Colorectal Cancer Screening in the US:

The Impact of Oversurveillance, Physician Supply and Coverage Mandates

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To God be the glory.

Dedication

To my wife, Gifty-Joy and my parents for all the sacrifices they make for me each day.

Abstract

Screening for precursor adenomatous polyps has been proven to be effective in reducing colorectal cancer mortality risk. Although most screening guidelines do not recommend any one of the several screening tests for CRC over the others, colonoscopy increasingly is being adopted as the primary test for screening. In addition, colonoscopy is recommended for post-polypectomy and post-colectomy surveillance of colorectal cancer. Despite the considerable evidence supporting the effectiveness of screening for CRC, its uptake has lagged considerably behind that of breast cancer screening. Over the past twenty years, the Department of Health and Human Services (DHHS), the Centers for Disease Control and Prevention (CDC) and many national, state and local organizations have embarked on several programs and campaigns in a bid to raise awareness about colorectal cancer and increase screening uptake. At the same time, there is a growing concern that the current physician supply is inadequate to support a broader colonoscopy-based screening and surveillance. This research examines these concerns from three fronts. First, we use a population-based state-transition Markov model of the natural history of colorectal cancer, applied to census data and prevailing screening guidelines, to forecast the demand for colonoscopy and examine the impact of premature post-polypectomy CRC surveillance on the annual volume of colonoscopies. Second, we combine the Behavioral Risk Factor Surveillance System (BRFSS) survey with physician resource data to examine the conditional effect of county-level physician supply on screening participation. Third, we use longitudinal BRFSS

survey data to estimate the effect of the policy of state-mandated colorectal cancer screening benefit by health insurers on the probability of an insured individual undergoing screening.

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Chapter 1: Specific Aims

Colorectal cancer (CRC) is the second leading cause of cancer death among cancers that affect both men and women in the United States with an estimated 51,000 deaths and 143,000 new cases in 2013[1]. The generally accepted theory of the natural history of colorectal neoplasms propounds that adenomatous polyps are precursors to colorectal cancer[1,2]. A logical implication of this theory is that a clinical intervention that removes adenomatous polyps should impede the development of colorectal cancer in an individual. Over the course of the last 25 years, there has been ample evidence that screening for colorectal cancer and precursor adenomatous polyps can reduce mortality and incidence[3–9]. Subsequent to empirical demonstration of the effectiveness of fecal occult blood screening in reducing colorectal cancer mortality through a randomized trial[10], there have been many screening guidelines issued by various professional societies and the United States Preventive Services Task Force (USPSTF)[11–15]. More recently there have been efforts to consolidate these guidelines by the issuing of joint guidelines[16–19]. While the details may have some variation, most colorectal screening guidelines recommend that average-risk individuals should be screened at regular intervals starting from age 50 years with one or a combination of the several screening tests available (Appendix 1). These include high-sensitivity fecal occult blood tests (FOBT), sigmoidoscopy and colonoscopy. Stool tests such as FOBTs and fecal immunochemical tests (FITs) generally are considered cancer detecting in contrast to more invasive tests such sigmoidoscopy and colonoscopy, which are considered cancer

preventing. Over time, the x-ray-based double-contrast barium enema test has fallen out of favor because of its low sensitivity. Meanwhile there are newer tests such as stool DNA and computed tomographic colonography (also referred to as virtual colonoscopy) that are not recommended by the USPSTF.

Of all the CRC screening tests currently in use, colonoscopy plays a pivotal role in colorectal cancer screening. Aside from its emergence as the most used primary screening test, positive or inconclusive results from any other tests typically have to be confirmed through a colonoscopy, which then allows for a subsequent polypectomy, if necessary. Colonoscopy also is recommended for the surveillance of individuals whose initial test revealed abnormal polyps. Most guidelines recommended a surveillance frequency of five years for low-risk (less than 1 cm) adenomas and three years for high risk (greater than 1 cm or 3 to 10) adenomas[17,18]. The emergence of colonoscopy as the primary CRC screening test presents several challenges because it is a procedure typically performed by gastroenterologists or general surgeons[20]. It is still an open question whether there is enough physician capacity to meet the demand for CRC screening if everyone adhered to current recommendations. The access problems that may be posed by capacity constraints would be made worse if physicians offered *premature* post-polypectomy CRC surveillance. CRC surveillance is deemed *premature* if the timing of the test is earlier than what is recommended by clinical guidelines[18,21]. The capacity question aside, there also is the issue of geographic disparities in the availability of gastroenterologists and general surgeons, which may have implications for screening participation. A third concern that arises

from a colonoscopy-favored screening program is the relatively prohibitive cost of colonoscopy compared to other screening modalities. As part of attempts to address the potential barrier posed by the relatively high cost of colonoscopy, several states passed laws that mandated health insurance companies to offer coverage of colorectal cancer screening. This dissertation examines the aforementioned issues through the following specific aims:

SPECIFIC AIMS

1. Forecast the demand for colonoscopy and examine the impact of premature post-polypectomy CRC surveillance on the annual volume of colonoscopies
2. Examine the association between CRC screening status and county-level primary care physician (PCP) and gastroenterologist (GI) supply.
3. Estimate the effect of state-mandated CRC coverage on the probability of an insured individual undergoing CRC screening.

Chapter 2: Statement of purpose and background

Over the past twenty years, the Department of Health and Human Services (DHHS), the Centers for Disease Control and Prevention (CDC) and many national, state and local organizations have embarked on several programs and campaigns in a bid to raise awareness about colorectal cancer and increase screening uptake[22–25]. Research suggest that CRC screening is a significant contributor to the decline of CRC mortality and incidence observed over the past two to three decades[26–28]. However, despite the considerable evidence supporting the effectiveness of screening for CRC, its uptake has lagged behind that of breast cancer screening (Appendix 2). The DHHS in its midcourse review of *Healthy People 2010* noted that while the overall CRC screening rates have increased in the last few years, the elimination of disparities remains a challenge[29]. In addition, there are wide variations in screening rates geographically, both at the state and at the county level (Figure 1).

None of the several CRC screening guidelines recommends one screening test over another and yet there has been an exponential increase in the use of colonoscopy mirroring a decrease in the use of other tests and FOBT particularly. Because colonoscopy is a common pathway for diagnosis and surveillance after polypectomy or resection and predominantly performed by gastroenterologists, its emergence as the de facto primary screening test of choice has implications on access. With an aging population and physician workforce, there is some concern that the demand for colonoscopies will likely outstrip capacity in the near future, barring any corrective measures[30,31].

Two of the key issues in the effort to increase CRC screening are (1) whether there is adequate capacity in the health system to accommodate higher screening rates[31–35]; and (2) understanding the causes of differential screening rates at several demographic levels[34]. The three papers in this dissertation attempt to inform the discussion about CRC screening uptake by investigating (1) the magnitude of the annual colonoscopy volume required under current screening guidelines, (2) the effect of county-level physician supply on screening test use, and (3) whether state-mandated CRC screening test coverage by healthcare insurers had any effect on screening rates.

SCREENING CAPACITY AND OVER-SCREENING

The first paper addresses the question of screening capacity by estimating the annual volume of colonoscopies that will be produced if screening recommendations are followed nominally or aggressively. There are very few estimates of the national capacity for colonoscopies [20,31,36]. Brown et al.[20] used a nationally representative survey of physicians, general surgeons and gastroenterologists conducted between November 1999 and April 2000 to estimate the number of sigmoidoscopies and colonoscopies that were performed in the United States. Based on the reported average volume and the number of practicing physicians in the United States, Brown et al. estimated that 5 million sigmoidoscopies and 4 million colonoscopies were performed in 2000 of which at least 1.6 million of the colonoscopies were for screening or surveillance.

Vijan et al.[31] used data from the Clinical Outcomes Research Initiative (CORI) database to calculate the average number of colonoscopies performed

per month by gastroenterologists who reported to the CORI database. Similar to the approach by Brown et al., they applied this average to the number of gastroenterologists in the United States to estimate the number of colonoscopies performed. They then marked the number up by 33% to account for colonoscopies performed by physicians and general surgeons. Vijan et al. estimated that 3.7 million colonoscopies were performed in 2003 of which 1.69 million were screening-related. It must be noted that while CORI includes a broad cross-section of practice types and provides a general description of patterns of colonoscopy utilization, the gastroenterologists who report to CORI do not constitute a nationally representative sample.

Based on a survey of a nationally representative sample of practices that perform lower endoscopic procedures, Seeff et al.[36] estimated that 2.8 million sigmoidoscopies and 14.2 million colonoscopies were performed in the United States in 2002. Unlike the approach taken by the two studies described above, Seeff et al. used the total number of procedures for a practice site rather than per individual in their estimate. The 17 million combined sigmoidoscopy and colonoscopy procedures for 2002 estimated by Seeff et al. represented an 89% increase over the Brown et al. estimate for 2000. While part of this increase is no doubt attributable to methodological differences, several studies have reported significant increases in the volume of screening colonoscopies since the introduction of Medicare coverage of screening colonoscopy for average-risk patients in 2001 [35,37]. Recent national surveys have also indicated a general increase in screening uptake [38–40]. Lieberman et al.[33] used data from the Clinical

Outcomes Research Initiative (CORI) to analyze colonoscopy utilization patterns between January 2000 and August 2002. They reported that 73.5% of all colonoscopies were performed in 50 to 80 year old patients. 60% of colonoscopies in this age group were for screening, including colonoscopies following an abnormal initial test, or surveillance. When these percentages were applied to the Seeff et al. estimate we arrived at 6.26 million annual screening or surveillance-related colonoscopies among those 50 to 80 years old.

Several changes have occurred since the few available estimates on CRC screening capacity were conducted. One of the most significant changes is a dramatic rise in colonoscopy use. We use a Markov decision model to estimate the annual volume of colonoscopies required at various levels of screening rates. We also examine the impact of reported over-surveillance practices by physicians.

PHYSICIAN DISTRIBUTION AND CRC TESTS USE

The landscape of test options has evolved significantly since the early years of CRC screening. Flexible sigmoidoscopy is now rarely used while some newer tests have joined the list. FOBT, which used to be the most used test, has dropped to less than 20% and colonoscopy now represents over 75% of all screening tests (Figure 2). While the overall uptake of CRC screening has seen a steady increase over the last decade, disparities have persisted. Several studies have consistently found disparities associated with age, education, income and access to primary care. The disparities in up-to-date colorectal cancer screening have been found to exhibit significant geographic variation[41].

Disparities aside, there are significant geographic differences in screening rates. There continue to be several programs aimed at improving screening among various target populations[42]. While these targeted interventions may be an important part of an overall strategy, it is crucial to understand the potential structural and systemic issues that make it difficult for specific subpopulations to access CRC screening. The effects of socio-economic status (SES) and the afore-mentioned individual-level risk factors that affect screening uptake have been examined extensively[40,43–46]. In contrast, the effect of systemic variation in physician availability has not received much attention.

Physician recommendation has been shown to be one of the major determinants CRC screening [47–52] but little work has been done to investigate the effect of the geographic distribution of physicians on area screening rates[53–55]. Two recent studies found that racial disparities in colorectal cancer screening may be attributable to geographic differences in physician availability when the usual SES risk factors were controlled for[53,55]. Soneji et al. used fixed-effect multivariate logistic regression to model the probability of receiving a FOBT within the past year or endoscopic screening within the past 5 years as a function of individual-level socio-economic factors and state-level physician supply[55]. They found that a disparity in the likelihood of recent CRC screening between whites and Hispanics became statistically indistinguishable after accounting for the interaction between race and state-level physician supply. Benarroch-Gampel et al. found from the analysis of Texas Medicare claims data that greater area availability of colonoscopists and PCPs is associated with increased use of

colonoscopy in whites but decreased use in minorities[53]. They defined colonsocopists as gastroenterologists and surgeons, family practitioners and other specialists who performed 5 or more colonoscopies per year.

The effects of access to healthcare on health outcomes have been well documented. In contrast, we wanted to estimate the effect of physician availability on the probability of undergoing screening, independent of socio-economic confounders. Our approach attempts to elicit the effect of geographic variation in PCPs and gastroenterologists supply on CRC screening rates at the county level. With colonoscopy becoming the de facto gold standard test and comprising over three quarters of all screening tests, it is acutely important to understand the barriers and predictors.

LEGISLATIVE MANDATES AND CRC SCREENING TEST USE

As part of the efforts to increase access to CRC screening the United States congress and several states have passed mandates binding insurers to cover CRC screening[56,57]. Congress mandated coverage of CRC screening for *high-risk* Medicare beneficiaries in 1998. The mandate was expanded to cover *average-risk* Medicare beneficiaries in 2001. Beginning in 1999, a patchwork of legislations and voluntary agreements in several states to induce health insurers to cover CRC screening has evolved, culminating in the Affordable Care Act[58] mandate which required all health plans post September 23, 2010 to cover colorectal cancer screening tests. These laws and agreements vary in the extent of mandated CRC screening benefits. Even though CRC screening guidelines issued by both the American Cancer Society and then U.S. Agency for Health

Care Policy and Research in 1997 included FOBT, sigmoidoscopy and colonoscopy[59], a survey of health plans in 1999-2000 found that 43% did not cover colonoscopy[60]. This observation led some to argue that the passage of state insurance coverage mandates was largely part of a barrage of legislation to regulate health insurers in the aftermath of the so-called HMO backlash [12,61].

Health Insurance Coverage Mandates

The argument for mandating coverage of specific services or conditions is predicated on the unique nature of the health insurance. According to Summers[62], the standard competitive equilibrium theory would indicate that health insurers and the insured will negotiate to a point where the marginal cost of providing the health benefit is equal to the value the insured places on the benefit. However, there is often mitigating factors that make it impossible to arrive at this ideal equilibrium. These factors include imperfect information between the insurer and the insured, and society's willingness to provide charity care for the uninsured when they become ill and lack the ability to bear the cost of care. The existence of imperfect information during the transactional process between the insurer and insured regarding the prevalence of a specific condition can lead to the undesirable consequence of adverse selection into the insurance pool. Because the provision of relatively low-cost preventive care can avert the use of future expensive therapeutic care, it would be reasonable to assume that providers of health insurance would be willing to offer coverage for those services. However, with the considerable churn in membership experienced by health plans in recent years, there may not be enough incentive to provide

coverage for preventive care because of the likelihood that the benefit of the averted catastrophic event may accrue to another insurer. The aforementioned argument would suggest that mandating CRC screening coverage is good policy. On the other hand, one of the fundamental arguments against mandates is overutilization of covered services. In the case of CRC screening coverage, it may lead to more frequent rescreening than would have been the case in the absence of a coverage mandate. There is some evidence of such overuse of colonoscopy. Another argument against mandates is that it increases the overall cost of providing health insurance and therefore prices out some firms or individuals[63]. Thus, while a mandate would make a specific benefit available to an insured individual, the society as a whole may suffer as a result of fewer people being insured. Moreover, health insurance coverage mandates could have wage-depressing effects as firms may overcome the constraint posed by the upward shift of the cost of providing insurance by reducing wages[62,64–66]. Mandates have also been shown to have a regressive effect. A recent study found that while Medicare coverage of colonoscopies for CRC screening increased the overall use by 3.5 percentage points. However, because those with higher levels of income and education had exhibited a greater increase in CRC test use, the authors suggest that coverage mandates, (ultimately financed by collective premiums), indirectly transfer resources from those disadvantaged to those who have access[67,68].

CRC Coverage Mandates

Between 1998 and 2010 several states passed laws or arranged agreements with health insurance organizations to offer coverage for CRC screening. Early adopters of CRC coverage included California, Illinois, Minnesota and Missouri. These mandates and agreements had varying scopes. Some states required a complete coverage of CRC screening based on the CRC screening guidelines from the American Cancer Society while others were not explicit on the extent of coverage. By 2010, 35 states, including the District of Columbia that had some form of mandated CRC screening coverage. For the purposes of our study, we included only states that have CRC coverage mandates that are backed by law and are specific in the coverage benefits. Previous studies of the effect of mandated health insurance benefits have mostly demonstrated minor effects on the desired health behavior outcomes [69,70]. Very few studies have examined the effect of mandates on public health screening participation and in particular the effects of CRC screening mandates on screening participation in the United States[71]. Consistent with similar studies on mandated health benefits for other diseases, the effect of CRC screening mandates on screening participation is inconclusive. We used a large national survey to assess the effect of state level legislation of screening rates.

