8]

[a]Each categorical variable was divided into 3 groups, low, medium and high base on the tertiles of distribution for that variable.

[b]The stroke belt states consists Mississippi, Tennessee, Louisiana, Georgia, North Carolina, Alabama, South Carolina and Arkansas.

		Bivariate	
		HR	[95%CI]
Hospital size and capacities			
Hospital beds			
	Below 100 beds	1.0	[reference]
	100 to 399 beds	14.4***	[11.7,17.8]
	400 beds and above	35.9***	[28.6-44.9]
Non-medical school affiliation		1.0	[reference]
Medical school affiliation		3.9***	[3.5,4.3]
No CABG surgery capacity		1.0	[reference]
Has CABG surgery capacity		7.7***	[6.9,8.6]
No PCI capacity		1.0	[reference]
Has PCI capacity		10.4***	[9.0,12.0]
Not member of a system		1.0	[reference]
Member of a system		2.7***	[2.4,3.1]
Case-mix index[c]			
	Low	1.0	[reference]
	High	7.7***	[6.9,8.6]
Demographics			
Share of elderly population[d]			
	Low	1.0	[reference]
	Medium	0.6***	[0.6,0.7]
	High	0.3***	[0.3,0.3]
Log(total population)		1.6	[1.6,1.7]
N		119,438	

Abbreviations: HR, Hazard Ratios; CI, confidence interval; CABG, coronary artery bypass graft; PCI, percutaneous coronary intervention

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[c]Case-mix index was only categorized into two groups low and high. The category high consists of the highest one-third of the case-mix distribution.

[d]This categorical variable was divided into 3 groups, low, medium and high base on the tertiles of distribution of the share of elderly population.

Table 5. Multivariate Hazard Ratios of Hospitals Achieving Stroke Certification, 2008 to 2016

		Model 1 (without poverty variable)		Model 2 (without income variable)	
		HR	[95%CI]	HR	[95%CI]
Economic[a]					
Income level					
	High	1.0	[reference]	X	
	Middle	0.8^{***}	[0.7,0.9]	X	
	Low	0.6^{***}	[0.5,0.7]	X	
Share of poverty population					
	Low	X		1.0	[reference]
	Medium	X		0.7^{***}	[0.6,0.8]
	High	X		0.6^{***}	[0.5,0.7]
Hospital ownership					
	Not-for-profit	1.0	[reference]	1.0	[reference]
	For-profit	0.9^{*}	[0.7,1.0]	0.8^{*}	[0.7,1.0]
	Government	0.9	[0.7,1.1]	0.9	[0.7,1.0]
Profit margin					
	Inter-quartile	1.0	[reference]	1.0	[reference]
	Lower-quartile	0.7^{***}	[0.6,0.8]	0.7^{***}	[0.6,0.8]
	Upper-quartile	1.2^{*}	[1.0,1.3]	1.1^{*}	[1.0,1.3]
Geographical Variation					
Rural locality		1.0	[reference]	1.0	[reference]
Urban locality		2.2^{***}	[1.7,2.8]	2.2^{***}	[1.7,2.8]
Non-critical access hospital		1.0	[reference]	1.0	[reference]
Critical access hospital		0.1^{***}	[0.0,0.2]	0.1^{***}	[0.0,0.2]

[a]Each categorical variable was divided into 3 groups, low, medium and high base on the tertiles of distribution for that variable.

	Model 1 (without poverty variable)		Model 2 (without income variable)	
	HR	[95%CI]	HR	[95%CI]
Hospital size and capacities				
Hospital beds				
Below 100 beds	1.0	[reference]	1.0	[reference]
100 to 399 beds	3.0***	[2.4,3.8]	2.9***	[2.3,3.7]
400 beds and above	3.7***	[2.8,4.8]	3.6***	[2.7,4.7]
Non-medical school affiliation	1.0	[reference]	1.0	[reference]
Medical school affiliation	1.2*	[1.0,1.3]	1.2*	[1.0,1.3]
No CABG surgery capacity	1.0	[reference]	1.0	[reference]
Has CABG surgery capacity	1.4***	[1.2,1.6]	1.4***	[1.2,1.6]
No PCI capacity	1.0	[reference]	1.0	[reference]
Has PCI capacity	1.7***	[1.4,2.1]	1.7***	[1.4,2.0]
Not member of a system	1.0	[reference]	1.0	[reference]
Member of a system	1.5***	[1.3,1.7]	1.5***	[1.3,1.7]
Case-mix index[b]				
Low	1.0	[reference]	1.0	[reference]
High	1.6***	[1.4,1.9]	1.6***	[1.4,1.9]
Demographics				
Share of elderly population[c]				
Low	1.0	[reference]	1.0	[reference]
Medium	1.0	[0.9,1.2]	1.0	[0.9,1.2]
High	1.3**	[1.1,1.5]	1.2*	[1.0,1.4]
Log(total population)	1.1**	[1.0,1.1]	1.2***	[1.1,1.3]
N	119,438		119,438	

Abbreviations: HR, Hazard Ratios; CI, confidence interval; CABG, coronary artery bypass graft; PCI, percutaneous coronary intervention

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[b]Case-mix index was only categorized into two groups low and high. The category high consists of the highest one-third of the case-mix distribution.

[c]This categorical variable was divided into 3 groups, low, medium and high base on the tertiles of distribution of the share of elderly population

Table 6. Stratified Multivariate Hazard Ratios of Hospitals Achieving Stroke Certification, 2008 to 2016

		Model 3 (urban hospitals)		**Model 4 (rural hospitals)**		**Model 5 (small[a] hospitals)**		**Model 6 (big[b] hospitals)**	
		HR	[95%CI]	HR	[95%CI]	HR	[95%CI]	HR	[95%CI]
Economic									
Income level[c]									
	High	1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
	Middle	0.7***	[0.7,0.8]	1.1	[0.5,2.5]	0.4***	[0.3,0.7]	0.8***	[0.7,0.9]
	Low	0.6***	[0.5,0.7]	0.6	[0.3,1.4]	0.3***	[0.2,0.5]	0.6***	[0.5,0.7]
Hospital ownership									
	Not-for-profit	1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
	For-profit	0.9	[0.7,1.0]	0.9	[0.5,1.7]	0.7	[0.4,1.1]	0.9	[0.7,1.0]
	Government	0.9	[0.8,1.1]	0.7	[0.3,1.6]	0.4	[0.2,1.1]	0.9	[0.8,1.1]
Profit margin									
	Inter-quartile	1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
	Lower-quartile	0.7***	[0.6,0.8]	0.8	[0.4,1.7]	0.4**	[0.2,0.7]	0.7***	[0.6,0.9]
	Upper-quartile	1.1*	[1.0,1.3]	1.7*	[1.1,2.8]	1	[0.7,1.5]	1.1*	[1.0,1.3]
Geographical variation									
Rural locality		X		X		1.0	[reference]	1.0	[reference]
Urban locality		X		X		2.5**	[1.4,4.4]	2.0***	[1.5,2.6]
Non-critical access hospital		1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
Critical access hospital		0.1*	[0.0,0.6]	0.1***	[0.0,0.3]	0.1***	[0.0,0.3]	0	[0.0,0.0]

The variables used in Model 1 are the same variables used in Models 3 to 6. The difference is that Models 3 to 6 are stratified based on the descriptions listed under the header of Table 6.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[a]Small hospitals refer to hospitals with less than 100 beds.

[b]Big hospitals refer to hospitals with 100 beds or more.

[c]The categorical variable was divided into 3 groups, low, medium and high base on the tertiles of distribution for mean income.

		Model 3 (urban hospitals)		Model 4 (rural hospitals)		Model 5 (small hospitals)		Model 6 (big hospitals)	
		HR	[95%CI]	HR	[95%CI]	HR	[95%CI]	HR	[95%CI]
Hospital size and capabilities									
Hospital beds									
	Below 100 beds	1.0	[reference]	1.0	[reference]	X		X	
	100 to 399 beds	2.9***	[2.3,3.7]	3.3***	[1.7,6.3]	X		X	
	400 beds and above	3.6***	[2.7,4.9]	10.9***	[3.1,37.6]	X		X	
Non-medical school affiliation		1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
Medical school affiliation		1.1*	[1.0,1.3]	1.8*	[1.0,2.9]	1.2	[0.7,2.0]	1.2**	[1.1,1.3]
No CABG surgery capacity		1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
Has CABG surgery capacity		1.3**	[1.1,1.5]	2.7**	[1.4,5.3]	1.4	[0.8,2.6]	1.5***	[1.2,1.7]
No PCI capacity		1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
Has PCI capacity		1.7***	[1.4,2.1]	1.2	[0.6,2.3]	2.5***	[1.7,3.7]	1.6***	[1.3,1.9]
Not member of a system		1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
Member of a system		1.5***	[1.3,1.7]	1.9*	[1.1,3.2]	2.1**	[1.3,3.4]	1.4***	[1.2,1.6]
Case-mix index[d]									
	Low	1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
	High	1.6***	[1.4,1.9]	1.7	[0.9,3.0]	1.2	[0.8,1.9]	1.7***	[1.4,1.9]
Demographics									
Share of elderly population									
	Low	1.0	[reference]	1.0	[reference]	1.0	[reference]	1.0	[reference]
	Medium	1	[0.9,1.2]	0.9	[0.4,1.7]	1	[0.6,1.5]	1.1	[0.9,1.2]
	High	1.3*	[1.0,1.5]	1.4	[0.7,2.8]	1.3	[0.7,2.2]	1.4***	[1.1,1.6]
Log(total population)		1.1*	[1.0,1.1]	1.3*	[1.0,1.7]	1	[0.8,1.1]	1.1***	[1.1,1.2]
N		55,103		64,336		73,787		45,697	

Abbreviations: HR, Hazard Ratios; CI, confidence interval; CABG, coronary artery bypass graft; PCI, percutaneous coronary intervention

[d]Case-mix index was only categorized into two groups low and high. The category high consists of the highest one-third of the case-mix distribution.