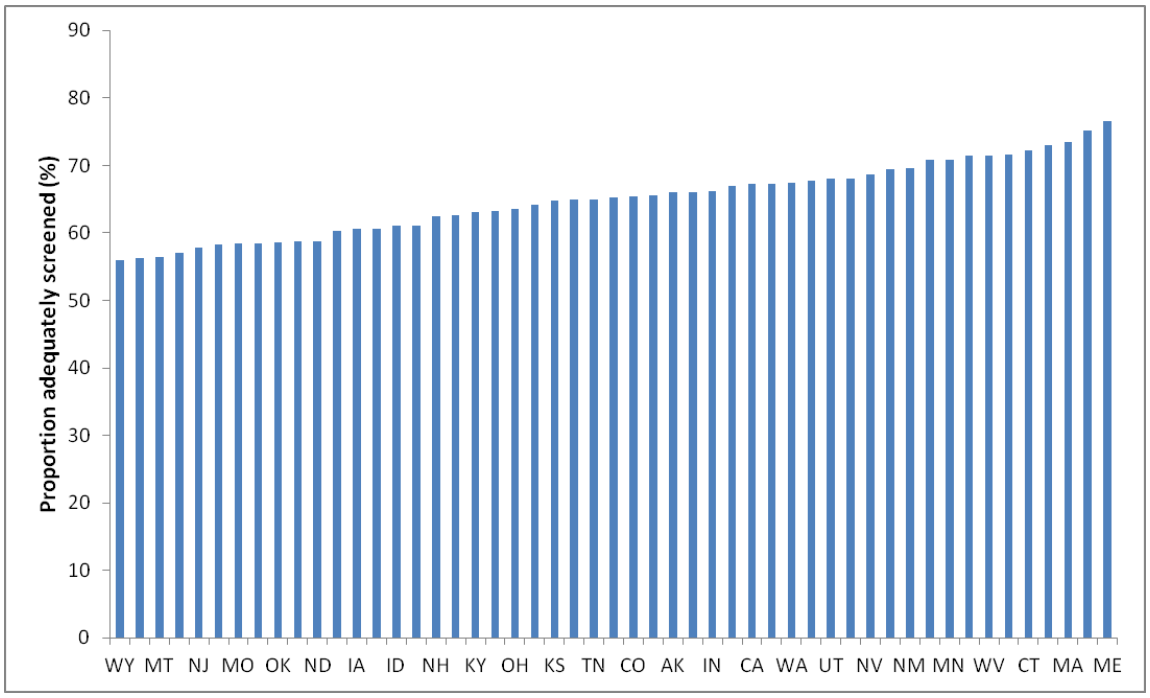
CONTRIBUTION OF DISSERTATION TO PREVIOUS WORK

This research aims to inform two critical questions that were part of the National Institutes of Health (NIH) state-of-the science conference convened in 2010[34]: 1) What factors influence the use of CRC screening, and 2) What are the

current and projected capacities to deliver CRC screening at a population level? The first paper in this dissertation attempts to estimate the volume of screening colonoscopies that will be generated under various scenarios of physician response to surveillance guidelines. We examine whether screening coverage mandates are useful tools for increasing screening participations.

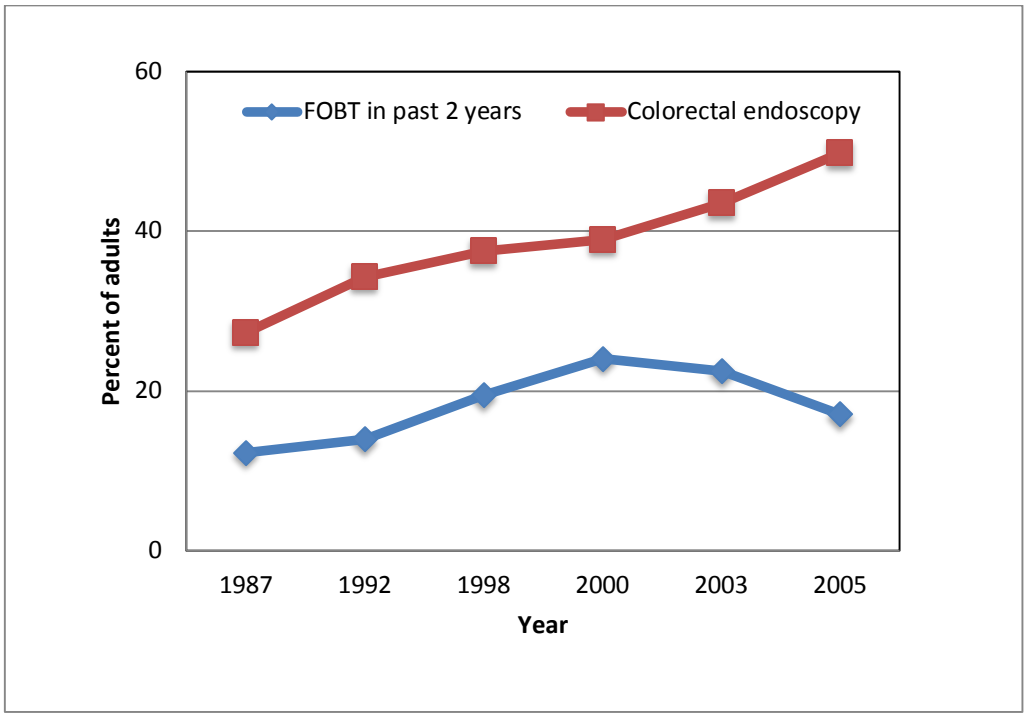
Some have argued that the fight to eradicate health disparities needs to focus on policies that address systemic inequitable access to healthcare in addition to individual characteristics[72]. The second and third papers in this dissertation examine the impact of forces outside of the individual's locus of control on their CRC screening usage. We look at the effect geographic variation in physician supply has on access to CRC screening status and also attempt to quantify the effect of state-mandated health insurance coverage of CRC screening.

Figure 1: Proportion of eligible adults who reported receipt of adequate FOBT or endoscopic testing in 2012*



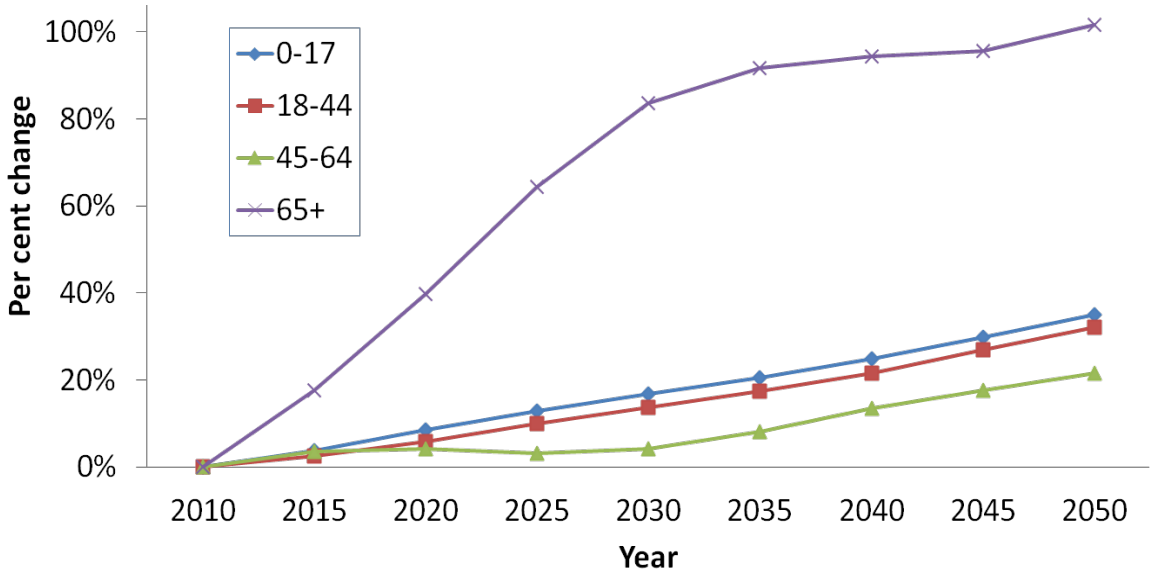
*Source data: Behavioral Risk Factors Surveillance System (BRFSS), 2012 survey

Figure 2: Percentage of adults aged 50 years and older who ever had a colorectal endoscopy or FOBT: 1987 – 2005



Source data: Centers for Disease Control and Prevention, National Center for Health Statistics. National Health Interview Survey

Figure 3: United States population growth relative to 2010 baseline



Source data: United States Census Bureau

Chapter 3: The impact of early aggressive surveillance for colorectal cancer

INTRODUCTION

Colonoscopy is the common diagnostic pathway for all primary screening tests for colorectal cancer (CRC). Although most screening guidelines do not recommend any one of the several screening tests for CRC over the others, colonoscopy increasingly is being adopted as the primary test for screening [33,35,73]. In addition, colonoscopy is recommended for post-polypectomy and post-colectomy surveillance of CRC. The National Cancer Institute's *Cancer Trends Progress Report 2009/2010 Update* [74] reported that between 2000 and 2008, while the national uptake of fecal occult blood test (FOBT) for CRC screening decreased, use of colonoscopy rose exponentially in the same period. Efforts over the last decade to raise the awareness of the benefits of CRC screening,[75] as well as increased accessibility (e.g., Medicare coverage since 2001 [76]) to colonoscopy, are expected to cause overall screening rates, and uptake of colonoscopy in particular, to continue to rise. Additionally, the volumes of inpatient and outpatient colorectal procedures are forecasted to grow by 40.6 and 21.3 percent, respectively, as a result of the ageing of the US population [30] (Figure 3). All CRC screening tests impose a downstream demand for colonoscopies through diagnostic testing and surveillance. Concerns therefore have been raised about the adequacy of the current capacity in the health care system to meet continuing growing demand for colonoscopies resulting from a higher screening uptake over time coupled with a shift towards the use of

colonoscopy as the primary screening test [20,31,32,77]. The conclusions from the few studies on the capacity for endoscopic screening have been mixed [20,32,36]. Two of the studies found that the current endoscopic capacity in the United States is inadequate to meet screening requirements if CRC screening rate among the eligible population reached 70% [20,31]. One other study concluded that providing a one-time screen endoscopic screening for the unscreened population could take up to 10 years [32]. Moreover, these studies predated the marked shift towards the use of colonoscopy as the screening test of choice.

The limitations of the existing studies on endoscopic capacity aside, recent evidence of aggressive or premature post-polypectomy CRC surveillance suggests that we need to reexamine the demand for colorectal colonoscopy with respect to the physician capacity to provide it [78–81]. Surveillance colonoscopy is recommended for patients who undergo surgical resection of Stage I, II, or III colon and rectal cancers or curative-intent resection of Stage IV cancers [82]. A survey of gastroenterologists and surgeons found that 24% of gastroenterologists recommend surveillance of a hyperplastic polyp, contrary to many of the existing guidelines [80]. A recent national survey of primary care physicians in open-access systems found that 61% of the respondents would recommend surveillance of a hyperplastic polyp in five years or less [83]. The study also found that 71% of the physicians would recommend surveillance of a single tubular adenoma in three years or less. Hyperplastic polyps are benign nonneoplastic lesions and are found in 10% of persons who are screened. Current guidelines recommend that patients presenting hyperplastic polyps undergo screening every 10 years, while

those with one or two tubular adenomas undergo screening in 5-10 years[18,19,21,84]. Both of the above surveys also reported that gastroenterologists, surgeons and primary care physicians often recommended surveillance in excess of guidelines. With surveillance accounting for 36.5% of all colonoscopies among 50 to 80 year old patients [33], premature surveillance can have a significant impact on the annual volume for colonoscopies. In this study, we use CRC screening uptake and census data together with a Markov simulation model to forecast the demand for colonoscopy and examine the impact of premature post-polypectomy CRC surveillance on the annual volume of colonoscopies.

METHODS

Markov model of the natural history of CRC

We used a state-transition Markov model to simulate the natural history of CRC based on the adenoma-carcinoma sequence [1,2]. The model included the following health states: disease-free, precancerous adenomatous polyps (low-risk, defined as < 1cm or high-risk, defined as ≥ 1cm), preclinical cancer (local, regional or distant), clinical cancer (local, regional or distant), and death (Figure 4). At the start of the simulation, a cohort of 50-year old persons with an average risk of CRC enters the model and progress annually through various states until death. A person may die from CRC-related causes or from other causes as determined by age-specific mortality rates. We modeled annual transitions through the various health states based on probabilities estimated through calibrations to polyp prevalence and cancer incidence from epidemiologic data.

We calibrated our natural history model to data from the Survival, Epidemiology, and End Results Program (SEER) from the early 1970s[85] under the assumption that CRC screening was low at that time and therefore the effect of screening on CRC observed incidence was not significant. Figures 5 and 6 show that age-specific and stage-specific CRC incidence rates produced by our model matched epidemiologic data from SEER.

Data

Key parameter estimates used in the model are included in Table 1. Parameter estimates for the natural history model were obtained from screening and autopsy studies available in the literature. Estimates of CRC prevalence and mortality were obtained from SEER data. We applied age-specific population estimates from the current census projections of the United States population to calculate the final number of annual colonoscopies.

Screening and surveillance

We superimposed on the natural history model a screening mechanism that either could identify and remove adenomas or identify, stage, and treat CRC. The screening strategies we considered included annual FOBT, flexible sigmoidoscopy (FS) every 5 years, FOBT/FS combined and colonoscopy every 10 years for average-risk persons 50 years or older[18,19,84]. Persons who tested positive with FOBT, FS or the combination test received a follow-up colonoscopy. Polyps found during colonoscopy were removed. Persons who underwent polypectomy returned to a disease-free state; however, their transition probability to a low-risk polyp state was higher than that of disease-free persons who did not

have a history of adenomatous polyp, and also depended on whether their previously diagnosed polyp was of low or high risk. The probability of developing a low-risk polyp from a disease-free state increased 2-fold for those with a history of low-risk polyps and 4-fold for those with a history of high-risk polyp compared to those with no polyp history. Persons with a history of high-risk polyp underwent surveillance every three years while those with a history of low-risk polyp had a surveillance schedule of every five years in accordance with surveillance guidelines[18,86]. Persons who were screened positive with CRC were moved to a "detected cancer" state. Survival for persons with either detected or undetected CRC was based on SEER relative survival data. For each screening or surveillance encounter, we modeled the fatal risk associated with colonoscopy.

Estimating the number of colonoscopies performed annually

For any particular screening strategy, we simulated a cohort of average-risk 50-year olds to estimate the expected number of colonoscopies an individual would undergo each year, as well as life-years gained relative to no screening. The stopping age for screening was 75 years, and 80 years in the case of those undergoing surveillance. The cohort-specific results were extrapolated to the US population aged 50 years and older by using age-specific census population data. For the population eligible to be screened, we ran the model for each age-group starting at age 50 years and obtained the number of colonoscopies generated annually by the cohort until they no longer were within the screening and surveillance recommendations. For example, to estimate the number of

colonoscopies performed on those aged 50 - 80 years in 2010, we ran the model for 30 cohorts of 50-year-old persons from 1980 through 2010. Persons who were 50 years old in the 1980 will be 80 years old at iteration 30 of the simulation, coinciding with the year 2010. The total number of colonoscopies for any particular calendar year was calculated by summing the number of colonoscopies performed for all ages. We then adjusted the results to reflect the uptake rate of CRC screening. To obtain the total number of colonoscopies resulting from the use of a combination of different screening tests, we ran the model separately for each test and calculated a weighted sum using test type distribution data from the 2005 National Health Interview Survey (NHIS) on CRC test use[38,74].

We used US Census population projections to estimate the future volume of colonoscopies under the simplifying assumption that the natural history parameters will remain constant. We further assumed that screening tests will comprise of 75% colonoscopy and 25% FOBT. This assumption is based on the fact that analysis from the 2005 NHIS found that 76.4% of the screened population received colonoscopy, 18.1% received FOBT and 5.5% were screened with FS only, or in combination with FOBT[38]. Screening uptake in the future years were extrapolated by fitting a polynomial regression to the available screening uptake data from 2000 through 2008[74].

To examine the impact of premature post-polypectomy CRC surveillance, we specified that a proportion of patients with a history of adenomas undergo surveillance at a shorter time interval than the guidelines recommend [78–81].

Patients with a history of high-risk polyps were allowed to undergo early surveillance at one or two years, or at the recommended three years. Those with a history of low-risk polyps were allowed to undergo early surveillance at three or four years, or at the recommended five years. We calculated the number of CRCs and colonoscopy-related deaths that would result under each of the scenarios. We examined the harms and benefits of premature surveillance by estimating the number of colonoscopy-related deaths as well as CRC deaths. First, under the recommended surveillance levels, and then under the assumption that 50% of the surveillance recommended at three years were done annually.

RESULTS

Current volume of colonoscopies

Under the assumption that screening and surveillance guidelines were adhered to and uptake was 50%, we estimated that 6.62 million colonoscopies related to CRC screening and surveillance were performed in 2008 (Table 2). We projected that 37.4% of the total colonoscopies performed were for surveillance. If 50% of the patients who were supposed to have received surveillance at 3 and 5-year intervals received premature surveillance at 1 and 3-year intervals respectively, the annual volume of colonoscopies would increase to 7.6 million, a difference of about 1 million.

Projected demand for colonoscopies

We forecasted the annual number of colonoscopies up to the year 2020 under the assumption that screening uptake will increase gradually from the current 54% to 70% based on the trend from previous years. We also assumed that primary screening tests comprised of 25% FOBT and 75% colonoscopy. At a screening uptake of 54% and without accounting for premature surveillance, we forecasted that 7.0 million colonoscopies would be performed in 2010 (Figure 6). By 2020, the volume of colonoscopies would be 11.2 million based on an estimated screening uptake of 71%. We found that the number of colonoscopies estimated to have been performed in 2004[36] is approximately equal to number estimated by our model for 2005 under the assumption that there was 50% premature post-polypectomy surveillance colonoscopies.

Impact of premature postpolypectomy surveillance

The number of colonoscopies projected for 2010 increased by a million from 7.0 million to 8.3 million if 50% of patients who have had a polypectomy underwent premature screening at one-year instead of three-year intervals and at three-year instead of five-year intervals.

We did a sensitivity analysis to estimate the volume of colonoscopies under different premature surveillance intervals. We considered surveillance intervals of one year, three years or the recommended five years for individuals with history low-risk polyps. For those with history high-risk polyps, we considered intervals of one year, two years or the recommended three years. In all cases we assumed that 50% of surveillance colonoscopies were premature.

We estimated that at a screening uptake of 50%, 6.5 million colonoscopies were performed in 2009, not accounting for premature surveillance. However, this number increased by up to 70% to 11 million colonoscopies if 50% of all individuals who underwent polypectomy were put under annual surveillance.

If all the eligible population were screened from 1979 through 2009 under the current screening guidelines, we estimated 55,625 CRC deaths and 1,268 colonoscopy-related deaths in 2009. If we assume that 50% of those with high-risk adenomas were put on annual surveillance instead of the recommended three-year interval, we projected that CRC deaths in 2009 would have been reduced by 731 (1%) while colonoscopy deaths would have increased by 99 (8%).

DISCUSSION

Although most screening guidelines do not specify colonoscopy as the preferred screening modality, its utilization has increased markedly in recent years. Despite the fact that only 65% of the eligible population is currently being screened [87], there has been anecdotal evidence that there is colonoscopy shortage in some areas of the nation [88]. Ongoing campaigns to raise the awareness about the benefits of CRC screening, coupled with overuse of colonoscopy in some settings, highlight the need to understand the current resource requirements and capacity for colonoscopy. In a statement released after the 2010 State-of-the-Science Conference on *Enhancing Use and Quality of Colorectal Cancer Screening*, the National Institutes of Health concluded that a better understanding is needed about "the projected demand, and the impact of

overuse and misuse on capacity estimates" [34]. Our analysis used current screening data in a simulation model to forecast the annual volume of colonoscopies and examined some of the impacts of overuse of colonoscopy.

Based on current screening and surveillance guidelines we found that the annual volume of colonoscopies is could double between 2006 and 2020 to about 11.2 million. Additionally, we found that even a conservative assumption about premature post-polypectomy surveillance resulted in an additional 18% increase in the volume of colonoscopies.

The few available estimates of the national physician capacity for colonoscopies reported vastly different numbers[20,31,36]. Moreover, an estimate of the available national capacity to provide colonoscopy is only a first step. It does not address the geographic distributional differences, which may be pertinent to the issue of disparities. Recent national surveys have indicated a gradual increase in screening uptake[38–40]. Concurrent to this increase in screening uptake is a dramatic shift towards colonoscopy as the preferred screening test. However, until recently, the USPSTF did not explicitly model the outcomes of screening guidelines[89]. The impact of any particular screening schedule on the colonoscopy demand and supply equation is not well understood.

Our study made an assumption that FOBT and colonoscopy were the two major tests for CRC. While that assumption has largely been true in the last five years, the test landscape is gradually evolving. Some tests have fallen out of favor and newer tests are gaining acceptance. More studies are needed to understand the impact these changes on the resources needed for an equitable

access to screening. Also, an analysis that examines capacity at an aggregate level fails to account for important regional and local dynamics, which may have a significant impact on access. We address the impact of geographic distribution of physicians in our second paper.

STUDY LIMITATIONS

Our study has some limitations. We assumed that once a person started screening with a particular test that same test would be used throughout the person's screening lifetime. In practice, individuals may start with one screening test and switch to another. Our model also assumed that all adherent individuals started screening at 50 years and adherence with screening and surveillance guidelines is perfect once a person underwent the first screening. The impact of this assumption on the total number of colonoscopies was somewhat mitigated by adjusting the overall screening uptake rate.

We also did not consider the role newer tests such as computed tomographic colonography (CTC) will play in the future of CRC screening. There are several ongoing trials aimed at assessing the performance of CTC in detecting adenomas and the debate about the CTC as a comparable CRC screening tool to colonoscopy is gaining momentum.

CONCLUSION

Premature surveillance increases the volume of colonoscopies by as much as 70% with a relatively small benefit while imposing substantial risks. The aging of the US population and the increased accessibility of healthcare through

the Affordable Care Act are expected to substantially increase the demand for healthcare services. This growing demand for healthcare services in not matched by increased production of health professionals. Etzioni et al. estimated that CRC procedures will grow by up to 40.6 percent by 2025. In light of some evidence of insufficient access to colonoscopy and the expected increase in the population eligible for screening[90], premature surveillance will impose a further strain on the limited resources. Such a constraint may exacerbate existing disparities in CRC screening. In the next paper, we investigate the association between county-level physician supply and an individual's probability of undergoing CRC screening.

Figure 4: Health states used in modeling the natural history of colorectal cancer

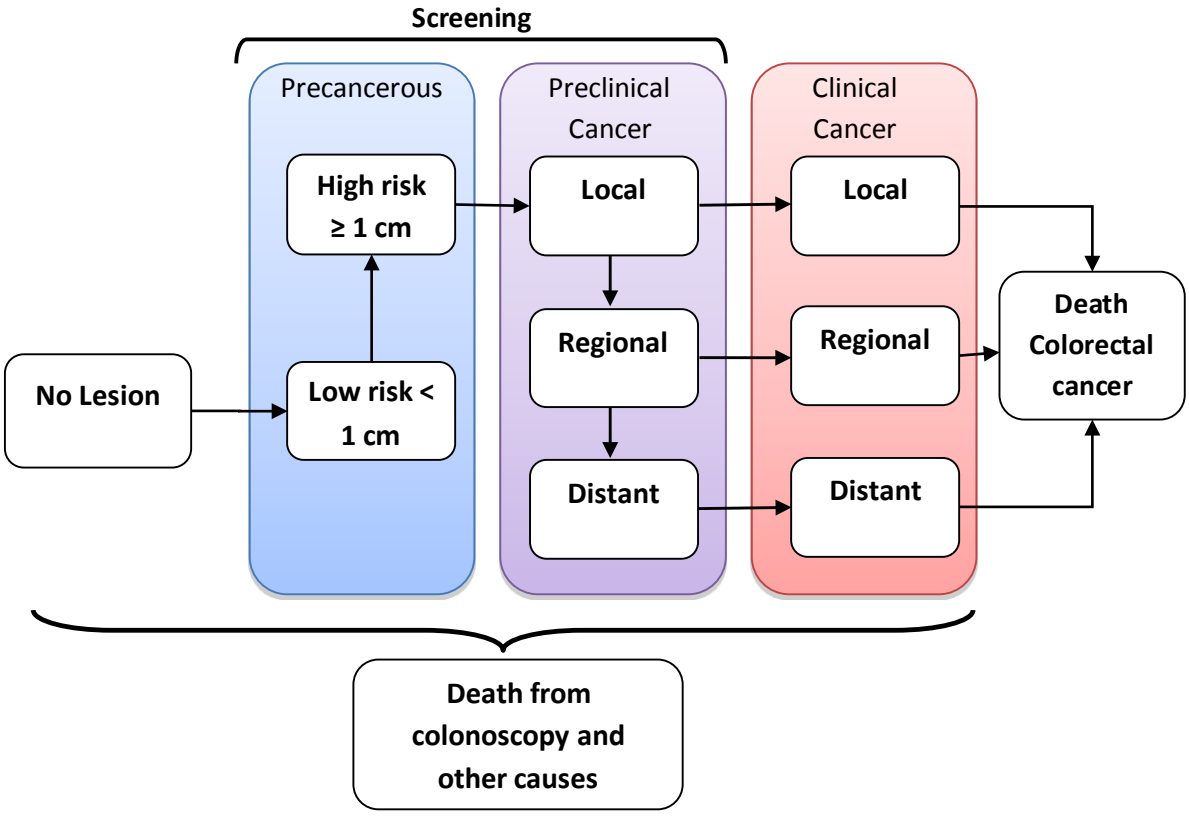


Table 1: Inputs used in the Markov Model

Variable	Value, %	References
Natural history		
Prevalence of polyps at age 50 years	20.0	[91–96]
Low-risk (< 1cm)	90.5	[97–99]
High-risk (≥ 1cm)	9.5	[97–99]
Prevalence of preclinical cancer at age 50 years		
Localized	0.1	[85]
Regional	0.02	[85]
Distant	0.001	[85]
Annual transition probability from		
Normal epithelium to low-risk polyp	Age-specific	[91–96]
Low-risk polyp to high-risk polyp	1.62	[100–102]
High-risk polyp to localized cancer	3.58	[103]
Localized cancer to regional cancer	28.0	[85]
Regional cancer to distant cancer	63.0	[85]
Annual probability that CRC will become symptomatic		[85]
Localized cancer	25.0	[85]
Regional cancer	55.0	[85]
Distant cancer	100.0	[85]
Annual CRC-specific mortality rate		
Localized cancer	0.2	[85]
Regional cancer	3.2	[85]
Distant cancer	56.6	[85]

CRC = colorectal cancer, FOBT = fecal occult blood test

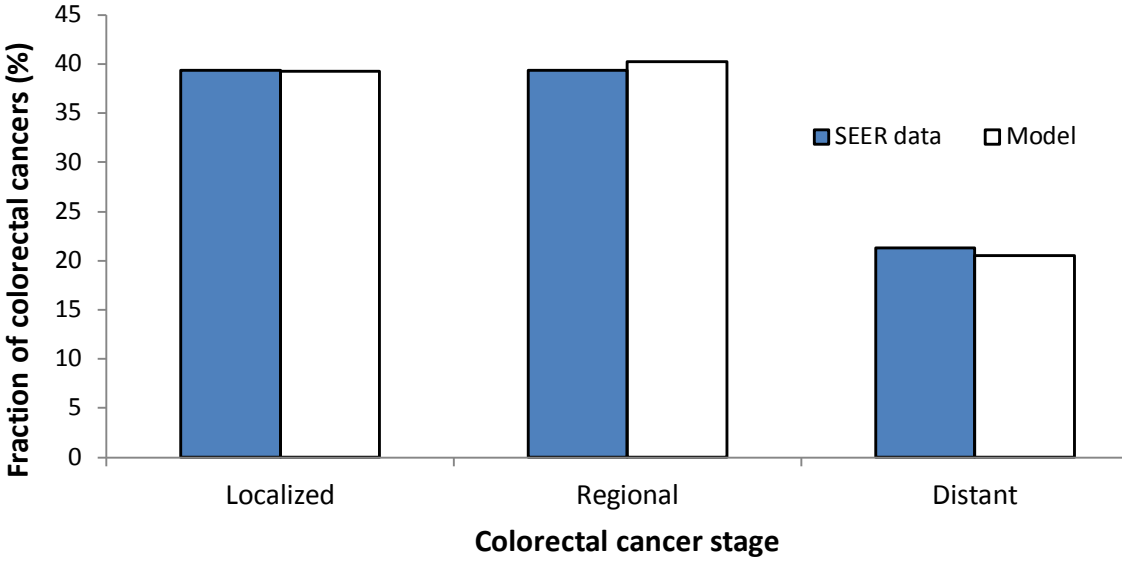
Table 1 (Continued): Inputs used in the Markov Model

Variable	Value, %	References
Test characteristics		
FOBT sensitivity for polyps	10.0	[3,104]
FOBT sensitivity for cancer	60.0	[41,42]
FOBT specificity	92.0	[41,42]
Colonoscopy sensitivity for low risk polyps	85.0	[59,105]
Colonoscopy sensitivity for high risk polyps and cancer	95.0	[59,105]
Colonoscopy specificity	100.0	[59,105]
Probability of dying from colonoscopy	0.01	[59,105]
Polyps and cancer reachable by sigmoidoscope	50.0	[11,59]
Sigmoidoscopy sensitivity for reachable low-risk polyps	85.0	[59,105]
Sigmoidoscopy sensitivity for reachable high-risk polyps	95.0	[59,105]
Sigmoidoscopy sensitivity for reachable cancer	95.0	[59,105]
Sigmoidoscopy specificity	100.0	[59,105]

CRC = colorectal cancer, FOBT = fecal occult blood test

Figure 5: Stage-specific CRC incidence rates

Figure 6: Age-specific CRC incidence rates



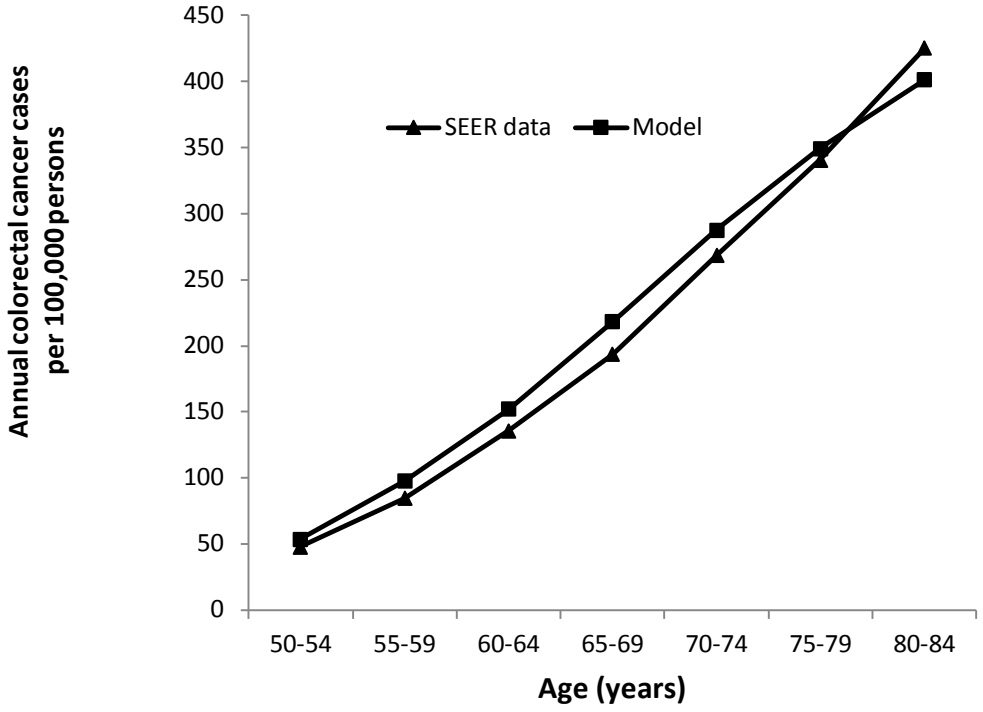


Table 2: Estimated number of colonoscopies performed in 2008 at recommended surveillance and at 50% premature surveillance. (Compliance at 50%)

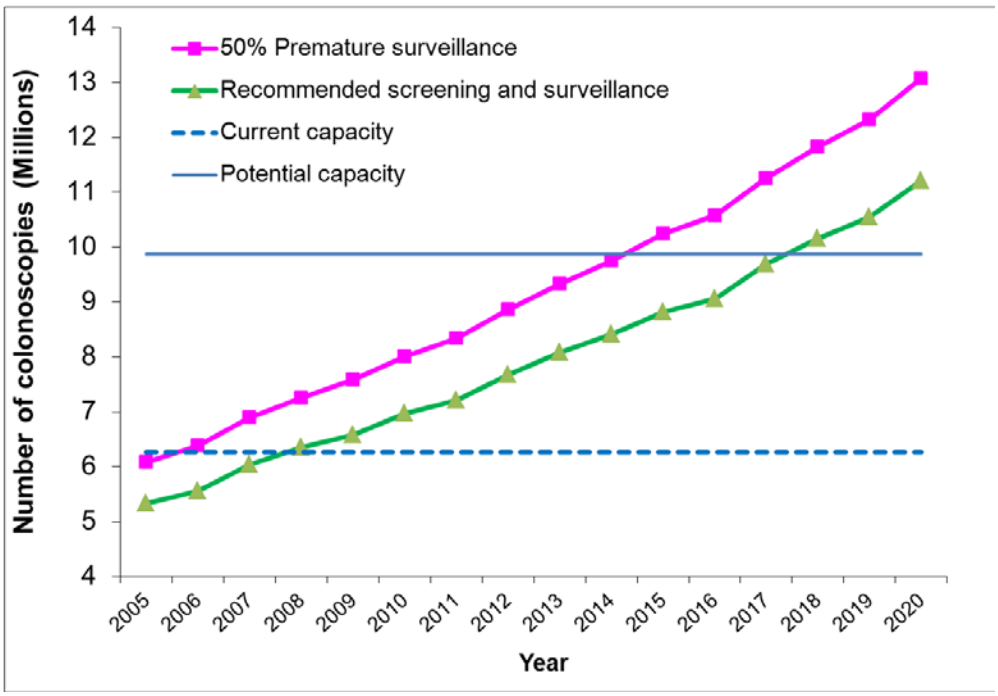
Primary test	Percent of all tests performed (%)	Number of colonoscopies at recommended surveillance (Millions)	Number of colonoscopies at 50% premature surveillance[‡] (Millions)
Colonoscopy	76.4	5.58	6.34
FOBT	18.1	0.94	1.09
Sigmoidoscopy	4.4	0.08	0.14
FOBT/Sig	1.1	0.02	0.04
Total	100	6.62	7.61

[‡] Surveillance at 1 year instead of every 3 years and at every 3 years instead of 5 years

Table 3: Estimated number of colonoscopy-related and cancer deaths in 2009 assuming 100% screening uptake over the last 30 years

	Number of colonoscopy-related deaths	Number of cancer deaths
Recommended surveillance	1,268	55,625
50% of surveillance recommended at 3 years is done annually	1,367	54,894
Net (% change)	99 (8%)	-731 (1%)

Figure 7: Projected annual demand for colonoscopies when primary test type distribution is 75% colonoscopy and 25% FOBT



Chapter 4: Physician Supply and CRC Screening Rates

INTRODUCTION

Evidence of the clinical[10,106–111] and cost effectiveness[89,112–115] of colorectal cancer (CRC) screening has accumulated since the 1990s. In spite of the considerable evidence as well as several campaigns supporting CRC screening, only 65% of the eligible population was compliant with screening in 2012[87]. In addition to the relatively low screening rates, there is a lot of variation geographically, with rates ranging from 57% to 75% among states in 2010[116].