A. ECONOMIC RELATED VARIABLES

In Figure 2, I show the Cox proportional cumulative hazard curves of all hospitals by income level, poverty level, hospital ownership and profit margin. In my survival analysis, "failure" is where a hospital achieves stroke certification. The hazard rate is thus probability that a hospital achieves stroke certification in each time period (i.e. quarter-year), given that it has not achieved such certification in the previous quarter. The cumulative hazard is then the summation of hazard rates across the study period.

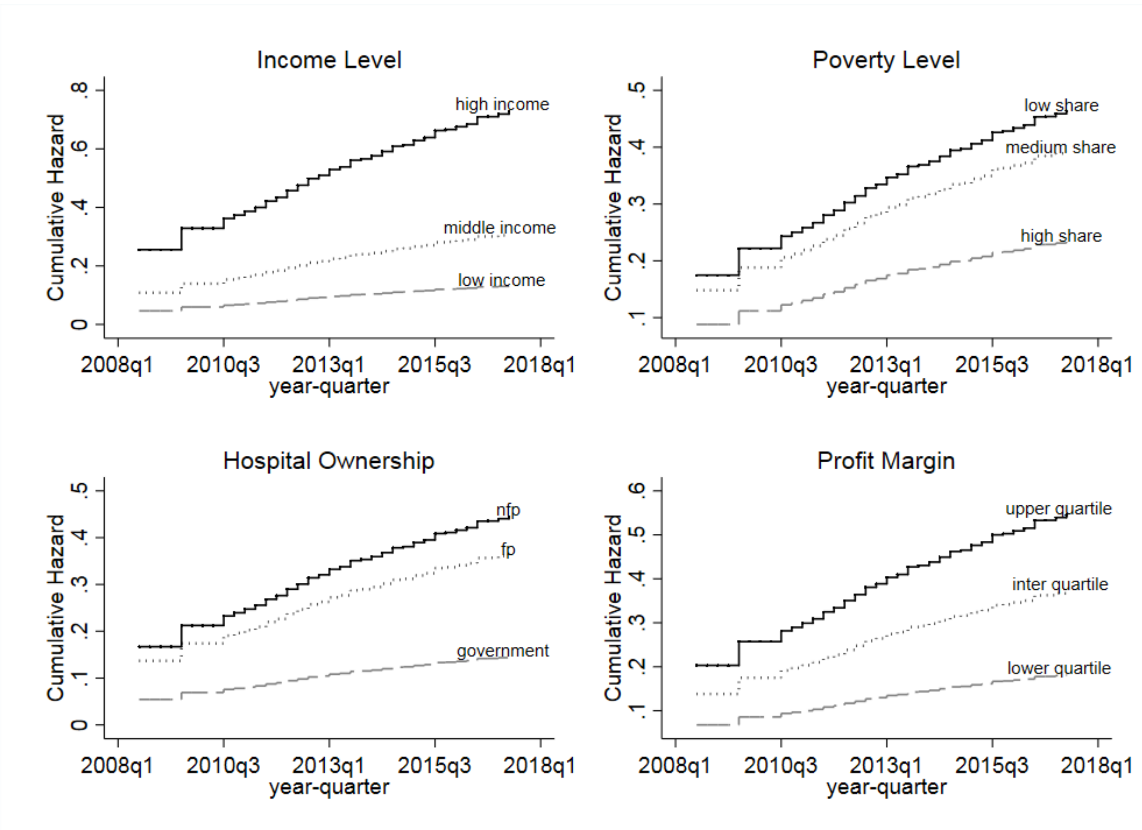

Figure 2. Cox Proportional Cumulative Hazard Curves of Hospitals by Economic Related Variables

At the end of the study period, fourth quarter 2016, the cumulative hazard of a hospital in a high-income Hospital Service Area (HSA) (i.e., mean income >$64,216) is about 73%, compared with 30% for hospitals in middle income HSAs (i.e., mean income between \$52,170 to \$64,216) and 13% for hospitals in low income HSAs (i.e., mean income < \$52,170). For poverty level, the cumulative hazard of a hospital in an HSA with a low share of population living below the Federal Poverty Line (FPL) (i.e., less than 12.1% of population), is about 47%. This is compared to 39% for hospitals in an HSA with a medium share of population living below the FPL (i.e., 12.1% to 16.6% of population) and 23% for hospitals in an HSA with a high share of population living below the FPL (i.e. greater than 16.6% of population). In terms of hospital ownership, the cumulative hazard of a not-for-profit hospital achieving stroke certification is about 45%. This is compared with 36% for for-profit hospitals and 14% for government hospitals. For profit margin, the cumulative hazard of a hospital in the upper quartile of profit margin distribution (i.e., profit margin > 4.5%), achieving stroke certification is about 55%. This is compared with 37% for hospitals in the inter-quartile of profit margin distribution (i.e., profit margin between -7.2% to 4.5%) and 18% for hospitals in the lower quartile of profit margin distribution (i.e. profit margin below -7.2%).