CRC screening is recommended by the United States Preventive Services Task Force (USPSTF), the U.S. Multisociety Task Force and the American Cancer Society (ACS) for average-risk individuals starting at age 50[21,117,118]. Recommended screening tests include annual fecal occult blood tests (FOBT), flexible sigmoidoscopy every 5 years, colonoscopy every 10 years, and more recently, computed tomographic colonoscopy. FOBT use increased steadily throughout the 1990s until 2001, after which a sharp decline in use began[119]. The sharp decline in the use of FOBT coincided with a reciprocal increase in colonoscopy use. The emergence of colonoscopy as the primary CRC screening test poses potential access problems, which are not associated with FOBT. Although CRC incidence and mortality have been decreasing steadily for more than a decade[27], disparities remain among racial groups and socio-economic strata[120–122]. Not surprisingly, disparities also exist in CRC screening test use[40,123,124,124,125].

Nationally representative studies have shown that CRC screening participation is associated with a number of demographic characteristics, including health and behavioral risk factors and patient-level access to health[23,25–29]. In smaller studies, physician recommendation of screening ranked high among factors associated with adherence to CRC screening[43,47,51,126,127]. While patient-level characteristics associated with CRC screening participation have been well examined, the effect of physician supply has not received a similar level of study. Moreover, there is evidence that the supply and geographical distribution of physicians can impact healthcare delivery, utilization and outcomes[128–130]. To expand our understanding of the disparities associated with CRC screening participation, we combine survey data and physician resource data to examine the conditional effect of regional physician supply on screening participation.

AIM

In this study, we examine the relationship between CRC screening rates and physician supply. Specifically, we used survey data to analyze the association between CRC screening status and county-level primary care physician (PCP) and gastroenterologist (GI) supply.

METHODS

Data

We used data from the 2010 Behavioral Risk Factor Surveillance System (BRFSS) survey to obtain individual-level screening status, county screening

rates and other demographic characteristics, both at the individual and county level. The BRFSS is a state-level survey that measures the prevalence of major behavioral risks, chronic health conditions and use of preventive services among adults associated with premature morbidity and mortality[131]. Initially launched in 1984 with only 29 states, the BRFSS now collects data on residents nation-wide through annual telephone-based random digit dialing surveys. The BRFSS survey included questions on CRC screening participation in 1997, 1999, and every even year starting from 2002. We based our analyses on the subpopulation of respondents aged 50 to 80 years who indicated that they had not been previously diagnosed with colon or rectal cancer. Although the USPSTF recently recommended 75 years as the cutoff age for screening of average-risk individuals, we used 80 years as the cutoff age because the survey questions elicited retrospective screening status[117]. All cases with missing values were excluded from our analyses.

County-level physician counts and census demographic data were obtained from Health Services Resource Administration's (HRSA) Area Health Resource File (AHRF). The AHRF includes data on health professions, socioeconomic and environmental characteristics maintained at the county level[132]. We merged the BRFSS and physician datasets using county FIPS code as the common key.

Variables

Our main outcome variable was a respondent's CRC screening status. The BRFSS survey included questions on FOBT and endoscopy use for all

respondents 50 years or older. We created two binary variables that determined each respondent's FOBT status and endoscopy status (i.e., flexible sigmoidoscopy or colonoscopy). FOBT status was defined as having received a blood stool test in the past two years or not.

Each respondent's FOBT status was determined from the following two questions on the BRFSS survey:

> *(1) A blood stool test is a test that may use a special kit at home to determine whether the stool contains blood. Have you ever had this test using a home kit?; and*
>
> *(2) How long has it been since you had your last blood stool test using a home kit?*

Sigmoidoscopy or colonoscopy use was determined from the following three BRFSS survey questions:

> *(1) Sigmoidoscopy and colonoscopy are exams in which a tube is inserted in the rectum to view the colon for signs of cancer or other health problems. Have you ever had either of these exams?*
>
> *(2) For a sigmoidoscopy, a flexible tube is inserted into the rectum to look for problems. A colonoscopy is similar, but uses a longer tube, and you are usually given medication through a needle in your arm to make you sleepy and told to have someone else drive you home after the test. Was your most recent exam a sigmoidoscopy or a colonoscopy?; and*
>
> *(3) "How long has it been since you had your last sigmoidoscopy or colonoscopy?"*

Endoscopy status was defined as having received either flexible sigmoidoscopy in the last five years or colonoscopy in the last 10 years, or not.

Physician Density

The primary predictor for the analyses was the county physician per population ratio, which we termed physician density. From the AHRF data, we calculated three physician densities, namely, GI density, GI and general surgeon (GS) density and PCP density. PCPs included general family medicine, general practice and general internal medicine specialties. We defined physician density as the number of physicians engaged inpatient care per 100,000 persons 18 years and older. We used the adult population as the denominator because we excluded pediatricians and pediatric subspecialties. Physician densities were calculated for years 2001 through and 2010 and averaged. Only physicians designated as active and in clinical practice in the AHRF database were included our analysis. An examination of county-level physician densities revealed several counties with extreme values. Also, we expected that physician productivity would be affected by the available capacity. To account for the non-linear relationship between physician density and CRC screening status, we created categorical variables for GI, GS and PCP densities by grouping GI and GS into quartiles and PCP into quintiles (Appendix 3 - Appendix 6).

Other variables

Individual level characteristics such as gender, race, age, marital status, education and income level obtained from the BRFSS data were included in our models. Based on exploratory analysis and findings from previous studies that

examined factors associated with screening participation[23,40–43], we included a set of health and risk factor predictors as well as patient-level predictors for health care access. Health and risk factor predictors included *self-rated health status*, *cigarette smoking*, *alcohol use*, *physical activity* and *body mass index*. For patient-level health care access variables we included "*having a doctor or usual place of care"*, "*having health insurance"* and "*time since last doctor visit"* (Table 5). Because educational attainment and income were strongly correlated, we avoided multicollinearity in our models by creating a new composite variable, to serve as a socio-economic status (*SES*) indicator.

Statistical Analyses

We analyzed an individual's screening status with a series of binary and multinomial multiple logistic regression models. We modeled screening with FOBT and screening with endoscopy independently using physician density and a set of demographic and other explanatory variables (Table 6). We also conducted analysis on an outcome of having been screened with either FOBT or endoscopy. Our exploratory analysis indicated a strong correlation between CRC screening participation and prostate specific antigen (PSA) test use among men and mammography use among women. We therefore ran separate analyses for men and women in order to independently adjust for the effect of either test.

CRC screening participation rates among states in the United States has a range of more than 18 percentage points[116]. To examine whether there were some endogenous characteristics within states, which enabled screening

participation or otherwise, we analyzed the effect of physician density on the probability of being up-to-date with CRC screening status for states with high CRC screening participation rates compared to those with low participation rates. We therefore ran two separate models for the five states with screening rates in the 25th percentile and five states above the 75th percentile.

Marginal effects were calculated for each predictor following each regression estimation. All statistical analyses were performed using survey commands in Stata version 12 (StataCorp 2011) and the weighting scheme employed in the BRFSS survey data was applied.

RESULTS

Study Population

Our analysis sample included the population aged 50 to 80 years who answered questions about CRC screening on the 2010 BRFSS survey. The proportions of the eligible population that were up-to-date with FOBT, endoscopy and either test were 18.0% (95% CI, 17.8% - 18.3%), 61.7% (95% CI, 61.3 - 62.0) and 66.7% (95% CI, 66.3 - 67.0 &), respectively (Table 5). Overall, women were more likely than men to have undergone screening with either test: 67.3% (95% CI, 66.9 - 67.7%) versus 65.9% (95% CI, 65.4 - 66.5%). Women also were more likely to have undergone endoscopy, with participation at 62.3% (95% CI, 61.9 - 62.8%) compared to men, at 61.6% (95% CI, 61.0% – 62.2%). Conversely, more men used FOBT with participation at 18.6% (95% CI, 18.2% - 19.0%) compared to women, at 17.5% (95% CI, 17.2% - 17.8%). Among all

races, Non-Hispanic whites were the most likely to have undergone endoscopy, with participation at 64.9% (95% CI, 64.5-65.2%) followed by blacks, Hispanics and *Other* at 61.8%, 53.7% and 47.7%, respectively. Among blacks, 22.2% (95% CI, 21.1% - 23.3%) received FOBT, more than any other race or ethnicity. Both FOBT and endoscopy use increased with age but at a decreasing gradient. Overall screening participation was least among those 50 - 54 years old at 49.9% (95% CI, 49.1 - 50.8%), and peaked at 77.7% (95% CI, 76.9% – 78.4%) among those 70 –74 years. Current smokers were about 20% less likely to have undergone endoscopy than non-smokers. Those who reported having a doctor or usual place of care were more than two times more likely to have undergone FOBT, endoscopy or either test.

Men who underwent prostate-specific antigen (PSA) testing in the last two years were three times more likely to have undergone FOBT than those who did not (24.0% versus 7.9%). For endoscopy, having undergone PSA testing in the last two years doubled the chance of being up-to-date (72.8% versus 36.6%). Mammography status within the last two years exhibited a similar association with both FOBT and endoscopy test use (Table 5). Appendix 7 shows a positive monotonic relation between quartiles of county-level gastroenterologist density and being up-to-date with endoscopic screening. A similar relationship was exhibited between county-level PCP density and being up-to-date with endoscopic screening (Appendix 8).

Adjusted patterns of association between outcomes and predictor variables were similar to the unadjusted rates. Blacks were significantly more

likely to have received FOBT than whites (4.0 increase among men; 5.2 increase among women). When either test was considered, there was no significant difference in the adjusted probability of having undergone CRC screening between blacks and whites among men. Among women, blacks were significantly more likely to have undergone either test compared to whites. Having undergone PSA test or mammography within the previous two years produced the largest increases of 22.2 and 27.9, respectively, in the adjusted probability of being screened with either FOBT or endoscopy.

Physician Density and Screening Participation

The categorical variable GI density was obtained by grouping the county GI densities of respondents into quartiles with the first quartile from 0 to 1.3, second quartile from 1.3 to 4.2, third quartile from 4.2 to 6.8, and the last quartile greater than 6.8 per 100,000 persons. County-level PCP density was grouped into quintiles because the range was considerably greater than that of GI density. The quintiles ranged from 2 to 53.3, 53.3 to 71.3, 71.3 to 88.5, 88.5 to 113.7 and greater than 113.7 per 100,000 persons. In order to adjust for the effect of PSA test use among men and mammography use among women, we performed separated analysis for each gender.

We found a statistically significant association between county-level GI density and the adjusted probability of having undergone endoscopy for CRC screening in the past 10 years (Tables 6 and 7). The adjusted probability of having undergone endoscopy within the past 10 years increased by 3.9% (95% CI, 1.9 - 6.0%) for men and 3.0% (95% CI, 1.3 - 4.7%) for women who resided in

a county with GI density greater than 6.8 per 100,000 persons compared to the baseline GI density of less than 1.3 per 100,000 persons. County-level PCP density was a significant predictor of an individual's endoscopy status among men but not women. Among men, the adjusted probability of having undergone endoscopy increased significantly by 2.4 (95% CI, 0.1 - 4.8) at PCP density greater than 113.7 per 100,000 persons.

In the equivalent analysis with FOBT status as the predictor, we did not find a significant or monotonic association between either GI density or PCP density and the adjusted probability of being screened with FOBT among men or women. However, there was a significant effect of GI density on the adjusted probability of having received either FOBT or endoscopy.

States with low screening rates compared to states with high screening rates

From our analytical sample, we obtained two subpopulations comprised of observations from counties from states with the highest five screening rates and from counties from states with the lowest five screening rates. Only states with at least 10 counties were considered. We repeated the logistic regression analysis separately for these two subpopulations. In the states with the lowest screening rates, there was a significant association between county-level GI density and the adjusted probability of having undergone CRC screening with either test (Table 8). We did not find a significant association between GI density and CRC screening status among respondents from states with the highest screening rates. PCP density had no significant effect on the CRC screening status of respondents from the states with low screening rates. On the other

hand, for the states with the highest screening rates, the adjusted probability of having undergone either test increased by 5.2 (95% CI, 0.2 - 10.3) for those who resided in counties with PCP density greater than 113.7 per 100,000 persons compared with the baseline.

While the effect of GI density on CRC screening status was considerably different for states with the lowest screening rates versus states with the highest screening rates, the effects of the other covariates in our model were similar for the two subpopulations (Table 3).

Is Effect of PCP density on CRC screening status moderated by GI density?

PCPs may influence screening uptake in two ways. First, by recommending screening to their patients[126,133] and second, by performing endoscopic screening [20,36]. We therefore included interaction terms in our models to determine whether the effect of PCP density on endoscopic screening status was moderated by GI density. We found no sizeable interaction between PCP density and GI density (Appendix 10).

DISCUSSION

Our analyses of the 2010 BRFSS data found that GI density, and to a lesser extent PCP density, are predictors of undergoing endoscopic CRC screening. The adjusted probability of undergoing endoscopy was 3.9 percentage points greater among male respondents of counties with GI densities in the fourth quartile of the distribution, compared to the first quartile. Among female respondents, the increase was 3.0 percentage points. The effect of GI

density on CRC screening persisted even when the outcome was either FOBT or endoscopy. In addition, the association of GI density and the adjusted probability of undergoing endoscopic screening was more pronounced in states that had the lowest CRC screening rates. The results of our analyses were consistent with other studies that evaluated the association between physician density and CRC screening and outcomes[128,134].

The adjusted probability of having been screened with FOBT showed a small association among male respondents who resided in counties with PCP density greater than 88.5 per 100,000 persons. This result was contrary to our expectation and suggests that PCPs are more likely to perform endoscopy when the PCP to patient ratio exceeded a certain threshold.

Our analyses suggest that the continued decline of FOBT use and the concomitant increase in the use of endoscopy as the primary CRC screening test has the potential to widen disparities if the geographic distribution of GIs is skewed. However, CRC screening disparities may be mitigated by encouraging the use of FOBT. For example, we found that although a lesser proportion of black males have undergone endoscopy, compared to whites, there was no significant difference in the overall screening rate.

States with the lowest screening rates showed strong association between GI density and CRC screening status of respondents, but no such effect was found with states with the highest screening rates. For the subgroup of states with the highest screening rates, we observed that a PCP density of greater than 113.7 per 100,000 persons was associated with a 5.2 point marginal increase in

the probability of undergoing screening. Although endoscopies are mainly performed by GIs, earlier studies indicated that a substantial number of PCPs performed endoscopies for CRC screening. Further work is needed to understand the underlining cause of the disparate effect of GI density in the two sub populations. There may be some underlining geographical or policy differences that differentially impact CRC screening uptake. One consideration is examining the effect of state-level CRC screening mandates and campaigns on screening participation. In addition, the effect of physician supply on health outcomes may operate differently for metropolitan verses non-metropolitan areas.[128]

Several studies have examined the physician supply required to provide the annual number of endoscopies that would be generated by different CRC screening strategies[31,32,135,136]. However, these studies approached the problem from a national or state perspective and did not address the effects of small-area variation in physician supply. While the overall physician supply is of great importance to delivering health care, geographic distribution may affect disparities in health outcomes.

STUDY LIMITATIONS

There are several limitations in our study. First, a respondent's county or even state of residence at the time of the BRFSS survey interview may not be the same county where he/she resided five or ten years before. As a result, it may be inaccurate to associate an endoscopy received five to ten years ago with a particular geographic location. Second, the assumption that respondents

sought and received endoscopy in their county of residence may not be an accurate one. It is possible that respondents underwent endoscopy in facilities outside their county of residence. Perhaps, a more accurate analytical strategy would be one that considers physician density within some radius of the respondent's residence. However, such analysis requires information that is unavailable in the BRFSS data. Third, the BRFSS data did not allow us to disentangle diagnostic endoscopies from those performed solely for CRC screening. The distinction is important because barriers to undergoing endoscopy may operate differently for diagnostic versus screening tests. Fourth, the BRFSS data are self-reported and may suffer from recall bias and as a result in inaccuracies in the reported timing of screening tests received in earlier years. Fifth, physician supply data sourced from the American Medical Association have inaccuracies because of reporting lags and self-reporting [137]. The effect of reporting lags was partly mitigated by our use of average counts over the period from 2001 to 2010. Last, our study did not take geographic variation in physician practice styles into account. Variation in physician productivity could confound the association between physician density and screening status.

CONCLUSION

Geographic variations in CRC screening may be partly attributable to inequalities in physician supply, particularly, GIs. Efforts aimed at reducing disparities in CRC screening may need to consider, in addition to individual factors, the role played by physician supply and capacity.

Table 4: Percentage of respondents who reported undergoing CRC screening within recommended time intervals, BRFSS, 2010

	FOBT in the past 2 years			Up-to-date with endoscopy[a]			Up-to-date with FOBT or endoscopy		
Characteristic	N	%	95% CI	N	%	95% CI	N	%	95% CI
Total	255521	18.0	[17.8, 18.3]	256987	61.7	[61.3, 62.0]	257473	66.7	[66.3, 67.0]
Gender									
Female	157916	17.5	[17.2, 17.8]	159165	62.3	[61.9, 62.8]	159436	67.3	[66.9, 67.7]
Male	97605	18.6	[18.2, 19.0]	97822	60.9	[60.3, 61.5]	98037	65.9	[65.4, 66.5]
Age									
50 - 54	45085	11.8	[11.3, 12.3]	45180	44.9	[44.1, 45.7]	45206	49.9	[49.1, 50.8]
55 - 59	48733	15.6	[15.1, 16.2]	48974	61.3	[60.6, 62.1]	49022	66.0	[65.3, 66.7]
60 - 64	49453	20.3	[19.7, 21.0]	49807	66.9	[66.2, 67.6]	49880	72.2	[71.5, 72.9]
65 -79	43437	22.6	[21.9, 23.2]	43796	71.1	[70.3, 71.8]	43893	76.3	[75.5, 77.0]
70 - 74	35210	23.4	[22.6, 24.2]	35466	73.0	[72.2, 73.7]	35560	77.7	[76.9, 78.4]
75 - 80	33603	23.4	[22.7, 24.2]	33764	72.6	[71.8, 73.4]	33912	77.6	[76.8, 78.3]
Race/Ethnicity									
White	208418	18.0	[17.7, 18.2]	209989	64.0	[63.7, 64.4]	210326	68.8	[68.4, 69.1]
Black	18884	22.2	[21.1, 23.3]	18825	61.2	[60.0, 62.5]	18894	67.1	[65.9, 68.3]
Hispanic	13250	14.5	[13.4, 15.5]	13204	47.1	[45.5, 48.7]	13238	53.0	[51.4, 54.6]
Other	11776	18.6	[17.2, 19.9]	11770	53.1	[51.2, 55.0]	11799	59.2	[57.3, 61.0]
Marital status									
Unmarried	68822	16.5	[16.0, 17.0]	69109	53.0	[52.3, 53.7]	69232	58.7	[58.0, 5.94]
Widowed	41090	20.1	[19.4, 20.7]	41286	63.0	[62.1, 63.8]	41424	68.4	[67.5, 69.2]
Married	144834	18.3	[17.9, 18.6]	145812	64.3	[63.9, 64.7]	146035	69.0	[68.6, 69.4]
Self-rated health status									
Excellent	38923	17.5	[16.9, 18.2]	39249	61.8	[60.9, 62.8]	39292	66.6	[65.6, 67.5]
Very good	77988	18.2	[17.8, 18.7]	78631	64.2	[63.5, 64.8]	78742	69.2	[68.6, 69.8]
Good	79205	17.9	[17.5, 18.4]	79669	61.5	[60.8, 62.1]	79814	66.5	[65.9, 67.1]
Fair/Poor	58395	18.4	[17.9, 19.0]	58438	58.4	[57.7, 59.2]	58622	63.6	[62.9, 64.4]

Table 4. (Continued)

	FOBT in the past 2 years			Up-to-date with endoscopy[a]			Up-to-date with FOBT or endoscopy		
Characteristic	N	%	95% CI	N	%	95% CI	N	%	95% CI
Having a doctor or usual place of care									
No	21400	7.9	[7.28, 8.64]	21360	27.9	[26.8, 29.1]	21386	31.8	[30.6, 33.0]
Yes	233606	19.1	[18.8, 19.3]	235112	65.0	[64.6, 65.3]	235567	70.1	[69.7, 70.4]
Checkup in the last 12 months									
No	56304	8.6	[8.2, 9.1]	56498	41.1	[40.3, 41.8]	56538	44.6	[43.8, 45.3]
Yes	196944	20.8	[20.5, 21.2]	198219	67.8	[67.4, 68.1]	198656	73.2	[72.8, 73.6]
Physical activity within the past 30 days									
No	72562	16.2	[15.8, 16.7]	72765	56.0	[55.3, 56.6]	72938	60.9	[60.2, 61.6]
Yes	182639	18.7	[18.4, 19.0]	183899	63.8	[63.4, 64.2]	184211	68.8	[68.4, 69.2]
Smoking status									
Non-smoker	216176	18.6	[18.3, 18.9]	217652	64.5	[64.1, 64.8]	218060	69.3	[68.9, 69.7]
Smoker	38134	14.9	[14.3, 15.5]	38119	45.7	[44.8, 46.6]	38186	51.7	[50.7, 52.6]
PSA within the last 2 years									
No	29138	7.9	[7.4, 8.4]	29071	36.7	[35.7, 37.7]	29102	40.1	[39.1, 41.1]
Yes	63683	24.0	[23.4, 24.5]	63996	72.8	[72.1, 73.5]	64142	78.5	[77.8, 79.2]
Mammography within the last 2 years									
No	33550	7.1	[6.6, 7.5]	33654	33.3	[32.4, 34.2]	33681	36.8	[35.8, 37.7]
Yes	123310	20.2	[19.9, 20.6]	124485	69.9	[69.4, 70.3]	124719	75.3	[74.8, 75.7]

Table 4. (Continued)

	FOBT in the past 2 years			Up-to-date with endoscopy[a]			Up-to-date with FOBT or endoscopy		
Characteristic	N	%	95% CI	N	%	95% CI	N	%	95% CI
GI density[b]									
0 - 1.3	59550	17.0	[16.4, 17.5]	59840	58.3	[57.6, 59.1]	59948	63.3	[62.6, 64.0]
1.30 - 4.2	57445	18.3	[17.8, 18.9]	57747	61.4	[60.7, 62.0]	57859	66.6	[65.9, 67.3]
4.2 - 6.8	56265	19.5	[19.0, 20.1]	56696	62.2	[61.5, 63.0]	56793	67.8	[67.1, 68.6]
> 6.8	55715	17.6	[17.1, 18.1]	56134	66.0	[65.3, 66.6]	56239	70.0	[69.4, 70.7]
PCP density[c]									
2 - 53.3	46640	17.8	[17.2, 18.4]	46878	59.7	[58.9, 60.5]	46978	64.7	[63.9, 65.5]
53.3 - 71.3	46388	17.5	[16.9, 18.1]	46658	60.2	[59.4, 61.0]	46726	65.2	[64.4, 66.0]
71.3 - 88.5	45889	19.3	[18.7, 20.0]	46203	61.1	[60.2, 62.0]	46296	66.6	[65.7, 67.5]
88.5 - 113.7	46203	19.6	[19.0, 20.2]	46503	63.9	[63.0, 64.7]	46592	69.2	[68.4, 70.0]
> 113.7	43855	17.1	[16.5, 17.6]	44175	66.5	[65.8, 67.3]	44247	70.6	[69.9, 71.3]

[a] Up-to-date with endoscopy means flexible sigmoidoscopy in the last five years or colonoscopy in the last 10 years

[b] Number of gastroenterologists engaged inpatient care per 100,000 persons 18 years and older

[c] Number of primary care physicians engaged inpatient care per 100,000 persons 18 years and older

Table 5: Adjusted marginal changes of predicted probability of undergoing CRC screening, men, 50 - 80 years old

	FOBT			Endoscopy			Either test		
Characteristic	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
GI density (0 - 1.3)									
1.3 - 4.2	1.3	0.053	[0.0, 2.6]	1.9	0.020	[0.3, 3.5]	2.5	0.002	[0.9, 4.0]
4.2 - 6.8	0.9	0.204	[-0.5, 2.4]	1.8	0.049	[0.0, 3.6]	2.5	0.006	[0.7, 4.2]
> 6.8	-0.1	0.897	[-1.8, 1.6]	3.9	0.000	[1.9, 6.0]	3.8	0.000	[1.7, 5.8]
PCP density (2 - 53.3)									
53.3 - 71.3	-0.4	0.638	[-1.8, 1.1]	-0.5	0.584	[-2.3, 1.3]	-0.4	0.621	[-2.2, 1.3]
71.3 - 88.5	1.2	0.156	[-0.4, 2.8]	-0.3	0.782	[-2.2, 1.7]	0.1	0.902	[-1.8, 2.0]
88.5 - 113.7	0.8	0.369	[-0.9, 2.5]	1.8	0.079	[-0.2, 3.8]	1.3	0.185	[-0.6, 3.3]
>113.7	-1.3	0.183	[-3.1, 0.6]	2.4	0.038	[0.1, 4.8]	1.7	0.145	[-0.6, 4.0]
Age (0 - 54)									
55 - 59	3.0	0.000	[1.6, 4.4]	14.2	0.000	[12.4, 16.0]	13.0	0.000	[11.3, 14.8]
60 - 64	7.5	0.000	[6.1, 9.0]	15.5	0.000	[13.7, 17.4]	15.5	0.000	[13.7, 17.3]
65 -79	7.6	0.000	[6.1, 9.1]	18.4	0.000	[16.4, 20.3]	18.0	0.000	[16.1, 19.9]
70 - 74	7.9	0.000	[6.3, 9.6]	20.1	0.000	[18.1, 22.1]	18.5	0.000	[16.5, 20.5]
75 - 80	8.4	0.000	[6.6, 10.1]	21.3	0.000	[19.2, 23.4]	20.1	0.000	[18.1, 22.1]
Race (White)									
Black	4.0	0.000	[2.0, 6.0]	-1.3	0.248	[-3.4, 0.9]	-0.7	0.531	[-2.8, 1.4]
Hispanic	-0.6	0.610	[-3.0, 1.8]	-7.8	0.000	[-10.8, -4.9]	-6.4	0.000	[-9.2, -3.6]
Other	2.8	0.026	[0.3, 5.3]	-6.1	0.000	[-9.1, -3.2]	-4.4	0.003	[-7.2, -1.5]
Marital status (Unmarried)									
Widowed	-1.7	0.09	[-3.6, 0.3]	-3.1	0.012	[-5.6, -0.7]	-3.1	0.010	[-5.5, -0.7]
Married	-0.8	0.174	[-2.0, 0.4]	3.0	0.000	[1.6, 4.3]	1.9	0.005	[0.6, 3.2]

Table 5. (Continued)

Characteristic	FOBT			Endoscopy			Either test		
	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
SES									
1	1.9	0.118	[-0.5, 4.2]	5.9	0.000	[2.9, 8.8]	5.5	0.000	[2.6, 8.4]
2	1.3	0.205	[-0.7, 3.4]	9.2	0.000	[6.6, 11.8]	8.5	0.000	[6.0, 11.0]
3	1.0	0.359	[-1.1, 3.1]	15.3	0.000	[12.6, 18.0]	13.6	0.000	[11.0, 16.2]
Self-rated health (Excellent)									
Very good	-1.0	0.169	[-2.4, 0.4]	1.2	0.159	[-0.5, 2.9]	1.5	0.073	[-0.1, 3.1]
Good	-0.8	0.306	[-2.2, 0.7]	-0.6	0.518	[-2.3, 1.2]	0.0	0.998	[-1.7, 1.7]
Fair/Poor	0.6	0.495	[-1.1, 2.3]	2.2	0.031	[0.2, 4.2]	2.2	0.027	[0.2, 4.1]
Health plan (No)									
Yes	2.1	0.07	[-0.2, 4.3]	7.8	0.000	[5.3, 10.4]	7.4	0.000	[5.0, 9.7]
Has doctor (No)									
Yes	3.7	0.000	[1.6, 5.7]	15.3	0.000	[12.9, 17.6]	13.6	0.000	[11.4, 15.9]
Checkup within last 30 days (No)									
Yes	8.9	0.000	[7.7, 10.0]	10.4	0.000	[9.0, 11.9]	11.5	0.000	[10.1, 12.9]
PSA test within last 2 years (No)									
Yes	11.9	0.109	[10.9, 13.0]	20.2	0.188	[18.8, 21.7]	22.2	0.207	[20.7, 23.6]
Physical Activity									
Yes	1.6	0.006	[0.4, 2.7]	2.8	0.000	[1.5, 4.2]	2.8	0.000	[1.5, 4.1]
Smoker (No)									
Yes	1.5	0.038	[0.1, 2.9]	-6.3	0.000	[-7.9, -4.7]	-4.1	0.000	[-5.6, -2.5]

Table 6: Adjusted marginal changes of predicted probability of undergoing CRC screening, women, 50 - 80 years old

	FOBT			Endoscopy			Either test		
Characteristic	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
GI density (0 - 1.3)									
1.3 - 4.2	0.9	0.090	[-0.1, 1.9]	2.7	0.000	[1.4, 4.0]	2.3	0.000	[1.1, 3.5]
4.2 - 6.8	1.6	0.006	[0.4, 2.7]	2.5	0.001	[1.1, 3.9]	2.2	0.002	[0.8, 3.6]
> 6.8	-0.2	0.778	[-1.5, 1.2]	3.0	0.001	[1.3, 4.7]	1.4	0.102	[-0.3, 3.0]
PCP density (2 - 53.3)									
53.3 - 71.3	-0.5	0.441	[-1.6, 0.7]	-0.9	0.206	[-2.4, 0.5]	-0.7	0.317	[-2.1, 0.7]
71.3 - 88.5	0.5	0.423	[-0.7, 1.7]	-1.0	0.186	[-2.6, 0.5]	-0.5	0.506	[-2.0, 1.0]
88.5 - 113.7	1.2	0.063	[-0.1, 2.6]	0.3	0.719	[-1.3, 1.9]	1.5	0.069	[-0.1, 3.0]
>113.7	-1.6	0.028	[-3.0, -0.2]	1.1	0.250	[-0.8, 2.9]	1.2	0.204	[-0.6, 3.0]
Age (0 - 54)									
55 - 59	3.7	0.000	[2.6, 4.8]	15.1	0.000	[13.6, 16.6]	14.7	0.000	[13.3, 16.2]
60 - 64	7.2	0.000	[6.0, 8.3]	19.5	0.000	[18.0, 20.9]	19.2	0.000	[17.7, 20.6]
65 -79	8.7	0.000	[7.5, 9.9]	20.8	0.000	[19.3, 22.3]	20.6	0.000	[19.1, 22.1]
70 - 74	10.8	0.000	[9.4, 12.2]	22.9	0.000	[21.3, 24.5]	23.0	0.000	[21.5, 24.6]
75 - 80	10.4	0.000	[9.0, 11.9]	23.6	0.000	[21.9, 25.3]	23.8	0.000	[22.2, 25.5]
Race (White)									
Black	5.2	0.000	[3.7, 6.7]	0.8	0.315	[-0.8, 2.4]	1.7	0.029	[0.2, 3.2]
Hispanic	0.1	0.905	[-1.8, 2.0]	-5.0	0.000	[-7.4, -2.6]	-3.4	0.004	[-5.7, -1.1]
Other	2.2	0.034	[0.2, 4.2]	-6.1	0.000	[-8.5, -3.6]	-4.6	0.000	[-7.0, -2.3]
Marital status (Unmarried)									
Widowed	-0.4	0.476	[-1.5, 0.7]	-0.5	0.495	[-1.9, 0.9]	-1.4	0.043	[-2.8, 0.0]
Married	-0.4	0.444	[-1.3, 0.6]	1.9	0.001	[0.8, 3.0]	0.9	0.092	[-0.1, 2.0]

Table 6. (Continued)