In my bivariate analysis (Table 4), hospitals in a middle-income and low-income HSAs are less likely to achieve stroke certification than hospitals in a high-income HSA (respectively, Hazard Ratio [HR], 0.4; 95% CI, 0.4 – 0.5; HR 0.2; 95% CI, 0.2 – 0.2). For poverty level, hospitals in an HSA with medium share of population living under the FPL are less likely to achieve stroke certification than hospitals in an HSA with a low share of population living under the FPL (HR, 0.8; 95% CI, 0.8 – 1.0). Hospitals in an HSA with high share of population living under the FPL are also less likely to achieve stroke certification than hospitals in an HSA with a low share of population living under the FDL (HR, 0.5; 95% CI, 0.4 – 0.6). In terms of hospital ownership, for-profit hospitals are less likely to achieve stroke certification as compared to a not-for-profit hospital (HR, 0.8; 95% CI, 0.7 – 0.9). Government run hospitals are also less likely to achieve stroke certification compared to a not-for-profit hospital (HR, 0.3; 95% CI, 0.3 – 0.4). In terms of profit margins, hospitals in the lower quartile of profit margin distribution are less likely to achieve stroke certification than hospitals in the inter-quartile of profit margin distribution (HR, 0.5; 95% CI, 0.4 – 0.6). Hospitals in the upper quartile of profit margin distribution are more likely to achieve stroke certification than hospitals in the inter-quartile of profit margin distribution (HR, 1.5; 95% CI, 1.3 – 1.7).

In Table 5, I detail the results of my survival analysis with two multivariate models. Model 1 excludes the poverty variables and Model 2 excludes the income variables. I did not run a model with both income and poverty variables together as the income and the poverty variables are highly correlated and will bring about the problem of multicollinearity.

In my multivariate analysis (Table 5), the hazard ratio of income variables (for Model 1) and poverty variables (Model 2) are consistent with my hypothesis. After controlling for other area and hospital characteristics, hospitals in more affluent HSAs (i.e., higher income level, less share of poverty population) continue to be more likely to achieve stroke certification. Specifically, the hazard of hospitals in middle-income HSAs to achieve stroke certification is 0.8 relative to hospitals in high-income HSAs (95% CI, 0.7 – 0.9); the hazard of hospitals in low-income HSAs to achieve stroke certification is 0.6 (95% CI, 0.5 – 0.7). In terms of profit margins, hospitals in the lower quartile of profit margin distribution are less likely to achieve stroke certification than hospitals in the inter-quartile of profit margin distribution (HR, 0.7; 95% CI, 0.6 – 0.8). Hospitals in the upper quartile of profit margin distribution are more likely to achieve stroke certification than hospitals in the inter-quartile of profit margin distribution (HR, 1.2; 95% CI, 1.0 – 1.3).

I further examine whether urban versus rural hospitals and small (< 100 beds) versus big (> 100 beds) hospitals behave similarly when it comes to achieving stroke certification. I do so by running four stratified models. In Table 6, I report the results of the stratified models, Model 3 (Column 1) for urban hospitals only, Model 4 (Column 2) for rural hospitals only, Model 5 (Column 3) for small hospitals only and Model 6 (Column 4) for big hospitals only.

For stratified Model 3 (Table 6), I include only the observations for urban hospitals. The HRs are similar to that of Model 1. Specific for the income variables, I find that hospitals in middle-income HSAs are less likely to achieve stroke certification than hospitals in high-income HSAs (HR, 0.7; 95% CI, 0.7 – 0.8). Also, hospitals in low-income

HSAs are less likely to achieve stroke certification than hospitals in high-income HSAs (HR, 0.6; 95% CI, 0.5 – 0.7). In Model 4, where I include only the observations of rural hospitals, I observe a different pattern. Among rural hospitals, the hazard of achieving stroke certification is similar across income level of the community—the hazard ratio is close to one and not statistically significant when restricting the analysis to rural hospitals. In Models 5 and 6, the results for the income variables behave expectedly. What is interesting to note is where I limit my observations to only small hospitals, the effect of population income levels on achieving stroke certification, becomes more pronounced. For small hospitals, the hazard ratio of achieving stroke certification among hospitals in middle-income and low-income HSAs are 0.4 (95% CI, 0.3 – 0.7) and 0.3 (95% CI, 0.2 – 0.5), respectively, compared to hospitals in high-income HSAs.

B. GEOGRAPHICAL RELATED VARIABLES

In Figure 3, I show the Cox proportional cumulative hazard curve of all hospitals by Urban locality. At the end of the study period, the cumulative hazard of a hospital in an Urban locality achieving stroke certification is about 67%, compared with about 4% for hospitals in a rural locality.