	FOBT			Endoscopy			Either test		
Characteristic	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
SES									
1	0.2	0.845	[-1.4, 1.7]	2.7	0.010	[0.6, 4.8]	3.1	0.003	[1.1, 5.2]
2	0.5	0.510	[-0.9, 1.9]	8.5	0.000	[6.6, 10.4]	8.2	0.000	[6.3, 10.0]
3	0.6	0.426	[-0.9, 2.1]	13.1	0.000	[11.1, 15.0]	12.1	0.000	[10.2, 14.1]
Self-rated health (Excellent)									
Very good	0.2	0.719	[-0.9, 1.3]	2.4	0.001	[1.0, 3.8]	2.0	0.002	[0.7, 3.4]
Good	-0.5	0.364	[-1.7, 0.6]	4.3	0.000	[2.9, 5.8]	3.2	0.000	[1.8, 4.6]
Fair/Poor	0.3	0.696	[-1.1, 1.6]	8.0	0.000	[6.4, 9.6]	6.4	0.000	[4.8, 7.9]
Health plan (No)									
Yes	1.7	0.067	[-0.1, 3.4]	8.3	0.000	[6.1, 10.5]	7.2	0.000	[5.2, 9.2]
Has doctor (No)									
Yes	5.6	0.000	[3.6, 7.5]	13.0	0.000	[10.6, 15.4]	12.8	0.000	[10.6, 15.1]
Checkup within last 30 days (No)									
Yes	6.4	0.000	[5.4, 7.4]	9.4	0.000	[8.1, 10.7]	10.1	0.000	[8.8, 11.3]
Mammography within last 2 years (No)									
Yes	10.9	0.101	[10.1, 11.7]	26.8	0.255	[25.5, 28.1]	27.9	0.266	[26.6, 29.3]
Physical Activity									
Yes	2.1	0.000	[1.2, 2.9]	2.3	0.000	[1.3, 3.4]	2.7	0.000	[1.7, 3.7]
Smoker (No)									
Yes	-1.8	0.001	[-2.9, -0.8]	-7.4	s	[-8.8, -6.1]	-6.3	0.000	[-7.6, -5.0]

Table 7: Adjusted predicted marginal probability of having undergone either FOBT or endoscopy: Low screening participation states versus high screening participation states

	States with low screening rates			States with high screening rates		
Characteristic	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
GI density (0 - 1.3)						
1.3 - 4.2	3.7	0.007	[1.0, 6.4]	1.9	0.250	[-1.3, 5.0]
4.2 - 6.8	6.3	0.000	[2.9, 9.7]	0.1	0.950	[-3.4, 3.6]
> 6.8	8.2	0.000	[4.6, 11.8]	-1.7	0.491	[-6.6, 3.1]
PCP density (2 - 53.3)						
53.3 - 71.3	-2.4	0.065	[-5.0, 0.1]	-0.3	0.897	[-4.4, 3.8]
71.3 - 88.5	1.5	0.395	[-1.9, 4.9]	4.7	0.026	[0.5, 8.8]
88.5 - 113.7	-4.1	0.031	[-7.7, -0.4]	1.1	0.646	[-3.6, 5.7]
>113.7	-2.1	0.389	[-7.0, 2.7]	5.2	0.040	[0.2, 10.3]
Age (0 - 54)						
55 - 59	10.9	0.000	[7.7, 14.1]	13.1	0.000	[9.6, 16.7]
60 - 64	16.7	0.000	[13.5, 19.9]	15.9	0.000	[12.2, 19.5]
65 -79	17.8	0.000	[14.4, 21.1]	17.2	0.000	[13.6, 20.8]
70 - 74	17.7	0.000	[14.2, 21.2]	19.9	0.000	[16.0, 23.8]
75 - 80	19.3	0.000	[15.4, 23.1]	20.0	0.000	[15.8, 24.2]
Race (White)						
Black	-1.9	0.177	[-4.6, 0.9]	2.2	0.209	[-1.3, 5.8]
Hispanic	-7.7	0.016	[-14.0, -1.4]	-6.8	0.264	[-18.8, 5.2]
Other	1.5	0.494	[-2.9, 5.9]	-8.8	0.040	[-17.2, -0.4]
Marital status (Unmarried)						
Widowed	2.4	0.142	[-0.8, 5.5]	-0.7	0.720	[-4.8, 3.3]
Married	2.9	0.021	[0.4, 5.4]	3.6	0.007	[1.0, 6.2]
SES						
1	3.5	0.060	[-0.1, 7.1]	5.3	0.087	[-0.8, 11.4]
2	8.0	0.000	[4.8, 11.3]	8.5	0.002	[3.1, 14.0]
3	12.0	0.000	[8.4, 15.6]	12.1	0.000	[6.3, 17.8]
Self-rated health (Excellent)						
Very good	0.5	0.777	[-2.8, 3.7]	3.0	0.098	[-0.6, 6.6]
Good	2.9	0.075	[-0.3, 6.1]	5.7	0.003	[2.0, 9.5]
Fair/Poor	6.1	0.000	[2.8, 9.5]	9.4	0.000	[5.2, 13.6]
Health plan (No)						
Yes	6.2	0.001	[2.6, 9.9]	4.2	0.092	[-0.7, 9.1]
Has doctor						
No	11.9	0.000	[8.1, 15.6]	7.0	0.002	[2.5, 11.5]

Table 8. (Continued)

	States with low screening rates			States with high screening rates		
Characteristic	Marginal change	P>z	95% CI	Marginal change	P>z	95% CI
Checkup in last 30 days (No)						
Yes	13.4	0.000	[10.7, 16.0]	12.3	0.000	[9.0, 15.6]
PSA or Mammography (No)						
Yes	26.3	0.237	[23.7, 28.9]	22.6	0.192	[19.2, 26.0]
Physical Activity						
Yes	0.8	0.428	[-1.2, 2.9]	4.8	0.000	[2.2, 7.4]
Smoker (No)						
Yes	-5.3	0.000	[-8.0, -2.6]	-6.1	0.001	[-9.7, -2.4]
Gender (Female)						
Male	3.1	0.002	[1.1, 5.1]	4.8	0.000	[2.4, 7.2]

Chapter 5: Effect of state-mandated colorectal cancer screening benefits on screening participation

INTRODUCTION

Colorectal cancer (CRC) is the second leading cause of death among cancers that affect both men and women[138]. There has been mounting evidence over the past 20 years that screening can reduce CRC incidence and mortality [10,106,108–111,139,140]. Between 1998 and 2010 several states passed laws or arranged agreements with health insurance organizations to offer coverage for CRC screening[141]. States historically have used legislation to require health insurers to cover specific services or providers. These so-called mandated benefits may include coverage for specific health conditions and preventive services, the availability of specific professionals and coverage for certain populations[61,64]. Early adopters of CRC coverage mandates included California, Illinois, Minnesota and Missouri. The mandates and agreements established by states had varying scopes. Some states required a complete coverage of CRC screening based on the CRC screening guidelines from the American Cancer Society while others were not explicit on the extent of coverage. By 2010, a total of 35 states, including the District of Columbia had some form of mandated CRC screening coverage.

The positive correlation between having health care insurance and CRC screening is well-established[44,124,142]. However, the question of the effectiveness of mandates is specific to the extent of the benefits under a particular health care insurance. Empirical evidence about the effectiveness of state-mandated health

insurance benefits for colorectal cancer screening is limited. The only study that examined the association between mandates and CRC test use found a small positive correlation[71]. Two studies found that among those insured under Medicare, the extent of the covered benefits impacted the use of CRC tests[143,144]. Of the Medicare populations included in both studies, those who had better coverage were significantly more likely to obtain CRC screening.

In this paper, we use four waves of cross-sectional survey data to investigate the effectiveness of state-mandated CRC screening coverage. Specifically, we estimate the effect of state-mandated CRC coverage on the probability of an insured individual undergoing CRC screening.

METHODS

Data

The main data for our analyses were obtained by merging cross-sectional surveys from the Behavioral Risk Factor Survey System (BRFSS) [131]. We combined data from years 2002, 2004, 2006 and 2008. We did not use surveys conducted before 2001 in order to avoid any confounding effects of the Medicare coverage of CRC screening that began in 2001. Surveys collected after 2009 were also excluded because of the still-evolving effects of the coverage mandates introduced by the Patient Protection and Affordable Care Act of 2010[58]. The BRFSS provides publicly-available survey data collected annually through collaborations between the Centers for Disease Control and Prevention (CDC) and states. The telephone-based surveys collect data on U.S. residents 18 years or older regarding their health-related risk behaviors, chronic health

conditions, and use of preventive services. Data are available for all 50 states as well as the District of Columbia and three U.S. territories. The BRFSS has two sets of questions in each particular year, namely fixed core and standard core. The fixed core is a standard set of questions asked by all states that includes on questions on demographic characteristics. The rotating core is made up of two distinct sets of questions, each asked in alternating years by all states, addressing different topics. The questions about CRC screening use we employed in our analyses are part of the rotating core of question which have administered every even year since 2000.

In addition to the BRFSS data we compiled data on CRC coverage mandates from multiple sources, including the American Cancer Society, the National Cancer Institute's State Cancer Legislation Database and the National Council of State Legislatures (NCSL)[56,57]. Our study included only states which have CRC coverage mandates that are backed by law and are specific in the coverage benefits. For the purposes of our analysis, the position of states regarding insurance coverage for CRC screening could be classified in one of three groups, namely: (1) States that had no policy on insurance coverage for screening, (2) States that had some voluntary arrangement with insurance organization or legislation to offer coverage but coverage was not required by law, and (3) States that had passed legislation that required insurance organization to provide screening coverage in their offered policies and are specific in the coverage benefits. Our analysis included only states in the third group.

For each respondent in the BRFSS data, we created a variable that indicated the year a mandate was passed in their state of residence. From that we created a new categorical variable indicating whether the respondent was exposed to a CRC coverage mandate or not at the time of the interview. We included thirteen states had a colorectal cancer screening mandate between January 1, 2003 and January 1, 2008. Within this period, Nevada passed the first mandate on October 10, 2003 and New Mexico passed the last mandate on April 1, 2007. This ensured that each of the included states had a pre and post mandate period between 2002 and 2008.

Variables

CRC screening status

The BRFSS includes a CRC module designed to elicit information about the CRC test use among respondents. The CRC module includes questions on fecal occult blood test (FOBT) and endoscopic test (sigmoidoscopy or colonoscopy) use. The questions pertaining to each test included whether the test had been received and the time elapsed since the test was received. For each individual in the BRFSS data, we calculated three binary variables indicating whether they were adequately screened using 1) FOBT, 2) endoscopy (defined as either sigmoidoscopy or colonoscopy) or 3) either FOBT or endoscopy. We defined being adequately screened with FOBT as having been tested with FOBT within the last 2 years. To calculate FOBT status, we used the following two questions from the BRFSS survey:

(1) A blood stool test is a test that may use a special kit at home to determine whether the stool contains blood. Have you ever had this test using a home kit?; and

(2) How long has it been since you had your last blood stool test using a home kit?

An individual's endoscopy status, defined as having received sigmoidoscopy or colonoscopy in the last 5 years, was calculated from the following three questions:

(1) Sigmoidoscopy and colonoscopy are exams in which a tube is inserted in the rectum to view the colon for signs of cancer or other health problems. Have you ever had either of these exams?

(2) For a sigmoidoscopy, a flexible tube is inserted into the rectum to look for problems. A colonoscopy is similar, but uses a longer tube, and you are usually given medication through a needle in your arm to make you sleepy and told to have someone else drive you home after the test. Was your most recent exam a sigmoidoscopy or a colonoscopy?

(3) "How long has it been since you had your last sigmoidoscopy or colonoscopy?"

CRC coverage mandate

The primary predictor variable for our analyses is the whether a state had passed a comprehensive CRC screening coverage mandate or not at the time of the BRFSS survey interview. By a comprehensive CRC screening mandate, we mean a mandate that specified the ACS screening guidelines as a minimum benefit.

Other variables independent variables

All individual-level analyses included demographic characteristics such as race, marital status, education and income level obtained from the BRFSS data.

We also included health care access variables and risk factor indicators where they were available for all four waves of data (Table 10).

Statistical Analysis

To test the hypothesis that individuals exposed to state-mandated CRC screening coverage will have a greater probability of undergoing CRC screening we employed a difference-in-differences (DID) logistic regression model to analyze cross-sectional data pooled from different years. The sample for the DID analysis included individuals 50-75 years old who indicated having health insurance and resided in states that passed a CRC screening coverage mandate between 2003 and 2008. Only states that passed mandates that specified the American Cancer Society's CRC screening guidelines were included.

The DID model is commonly used to assess the impact of a policy by comparing the exposed (or treatment) group to those unaffected (control group) by the policy (Appendix 9). One of the desirable characteristics of the DID method is that it the differencing technique cancels out time-invariant heterogeneity between the treatment and control groups. A cardinal assumption of the DID method is that the treatment and control groups would exhibit the same underlying relative trends in the absence of the policy. This assumption is sometimes referred to as the parallel paths or common trends assumption.

For our analyses, one choice of treatment and control groups would be those 50 to 64 years of age residing in CRC screening coverage mandate states and non-mandate states, respectively. However, using non-treatment groups

from non-mandates in a DD or a triple difference estimation would be an incorrect specification if the impetus to pass CRC screening coverage mandates is endogenous to the same factors that promote the screening uptake. To control for the possible endogeneity of the passing of CRC screening coverage mandates, we use a comparison group from within the same state as the treatment group.

Because Medicare coverage of CRC screening was mandated in 2001, we assume that policy mandates enacted for commercial plans should have no effect on the screening behavior of Medicare-eligible individuals. In our analysis, we use the Medicare eligibility age of 65 years as the cut-off point to define our treatment and control groups. Specifically, we defined the control group as individuals 65 to 75 years old and the treatment group included those 50 to 64 years old. The DID model allows us to separate the underlining difference between the treatment group (50-64 years old) and the comparison group (65-75 years old) from the effect of the treatment (mandated CRC coverage)[145,146]. The general form of the DID estimation is provided in Equation 1.

Equation 1. Difference-in-difference model specification

$$Y_{ijt} = F(\beta_0 + \beta_1 Treat_{ijt} + \beta_2 Mandate_{ijt} + \beta_3 (Treat_{ijt} \times Mandate_{ijt}) + \beta_4 X_{ijt} + \varepsilon_{ijt})$$

$$where, \qquad Treat_{ijt} = \begin{cases} 0, & \text{if in 50-64 years old group} \\ 1, & \text{if in } >64 \text{ years old group} \end{cases}$$

$$Mandate_{ijt} = \begin{cases} 0, & \text{if pre-mandate period} \\ 1, & \text{if post-mandate period} \end{cases}$$

In Equation 1, $Treat_{ijt}$ is a binary variable indicating whether an individual from state *j* belongs to the treatment group or the comparison group. $Mandate_{ijt}$ is another binary variable indicating whether an individual, in year *t* of answering the survey, resided in a state that had passed a mandate or not. The interaction binary variable $Treat_{ijt}$ x $Mandate_{ijt}$ indicates whether an individual in state *j* was exposed to a mandate at time t. X_{ijt} represents a vector of covariates; including dummy variables for the year the survey was conducted to capture time secular trends. Y_{ijt} represents the probability of the ith individual in state *j* at year *t* underwent CRC screening or not. Time-invariant state effects were captured by including dummy state variables. The timing of the passage of mandates may in itself be serially correlated, going from one state to another. In addition, the panel data we used in the estimation may suffer from autocorrelation within states. These conditions can severely understate the standard deviation of the estimators. To account for intracorrelation, we estimated robust standard errors clustered at the state level [147].

RESULTS

Sample Characteristics

Our analysis sample consisted of a treatment group of adults 50-64 years old and a control group of 65-75 year old who had health insurance and resided in a state that passed a comprehensive CRC screening mandate between 2003-2008. A total of 50,934 respondents from were obtained BRFSS data from seven states that passed mandates during the study period were included.

Approximately half (52.2%) of the respondents had been exposed to a mandate for at least six months at the time of their interview. The use of FOBT declined between the pre-mandate and post-mandate periods (27.5% versus 21.5%). In contrast, there was an increase in the use of endoscopy from 38.8% in the pre-mandate period to 47.5% in the post-mandate period. The proportion of respondents who indicated having been screened for CRC with either FOBT or endoscopy also increased from 51.8% to 56.4%. The composition of race was similar between the pre-mandate and post-mandate periods. Whites made up 76.9% of the total sample. Of the remaining, 13.1% were black, 5.1% were Hispanic and 4.9% other race. The distribution of the pre- and post-mandate marital status and educational attainment of the respondents were almost identical. Income, smoking status, health status and history of mammography or prostate antigen specific (PSA) testing were distributed similarly in the pre- and post-mandate groups. We included a "refused" category for the income variable because it comprised 9.7% and 8.9% of the pre- and post-mandate groups, respectively.

Adjusted probabilities of having undergone CRC screening

To examine the effect of state-mandated CRC screening coverage on CRC screening participation, we performed several logistic models with state and time fixed effects. An initial model on the entire sample did not produce a significant mandate effect. In order to account for the separate effect of a respondent's mammography status and PSA testing status for women and men, respectively, we ran two independent models. Tables 11 and 12 show the odds

ratios and predicted marginal probabilities for separate models of women and men. The treatment group, represented by those 50-64 years old, was 11.62% and 15.2% points less likely to have undergone screening compared to those 65-75 years old for men and women, respectively. The largest effect detected in our model was associated with an individual's history of other screening tests. Among women, having had mammography within the previous two years resulted in absolute increase of 26.3% in the probability of having undergone CRC screening. A PSA test within the previous two years resulted in an absolute increase of 22.2% among men. The effects of education and income exhibited a trend found in other studies, with higher education attainment and income associated with a higher probability of having undergone CRC screening [44,60,124,142]. Behavioral risk factor of physical exercise and smoking status were significantly associated with the probability of having undergone CRC screening. CRC screening participation increased steadily from 2002 to 2008 by an absolute value of 1.3% to 6.9%. This trend is consistent with several studies [38,44,124,142].

The effect of state-mandated CRC screening coverage

The coefficient of Age50-64*Mandate represents the effect of mandated CRC screening coverage on the 50-64 years old group. No statistically significant effect was observed for mandates and undergoing screening with any test for either men or women. However, we found a mandate effect when we ran separate models that compared up-to-date screening with endoscopy versus otherwise (Tables 13 and 14). We observed a 0.6% (p=0.055) point increase in the probability of undergoing endoscopy among insured men who were exposed

to mandates. Among women, we did not a find a statistically significant effect of mandates on the insured 50-64 years old group. (See Appendix 11 and Appendix 12 for full model results). Our models with FOBT status as the outcome variable did not yield any significant results for men or women (Appendix 13 - Appendix 14).

DISCUSSION

We compared insured 50-64 year old persons to those 65-75 years old in states that passed CRC screening mandates between 2003 and 2008. In separate analyses for men and women we observed no significant change in the probability of having been screened with only FOBT or only endoscopy. The analyses for men did not yield any significant effect attributable to state-mandated CRC screening coverage. We found a small but significant increase in CRC screening participation among insured women who resided in states with CRC screening mandates.

To account for the possibility that effect of mandates, in terms of dissemination and subsequent change in beneficiaries' behavior, required time to manifest we examine three different specifications of the start of the post-mandate period. First we considered a post-mandate period that started immediately after the mandate went to effect. We then considered lags of six months and one year after a mandate went into effect to before the post-mandate period started. In all cases our conclusions did not change significantly.

Several reasons could account for the small magnitude of the effect. Primary among them is the Employee Retirement Security Act (ERISA) effect.

ERISA limited the power states had to regulate employee-provided health plans. As a result, an unknown but sizable proportion of the sample was exempt from mandates. An analysis of a subpopulation not exempt from the effect of coverage mandate may produce a different result. Another important consideration is the underlying factors influencing the enactment of mandated benefits. It is plausible that for states that mandated CRC screening coverage the impetus for passing the mandate also correlated with the other factors that were associated with screening uptake in the state. In other words, the motivation to pass the mandate was not necessarily borne out of an empirically determined need to provide CRC screening access. This potentially poses an endogeneity problem[148], in which case other estimation techniques have to be considered.

Theory and evidence suggest that mandated insurance benefits have both negative and positive consequences. For example, a mandated CRC screening benefit could increase utilization of CRC screening without increasing participation by facilitating repeated use among individuals who would undergo limited testing without the mandate. If a mandate has the undesirable effect of discouraging employers from offering some health insurance or pricing out individuals, then at the societal level, any gains derived from mandating coverage could be eroded by fewer individuals having access to health insurance.

STUDY LIMITATIONS

Our study has some limitations. First, and most importantly, ERISA exempts firms that self-insure from state insurance mandates[61] . With the

BRFSS data, it was not feasible to distinguish between ERISA-exempt individuals from those not exempt. The likely effect of this is that we may have mischaracterized individuals as having benefited from state mandates and consequently diluting the true effect of mandates. Second, by considering only states which had passed a mandate in the study period our analysis considered, we were unable to isolate effects that were common to mandate and non-mandate states. As a result, our analyses could be biased by disturbances that were not isolated to mandates. Third, our use of respondents 65-75 years old as a control group may not be appropriate. Other policies or factors outside of the state mandated coverage of CRC could have impacted the control group but not the treatment group. The alternative of using an equivalent age group of those 50-64 years old in non-mandate states has some challenges as well. In the alternative specification, systematic differences in the screening behaviors between the treatment states and control states will bias the analysis. Fourth, we could not separate CRC tests performed for solely for screening from those performed for diagnostic purposes. Thus, it was not possible to isolate the effects of predictors on screening colonoscopies only. However, it is unlikely that our analysis was substantially confounded since screening colonoscopies comprise a much greater proportion of all colonoscopies in the cohorts. Fifth, the BRFSS data are self-reported and may suffer from responder bias. Respondents may have inaccurately reported the time of their last CRC screening. The effect of such a systematic recall bias would be to generate a greater mandate effect.

CONCLUSION

Our study found that state mandated CRC screening coverage has a significant but small effect on the probability of insured women undergoing CRC screening.

The effect of health insurance coverage on utilization of CRC screening tests may operate at three levels, namely: (1) through physician recommendation by providing access to primary care; (2) whether the benefits under that insurance plan cover CRC screening; and (3) the level of cost-sharing embedded in the benefits. Our study was able to examine only the effect mandates operating at level two above. Further work is needed to understand fully the impact of state-mandated CRC screening benefits.

Table 8: States with comprehensive CRC screening coverage mandates, 2003-2007

State	Effective date of mandate
Nevada	10-Oct-03
Illinois	1-Jan-04
Arkansas	1-Aug-05
Oregon	23-Aug-05
Louisiana	1-Jan-06
Alaska	1-Jan-07
New Mexico	1-Apr-07

Table 9: Characteristics of analysis sample: U.S. adults aged 50-75 years with health insurance and reside in states with mandated CRC screening coverage, 2002-2008

	Pre-mandate		Post-mandate	
Charateristic	N	%	N	%
Total	69092	22.1	151498	77.9
FOBT	20184	30.1	38097	25.2
Endoscopy	31541	42.7	77786	49.5
FOBT or endoscopy	39500	55.7	91214	58.9
Gender (Female)	41750	52.6	92928	52.4
Age group (50 - 64 yr / 65 - 75 yr)	44411	66.9	95814	68.8
Race				
White	58031	80.2	123273	73.6
Black	3454	9.1	14482	9.3
Hispanic	3356	5.6	6408	10.7
Other	3555	5.1	5769	6.5
Marital status				
Married	42532	72.0	89924	71.0
Widowed	22695	24.0	50964	24.1
Never married	3608	4.0	10089	4.9
Education				
Less than high school	5743	10.3	15163	11.0
Graduated high school	18631	28.8	45262	26.5
Some college	19804	26.2	31637	25.6
Graduated college	24761	34.7	53526	36.9
Income				
less than $20,000	9264	13.0	22356	14.2
less than $35,000	14277	19.9	26310	16.5
less than $75,000	21926	33.2	43617	30.4
greater than $75,000	14144	23.6	37474	30.2
Refused	6219	10.4	14306	8.8
Smoker				
Current smoker	10980	16.9	24295	14.9
Former smoker	25621	36.9	55679	36.3
Never smoked	32177	46.3	70987	48.8
Excellent/Good Health (No/Yes)	14143	21.5	117795	21.5
Has doctor/usual place of care (No/Yes)	6096	8.3	10291	8.1
Physical activity in last 30 days (No/Yes)	16256	25.5	40848	25.7
Mammography in last 2 years (No/Yes)	5354	12.7	11125	12.5
PSA in last 2 years (No/Yes)	2552	11.8	4721	11.5

Table 10: Odds ratio and adjusted marginal changes of predicted probability of undergoing colorectal cancer screening with either FOBT or endoscopy for men

	Odds Ratio	P>z	95% CI	Marginal change
Age 50-64 years (No)				
Yes	0.51	0.000	(0.49, 0.53)	-11.6%
Mandate (No)				
Yes	0.93	0.125	(0.84, 1.02)	-0.1%
Age 50-64 * Mandate (No)				
Yes	1.00	0.956	(0.95, 1.06)	2.8%
Race (White)				
Black	1.01	0.788	(0.93, 1.1)	5.3%
Hispanic	1.00	0.953	(0.88, 1.13)	-2.2%
Other	0.96	0.699	(0.8, 1.16)	5.7%
Having a doctor (Yes)				
No	2.03	0.000	(1.53, 2.68)	13.1%
Education				
Graduated high school	1.17	0.000	(1.07, 1.27)	5.8%
Some college	1.24	0.000	(1.2, 1.28)	9.5%
Graduated college	1.33	0.000	(1.25, 1.41)	13.1%
Excellent/Good health (No)				
Yes	0.81	0.000	(0.73, 0.9)	-1.6%
Income (less than $20,000)				
less than $35,000	0.99	0.686	(0.92, 1.06)	-2.7%
less than $75,000	1.15	0.012	(1.03, 1.29)	0.2%
greater than $75,000	1.23	0.006	(1.06, 1.41)	1.4%
Refused to answer	1.19	0.004	(1.06, 1.33)	-0.4%
Smoker (Current)				
Former	0.84	0.000	(0.78, 0.91)	-2.3%
Never	1.24	0.000	(1.17, 1.31)	5.1%
Exercise in last 30 days (No)				
Yes	1.14	0.003	(1.04, 1.23)	1.2%
PSA in last 2 yrs (No)	3.09	0.000	(2.49, 3.83)	22.2%
Yes				
Year (2002)				
2004	1.07	0.555	(0.86, 1.33)	1.3%
2006	1.37	0.000	(1.26, 1.49)	1.9%
2008	1.34	0.004	(1.1, 1.63)	6.9%

Table 11: Odds ratio and adjusted marginal changes of predicted probability of undergoing colorectal cancer screening with either FOBT or endoscopy for women

	Odds Ratio	P>z	95% CI	Marginal change
Age 50-64 years (No)				
Yes	0.57	0.000	(0.5, 0.67)	-15.2%
Mandate (No)				
Yes	1.00	0.927	(0.94, 1.06)	-1.7%
Age 50-64 * Mandate (No)				
Yes	1.14	0.120	(0.97, 1.34)	0.0%
Race (White)				
Black	1.29	0.000	(1.2, 1.39)	0.3%
Hispanic	0.91	0.001	(0.85, 0.96)	-0.1%
Other	1.32	0.131	(0.92, 1.88)	-0.8%
Having a doctor (Yes)				
No	1.85	0.000	(1.55, 2.22)	16.0%
Education				
Graduated high school	1.29	0.000	(1.16, 1.43)	3.6%
Some college	1.53	0.000	(1.39, 1.68)	4.9%
Graduated college	1.81	0.000	(1.68, 1.96)	6.5%
Excellent/Good health (No)				
Yes	0.93	0.045	(0.86, 1)	-4.8%
Income (less than $20,000)				
less than $35,000	0.88	0.127	(0.75, 1.04)	-0.3%
less than $75,000	1.01	0.859	(0.93, 1.1)	3.2%
greater than $75,000	1.07	0.443	(0.91, 1.25)	4.6%
Refused to answer	0.98	0.853	(0.79, 1.21)	3.9%
Smoker (Current)				
Former	0.90	0.232	(0.76, 1.07)	-4.0%
Never	1.27	0.003	(1.09, 1.48)	4.9%
Exercise in last 30 days (No)				
Yes	1.06	0.149	(0.98, 1.14)	2.9%
Mammography last 2 yrs (No)	2.60	0.000	(2.2, 3.08)	26.3%
Yes				
Year (2002)				
2004	1.06	0.007	(1.02, 1.11)	1.5%
2006	1.09	0.250	(0.94, 1.26)	7.1%
2008	1.38	0.000	(1.16, 1.65)	6.7%

Table 12: Marginal change of undergoing screening with endoscopy among men

	Marginal change	P>z	95% CI
Age 50-64 years (No)			
Yes	-13.9%	0.000	(-16.8%, -10.9%)
Mandate (No)			
Yes	-0.9%	0.467	(-5.4%, 3.6%)
Age 50-64 * Mandate (No)			
Yes	0.6%	0.055	(-3.1%, 4.4%)

Table 13: Marginal change of undergoing screening with endoscopy among women

	Marginal change	P>z	95% CI
Age 50-64 years (No)			
Yes	-12.5%	0.000	(-16.2%, -8.7%)
Mandate (No)			
Yes	-0.8%	0.446	(-6.6%, 5.1%)
Age 50-64 * Mandate (No)			
Yes	3.7%	0.162	(-1.5%, 8.9%)

Chapter 6: Conclusions and Future implications

This dissertation investigated the effects of colorectal cancer (CRC) over-surveillance, county-level physician distribution and state-mandated health benefits on screening rates. Very little is known about the current or future capacity to deliver CRC screening at sustained high participation rates. In the first paper, we applied a Markov simulation model to estimate the annual demand for colonoscopies at various levels of screening uptake. We explicitly modeled the impact of aggressive surveillance on the annual volume of colonoscopies. Our findings show that aggressive surveillance adds a substantial number of colonoscopies with little benefit. Aggressive surveillance may accrue marginal benefits at the expense of increased probability of adverse outcomes. Additionally, in a system where gastroenterologist capacity is constrained, each unneeded surveillance colonoscopy is a test that could have gone to an unscreened person.

Even if the available per capita gastroenterologist indicates adequate capacity to accommodate higher screening rates, geographic distribution and access barriers can still prove to be significant barriers to realizing targets. There also is some evidence that physician geographic distribution can impact screening disparities [53,149]. In our second paper, we combined a nation-wide representative survey data and a physician registry to investigate the relationship between county-level physician supply and up-to-date CRC screening use. Considerable variation in county-level physician supply exists among US states. Our analysis found that the physician supply at the county level significantly

impacted the probability of an individual undergoing colonoscopy after other covariates were controlled for. This effect was more acute among males than females.

In the third paper we used longitudinal survey data to assess the impact of state-mandated CRC screening coverage on up-to-date screening rates. In our analysis of seven states that enacted mandates between 2003 and 2007 we did not find a statistically significant effect of mandates on screening rates. The absence of a significant effect of health insurance coverage mandates on screening rates is not entirely surprising. Several studies have found that among other factors, physician recommendation and socio-economic status are major predictors of CRC screening status. The strong correlation positive between county-level gastroenterologist density and endoscopic screening suggest that any positive effect of the health insurance coverage mandate may be blunted if the screening capacity and demand are geographically misaligned. Such a situation can induce overuse of screening tests among beneficiaries of the mandate.

We have shown that health insurance coverage of CRC screening tests does not necessarily translate into an expanded use. They may in fact be counter-productive[67]. A mandated benefit is of little use if there is no accessible gastroenterologist to provide that benefit. The association between county-level physician density and the probability of being up-to-date with CRC screening after controlling for person-level characteristics suggests that a sustainable solution to eliminating disparities should consider strategies that increase the

number of physicians in underserved areas. The challenge of addressing physician shortage in underserved areas is made even more formidable by a general shortage of physicians across the US[150,151]. One of the consequences of this shortage is that there is excess demand for physicians in urban and more attractive areas to the extent that no economic incentive exists for physicians to practice in acutely underserved areas. Several programs have therefore been developed at both the federal and state levels to provide incentives to physicians to serve in otherwise unattractive areas[152].

States offer student loan repayment programs for physicians who elect to serve in shortage areas. The federal government offers a similar program for physicians who serve at least 2 years in shortage areas through the National Health Service Corps[153]. Other incentives provided by states include income tax credits and J-1 visa waivers. J-1 visa waivers allow foreign medical graduates to avoid going back to their home countries for at least two years before they are allowed to work in the US in exchange of working in a shortage area. These programs have had some success in attracting and retaining primary care physicians in rural and underserved areas[153]. While most of the incentive programs are for primary/family physicians, notably, colonoscopies are mostly performed by gastroenterologists or colorectal surgeons[154]. The precipitous shift from FOBT to colonoscopy as the primary screening test means increasing the availability of primary care physicians may have only a limited impact on CRC screening rates. Some have called for the training PCPs and nurse practitioners to perform colonoscopies[20,155,156] as a way of addressing the inadequate number

of gastroenterologists and colorectal surgeons. In addition, it may be useful to use the physician incentive programs to carefully target gastroenterologists and colorectal surgeons to areas of need.

In our first paper, we found that up to one million excess colonoscopies could be performed annually if CRC surveillance is done more frequently than guidelines stipulate. Fewer unneeded surveillance colonoscopies would be performed if physicians adhered to guidelines and thereby freeing up colonoscopies for those who need them. However, several factors combine to prevent physicians from following guidelines. First, the lack of a singular gold standard recommendation means that physicians may be exposed to inconsistent messages regarding what the appropriate guidelines are. Even though the several recommendations issued by the USPSTF and various physician bodies do not differ significantly, the plurality can cause confusion. In recognition of the problem, recent recommendations have being issued by joint committees of stakeholder physician bodies[18,21]. Second, physicians have also exhibited a lack of knowledge of the details of guidelines within the recommendations[157]. Several recommendations with their frequent updates make it even more difficult for physicians to assimilate the guidelines. To overcome the problem would require more education for both physicians and the public on a singular baseline screening and surveillance guidelines. A gold standard recommendation notwithstanding, physicians still retain their autonomy in the delivery of care and could justify premature surveillance. Third, there is little incentive in a fee-for-service payment system for a physician to defer a

surveillance colonoscopy for a patient when confronted with ambiguity. The perverse incentive of fee-for-service payment system to reward even unnecessary interventions is problem that requires a health system-wide solution.