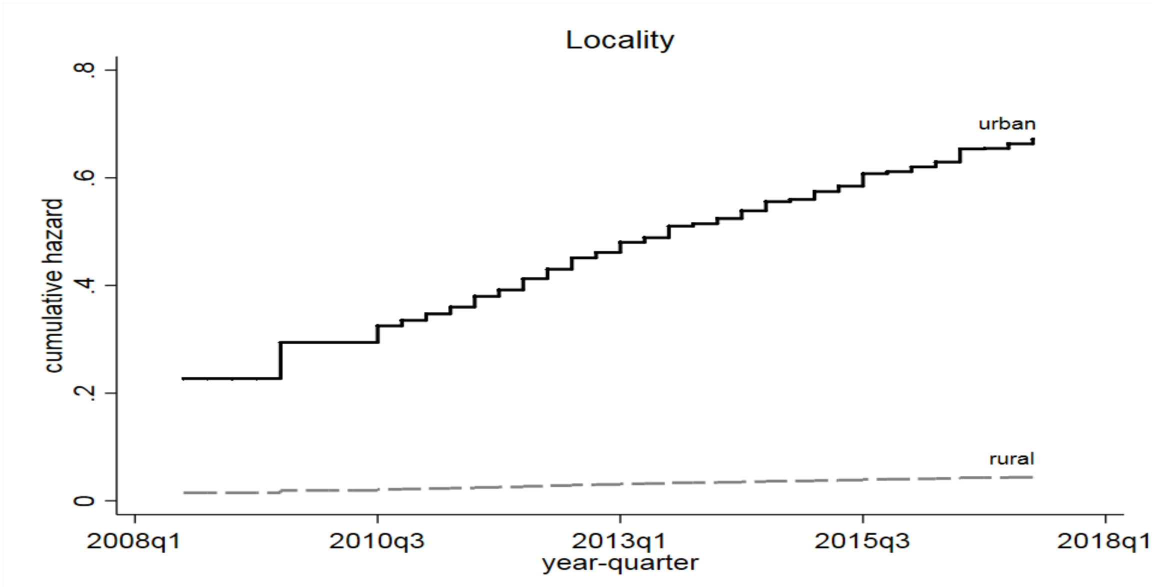

Figure 3. Cox Proportional Cumulative Hazard Curves of Hospitals by Locality

In terms of bivariate analysis (Table 4), hospitals in urban locations are more likely to achieve stroke certification than hospitals in rural locations (HR, 15.2; 95% CI, 12.1 – 19.0). In my multivariate analysis, Model 1 (Table 5), I find that hospitals in an urban location are more likely to achieve stroke certification than hospitals in a rural location (HR, 2.2; 95% CI, 1.7 – 2.8).

C. HOSPITAL CHARACTERISTICS

In Figure 4, I show the Cox proportional cumulative hazard curve of all hospitals by hospital beds. In addition to hospital beds which indicates hospital size, I describe the results for medical school affiliation as well. I use medical school affiliation as a proxy of resourcing and medical capabilities. I am assuming that, in general, medical school affiliated hospitals are better resourced and have better capabilities for learning purposes.

At the end of the study period, the cumulative hazard of hospitals with 400 or more beds achieving stroke certification is about 166%, compared to 67% for hospitals with 100 to 399 beds and 5% for hospitals with less than 100 beds. In terms of medical school affiliation, the cumulative hazard of a hospital with medical school affiliation achieving stroke certification is 91%. This is compared to 23% for hospitals with no medical school affiliation.

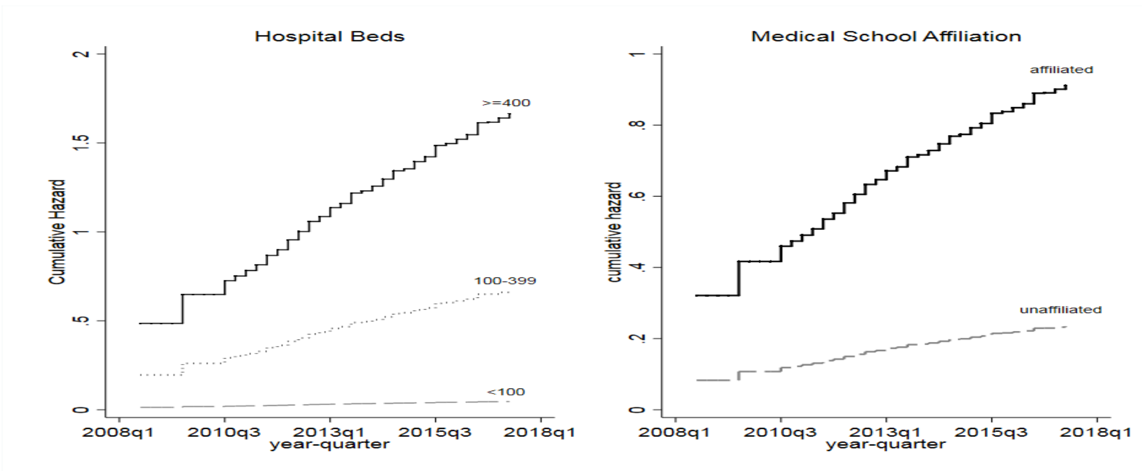

Figure 4. Cox Proportional Cumulative Hazard Curves of Hospitals by Hospital Characteristics

In my bivariate analysis (Table 4), I find that larger hospitals have higher probability of obtaining stroke certification. Compared to hospitals with fewer than 100 beds, the hazard ratio of hospitals with 100 to 399 beds is 14.4 (95% CI, 11.7 – 17.8); the hazard ratio of hospitals with 400 beds or more are 35.9; 95% CI, 28.6 – 44.9). After controlling for other hospital and HSA characteristics, the corresponding hazard ratio is 3.0 (95% CI, 2.4 – 3.8) and 3.7 (95% CI, 2.8 – 4.8) for hospitals with 100 to 399 beds and those with 400 or more beds, respectively. In terms of medical school affiliation, hospitals with medical school affiliation are more likely to achieve stroke certification than hospitals with no medical school affiliation (HR, 3.9 in bivariate model [CI, 3.5 – 4.3], and 1.2 in multivariate model [CI, 1.0 – 1.3)).

In Model 3 (Table 6), where observations are restricted to urban hospitals, the results for hospital beds remain consistent as per Model 1. However, in Model 4 (Table 6), where the observations are restricted to rural hospitals, the effect of bed size on achieving stroke certification increases substantially, particularly for hospitals with 400 beds and above. In Model 4, the hazard ratio of hospitals with 400 beds and above to achieve stroke certification is more than 10 times higher than hospitals with less than 100 beds (HR, 10.9; 95% CI, 3.1 – 37.6). Similarly, the effect of medical school affiliation is also more pronounced when restricting to rural hospitals (HR, 1.8; 95% CI, 1.1 – 2.9).

Separately, I examine whether the rate of adopting stroke center certification across income levels vary systematically by period. Specifically, I implemented interaction models that include *period x income level* interaction terms to Model 1. However, after including these interaction terms into my analysis, I observe that their results are not statistically significant across periods (results available upon request).

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V. CONCLUSION AND RECOMMENDATIONS

My analysis on the growth of stroke-certified hospitals over the study period of 2008 to 2017 identifies the hospital and population characteristics that strongly correlates with hospitals achieving stroke certification. In this chapter I discuss these characteristics as well as the communities who are at-risk of not having good access to stroke certified hospitals and as a result, quality stroke care.

Hospitals in low income Hospital Service Areas (HSA) are 40% less likely to achieve stroke certification than hospitals in high income HSAs. My primary finding is that economic incentives and drivers appear to be associated to whether a hospital achieves stroke certification. Hospitals that achieve stroke certification tend to be located in HSAs that have higher mean income, lower share of population living under the Federal Poverty Line (FPL) and higher profit margins.

While I will discuss the anomaly for Model 4 briefly, my primary finding is that economic incentives do shape hospitals' behaviors and influence whether hospitals decide to become for stroke-certified. I would like to suggest two possible reasons. Firstly, hospitals are incentivized to strive for stroke certification and achieve higher stroke care standards when their clientele are ready and able to pay for such care services. This is not unlike any other luxury goods/service provider who are willing to invest in additional features over plain vanilla equivalents, if they are able to charge a premium for their goods/services. I would recommend that further research analyzing service offering and patient insurance distribution between stroke certified and non-stroke certified hospitals to provide more insight on their differences. Secondly, there may be a possible effect related to reverse causality. People who are affluent are more likely to value their health and they may opt to move to HSAs where there is good access to quality stroke care. More affluent people moving to an HSA where there is a stroke-certified hospital will increase the mean income of the area.

That said, regardless of the reason for the association between population income and achieving stroke certification, what is apparent across both explanations is that there are less stroke-certified hospitals in low income communities and these communities are at-risk of not having good access to quality stroke care.

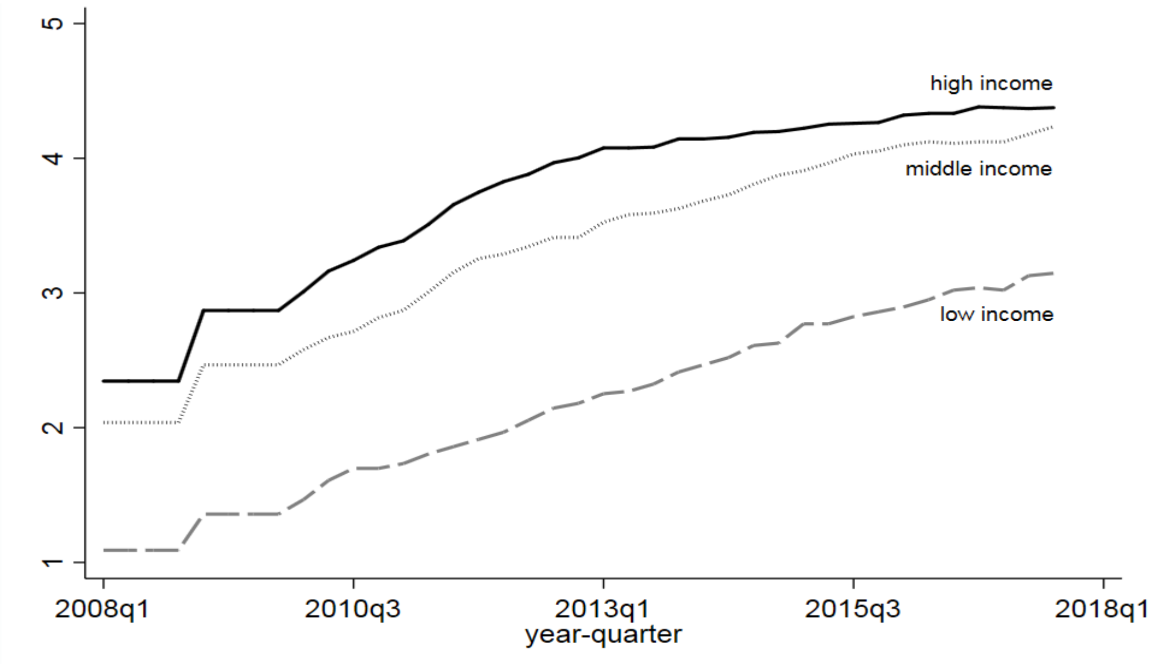

Figure 5. No. of Stroke-Certified Hospitals Per 1,000,000 Residents

As an aside, I do note that when I restricted the observations solely to rural hospitals (Model 4), the income and poverty variables are not statistically significant at the 95% level. I also observe that the effect of bed size and hospital capabilities (i.e., PCI capacities, CABG capacities) on achieving stroke certification increases substantially. This highlights that specific for rural hospitals, hospital size, resourcing and medical capacities may have a bigger impact than population mean income on whether or not a hospital achieves stroke certification.

Hospitals located in urban localities are 120% more likely to achieve stroke certification than hospitals located in rural localities. While a different method was employed in my study, this result is consistent with Uchino, Man, Schold and Katzan (2015) findings that stroke certification correlates with urbanization. Many rural hospitals typically play a role as a critical access hospital for the people living in these communities.

A unique characteristics of critical access hospitals are that they have to be more than 35 miles away from another hospital. As rural and critical access hospitals are less likely to be stroke certified, it also means that the rural communities that they serve are at risk of not having adequate access to quality stroke care and may have to travel a significant distance before they have access to a stroke-certified hospital.

Early adopters are more likely than late adopters to manage complex cases (1.60 case-mix vs. 1.47 case-mix). In Chapter III, I discuss some of the similarities and differences among hospitals that are early adopters of the stroke certification program (i.e., stroke-certified in 2008 or before) and hospitals I consider to be late adopter of the stroke certification program (i.e., stroke certified in 2009 or after). There are highly significant differences in the hospital capacities between early and late adopters. Early adopters are more likely than late adopters to have additional services that are generally considered to be profitable (such as trauma center, percutaneous coronary intervention capacity, and coronary artery bypass graft capacity). Early adopters are also capable of managing more complex patient cases as highlighted by the higher case-mix index. Further to that, there are also significant differences between these capacities when comparing between stroke certified hospitals and non-stroke certified hospitals.

This lends some evidence that stroke certification could really be an arms race among hospitals and the proliferation and growth of stroke-certified hospitals, is really market signaling at play. Hospitals that have the best capacities and capability to manage complex cases (i.e., early adopters) are the first to attempt to achieve stroke certification so as to disclose their quality and make known their standards to potential patients. Once that happens, the next-best hospitals (i.e., late adopters) would then be incentivized to achieve stroke certification. Finally, hospitals that choose not to pursue stroke certification may do so as some potential patients who are less information savvy may not perceive non-disclosure as a signal of the low stroke-care standards and quality.

In conclusion, I want to highlight how left to their own devices, hospitals may decide whether or not to pursue stroke certification based on economic incentives and competition for patient revenues. I also validate how the proliferation of stroke certification is uneven across geographical localities. As healthcare policy makers consider how to take organized stroke-care forward, they may want to pay particular attention towards improving quality stroke care access for low income and rural communities. In addition, policy-makers may also want to consider taking a more active role in optimizing the locations of stroke-certified hospitals.

LIST OF REFERENCES

Alberts, M. J., Hademenos, G., Latchaw, R. E., Jagoda, A., Marler, J. R., Mayberg, M. R., Starke, R. D., … & Walker, M. D. (2000). Recommendations for the establishment of primary stroke centers. *Journal of the American Medical Association, 283*(23), 3102–3109.

Alberts, M. J., Latchaw, R. E., Selman, W. R., Shephard, T., Hadley, M. N., Brass, L. M., Koroshetz, … & Walker, M. D. (2005). Recommendations for comprehensive stroke centers. *Stroke, 36*(7), 1597–1616.

Albright, K. C., Branas, C. C., Meyer, B. C., Matherne-Meyer, D. E., Zivin, J. A., Lyden, P. D., & Carr, B. G. (2010). Acute cerebrovascular care in emergency stroke systems. *Journal of the American Medical Association Neurology, 67*(10), 1210–1218.

Adeoye, O., Albright, K. C., Carr, B. G., Wolff, C., Mullen, M. T., Abruzzo, T., … & Kleindorfer, D. (2014). Geographic access to acute stroke care in the United States. *Stroke, 45*(10), 3019–3024.

American Heart Association. (n.d.). Primary stroke center certification overview sheet [Fact sheet]. Retrieved from http://www.heart.org/idc/groups/heart-public/@wcm/@hcm/@ml/documents/downloadable/ucm_455522.pdf

American Hospital Association. (2018, February). Fast facts on U.S. hospitals 2018. Retrieved from https://www.aha.org/statistics/fast-facts-us-hospitals

American Hospital Association (2014). AHA Annual Survey Database [Data set]. Retrieved from http://www.ahadata.com/aha-annual-survey-database-asdb/

Centers for Disease Control and Prevention. (2017, September 6). Stroke facts. Retrieved from https://www.cdc.gov/stroke/facts.htm

Centers for Disease Control and Prevention. (2016, December 12). History of the Coverdell program. Retrieved from https://www.cdc.gov/dhdsp/programs/pcnasr_history.htm

Centers for Disease Control and Prevention. (2015, November 6). Healthy people 2010. Retrieved from https://www.cdc.gov/nchs/healthy_people/hp2010.htm

Centers for Disease Control and Prevention. (2011). A summary of primary stroke center policy in the United States. Atlanta: U.S. Department of Health and Human Services. Retrieved from https://stacks.cdc.gov/view/cdc/12072

Centers for Medicare and Medicaid Services. (2017, August). Critical access hospital [Fact sheet]. Retrieved from https://www.cms.gov/Outreach-and-Education/Medicare-Learning-Network-MLN/MLNProducts/downloads/CritAccessHospfctsht.pdf

Dranove, D., & Jin, G. (2010). Quality disclosure and certification: theory and practice. *Journal of Economic Literature, 48*(4), 935–963.

Gorelick, P. B. (2013). Primary and comprehensive stroke centers: history, value and certification criteria. *Journal of Stroke, 5*(2), 78–89.

Govan, L., Weir, C. J., & Langhorne, P. (2008). Organized inpatient (stroke unit) care for stroke. *Stroke, 39*(8), 2402–2403.

Hacke, W., Kaste, M., Bluhmki, E., Brozman, M., Davalos, A., Guidetti, D., … & Toni, D. (2008). Thrombolysis with alteplase 3 to 4.5 hours after acute ischemic stroke. *New England Journal of Medicine, 359*(13), 1317–1329.

HealthData.gov. (2018, November 14). Case mix index. Retrieved from https://healthdata.gov/dataset/case-mix-index

Joint Commission. (n.d.a). Facts about advanced certification for comprehensive stroke centers [Fact sheet]. Retrieved from https://www.jointcommission.org/assets/1/18/Comprehensive_Stroke_Center_Certification.pdf

Joint Commission. (n.d.b). Stroke certification [Fact sheet]. Retrieved from https://www.jointcommission.org/assets/1/6/TJC-Stroke-brochure-final_web.pdf

Lichtman, J. H., Allen, N. B., Wang, Y., Watanabe, E., Jones, S. B., & Goldstein, L. B. (2009). Stroke patient outcomes in U.S. hospitals before the start of the joint commission primary stroke center certification program. *Stroke, 40*(11), 3574–3579.

Man, S., Cox, M., Patel, P., Smith, E. E., Reeves, M. J., Saver, J. L., ... & Fonarow, G. C. (2016). Differences in acute ischemic stroke quality of care and outcomes by primary stroke center certification organization. *Stroke, 48*(2), 412–419.

Marler, J. R., Tilley, B. C., Lu, M., Brott, T. G., Lyden, P. C., Grotta, J. C., ... & Kwiatkowski, T. P. (2000). Early stroke treatment associated with better outcome: the NINDS rt-PA stroke study. *Neurology, 55*(11), 1649–1655.

MedlinePlus. (2018, November 13). Thrombolytic therapy. Retrieved from https://medlineplus.gov/ency/article/007089.htm

McDonald, C. M., Cen, S., Ramirez, L., Song, S., Sarer, J. L., Mack, W. J., & Sanossian, N. (2014). Hospital and demographic characteristics associated with advanced primary stroke center designation. *Stroke, 45*(12), 3717–3719.

McKinney, J. S., Cheng, J. Q., Rybinnik, I., Kostis, J. B., & Myocardial Infarction Data Acquisition System (MIDAS 22) Study Group. (2015). Comprehensive stroke centers may be associated with improved survival in hemorrhagic stroke. *Journal of the American Heart Association, 4*(5), 1–8.

O'Toole Jr., L. J., Slade, C. P., Brewer, G. A., & Gase, L. N. (2011). Barriers and facilitators to implementing primary stroke center policy in the United States: results from 4 case study states. *American Journal of Public Health, 101*(3), 561–566.

Slivinski, A., Jones, R., Whitehead, H., & Hooper, V. (2017). Improving access to stroke care in the rural setting: the journey to acute stroke ready designation. *Journal of Emergency Nursing, 43*(1), 24–32.

Suzuki, S., Saver, J. L., Scott, P., Jahan, R., Duckwiler, G., Starkman, S., Su, Y., & Kidwell, C. S. (2004). Access to intra-arterial therapies for acute ischemic stroke: an analysis of the U.S. population. *American Journal of Neuroradiology, 25*(10), 1802–1806.

Uchino, K., Man, S., Schold, J. D., & Katzan, I. L. (2015). Stroke legislation impacts distribution of certified stroke centers in the United States. *Stroke, 46*(7), 1903–1908.

Xian, Y., Holloway, R. G., Chen, P. S., Noyes, K., Shah, M. N., Ting, H. H., … & Friedman, B. (2011). Association between stroke center hospitalization for acute ischemic stroke and mortality. *Journal of American Medical Association, 305*(4), 373–380.

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