Further research

The Patient Protection and Affordable Care Act is expected to expand healthcare coverage to millions of previously uninsured Americans. This influx of newly-insured patients is likely to put considerable strain on all healthcare resources. It is therefore imperative to reduce overuse of colonoscopy and gain a better understanding of the determinants of screening participation. While programs that target underserved populations are important, they are not the panacea for systematic shortages or structural distributional problems associated with physician supply. It is important to understand how geographic differences in physician supply affect screening rates and whether shortages impact the quality of colonoscopy.

Legislative mandates have been used extensively by states to ensure the availability of certain health care services. However, the effectiveness of mandates in improving screening rates is yet to be proven. Because these mandates have the potential of causing undesirable effects such as test overuse and increase the overall cost of insurance, it is important that more research is conducted to expand our understanding of the policy. As a policy tool, an important question about mandates that needs to be carefully weighed is whether the societal benefits they produce outweigh the costs.

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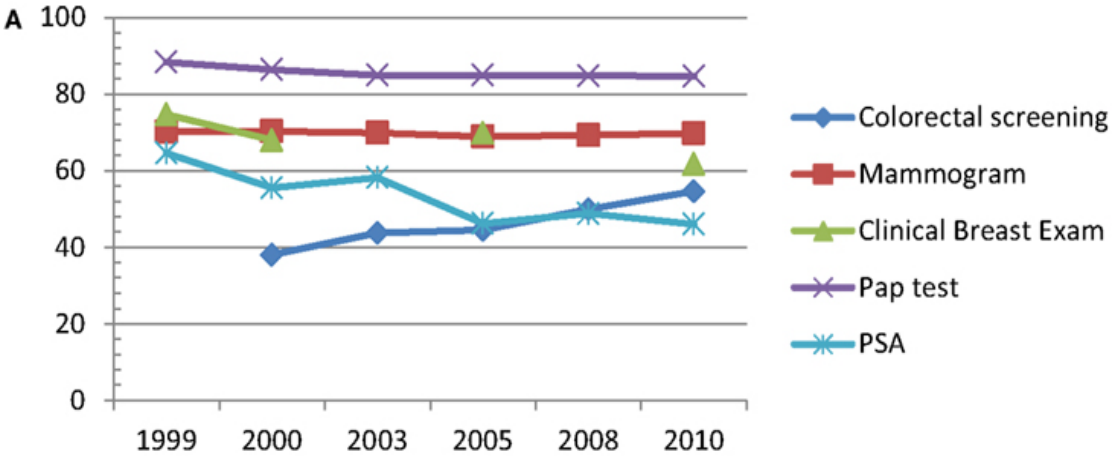
Appendices

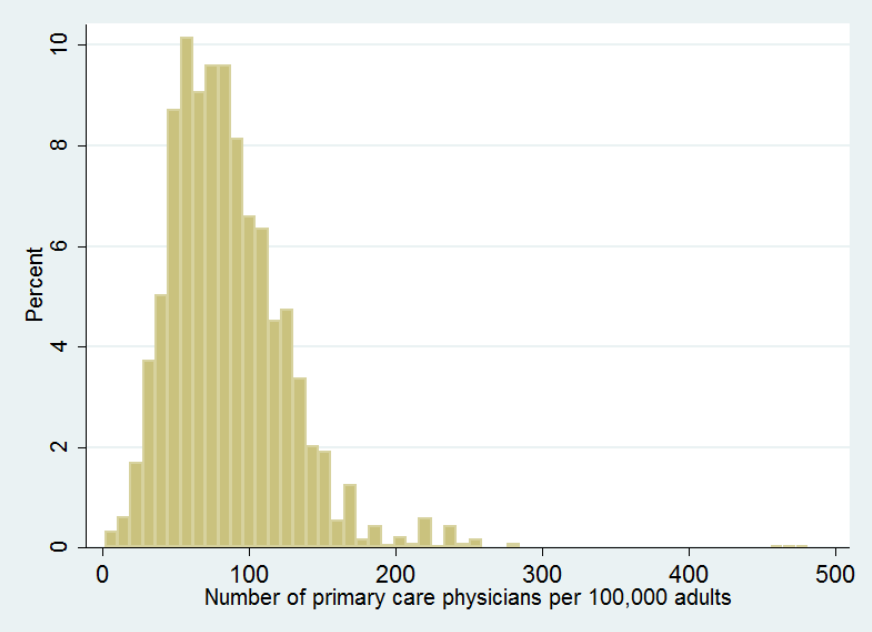
Appendix 1: Summarized CRC Screening guidelines: American Cancer Society, US Multi Society Task Force on CRC, American College of Radiology

Test	Interval
Flexible Sigmoidoscopy	Every 5 years
Colonoscopy	Every 10 years
Double Contrast Barium Enema	Every 5 years
Computed Tomographic Colonoscopy	Every 5 years
gFOBT high sensitivity	Annual
FIT high sensitivity	Annual

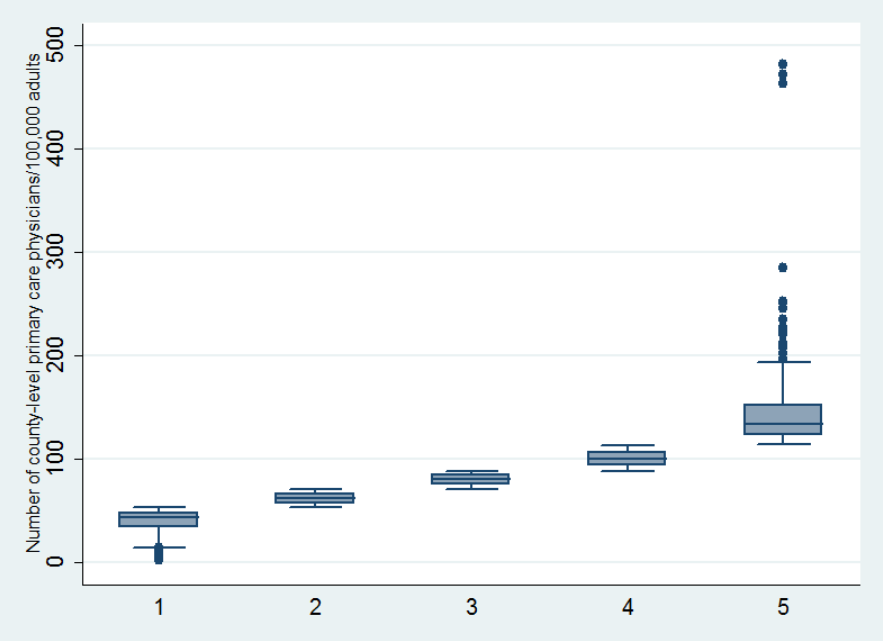
Appendix 2: Comparison of screening rates of various recommended screening tests, 1999 - 2010



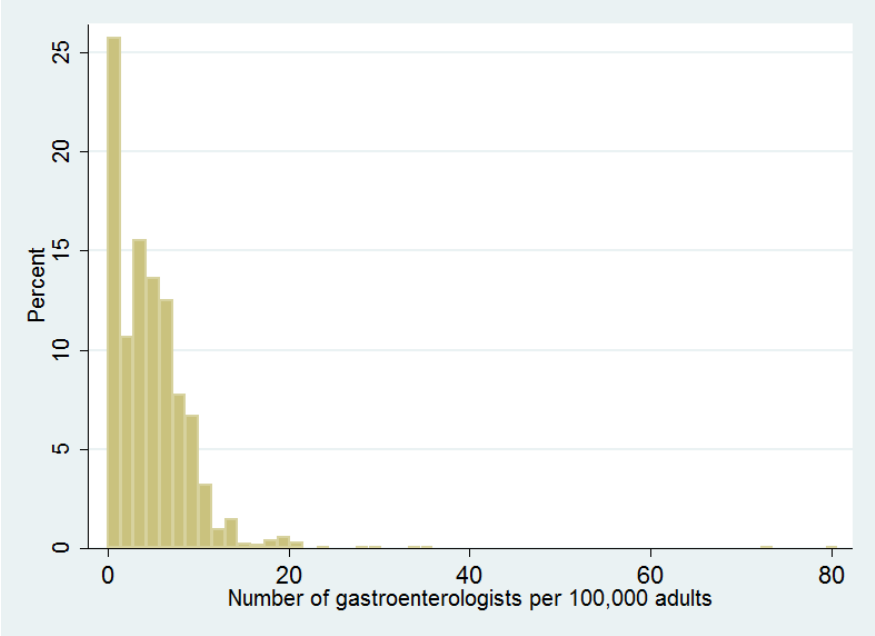
Appendix 3: Distribution of county-level primary care physicians per 100,000 adults



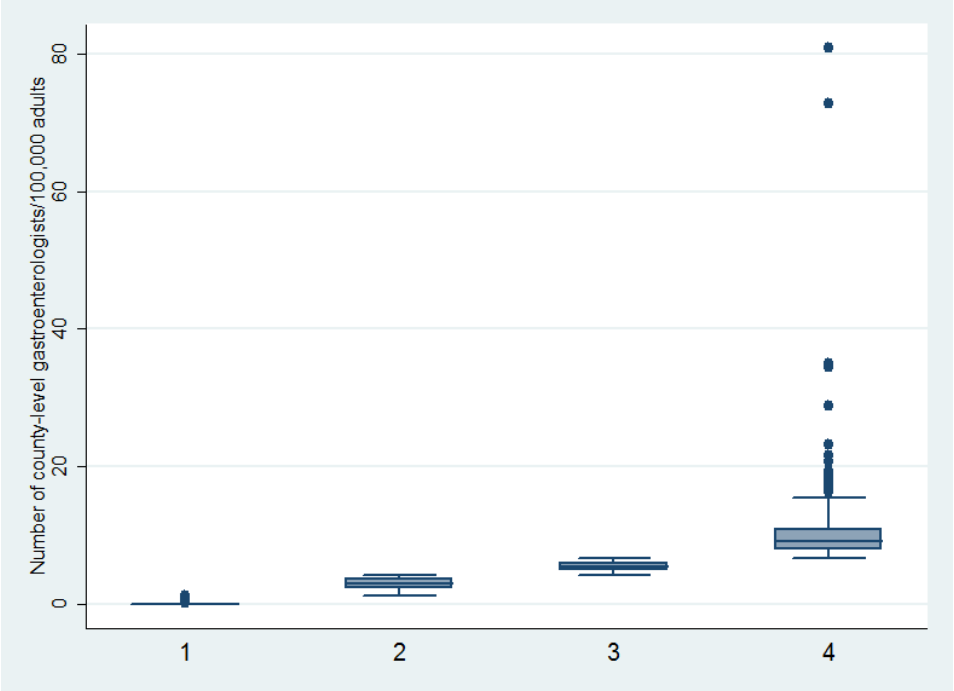
Appendix 4: Box plot of county-level primary care physician density at quintiles



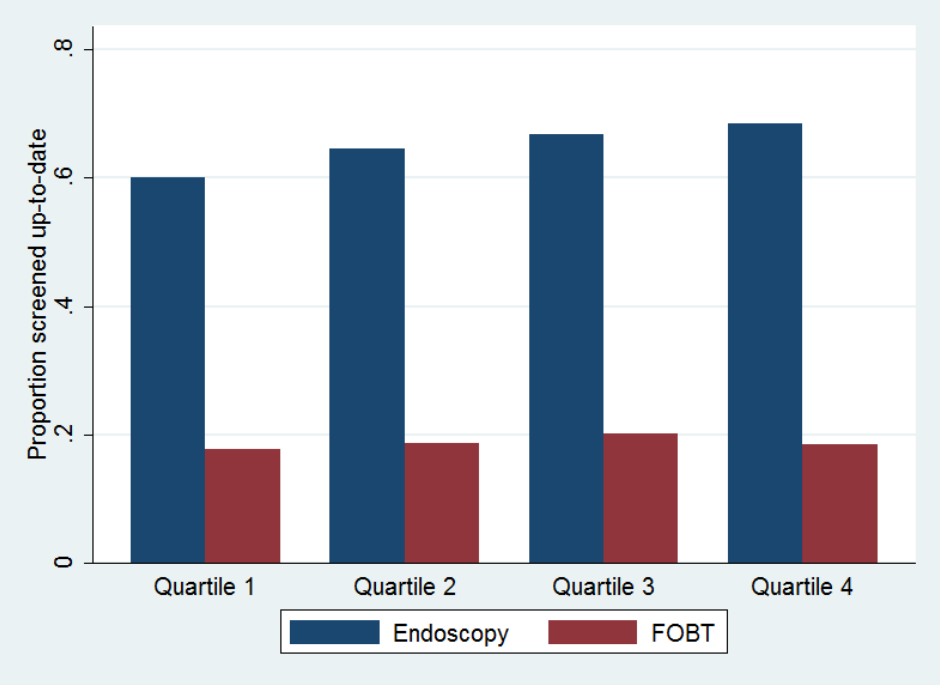
Appendix 5: Distribution of county-level gastroenterologists per 100,000 adults



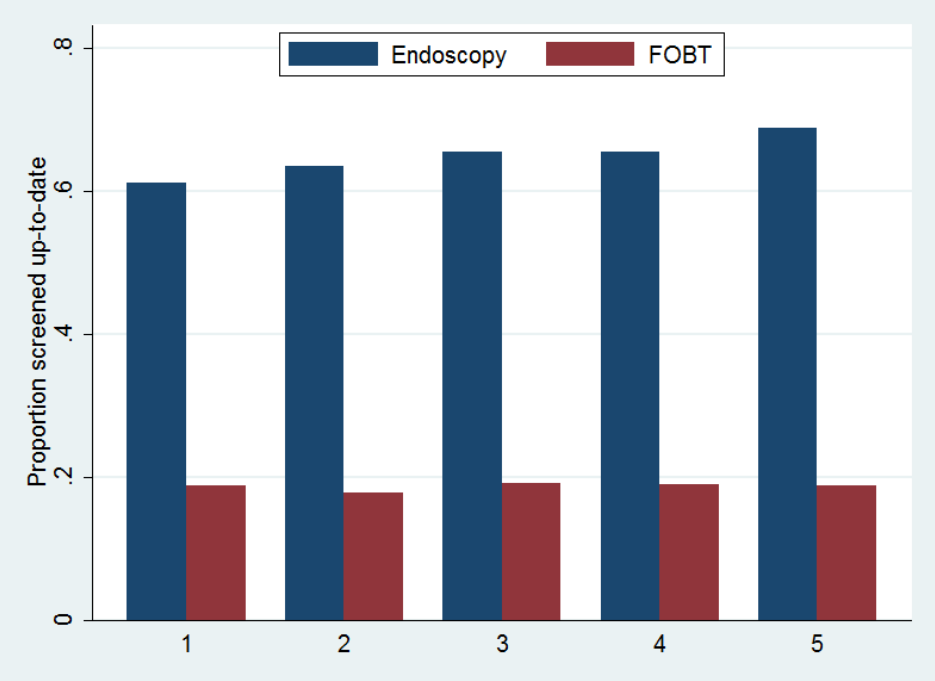
Appendix 6: Box plot of county-level gastroenterologist density at quartiles



Appendix 7: Proportion of the population up-to-date with FOBT and endoscopy test at quartiles of county-level gastroenterologist density



Appendix 8: Proportion of the population up-to-date with endoscopy and FOBT at quintiles of county-level primary care physician density



Appendix 9: Deriving the policy effect coefficient in the difference-in-difference model

$$Y_{ijt} = \beta_0 + \beta_1 Treat_j + \beta_2 Mandate_t + \beta_3 (Treat_j \times Mandate_t)$$

1. $E\left(Y_{ijt} \middle| Treat = 0, Mandate = 0\right) = \beta_0$
2. $E\left(Y_{ijt} \middle| Treat = 0, Mandate = 1\right) = \beta_0 + \beta_2$
3. $E\left(Y_{ijt} \middle| Treat = 1, Mandate = 0\right) = \beta_0 + \beta_1$
4. $E\left(Y_{ijt} \middle| Treat = 1, Mandate = 1\right) = \beta_0 + \beta_1 + \beta_2 + \beta_3$

Difference 1 (Equation 2 – Equation 1): $\beta_0 + \beta_2 - \beta_0 = \beta_2$

Difference 2 (Equation 4 – Equation 3): $\beta_0 + \beta_1 + \beta_2 + \beta_3 - (\beta_0 + \beta_1) = \beta_2 + \beta_3$

Difference in difference: $\beta_2 + \beta_3 - \beta_2 = \beta_3$

Appendix 10: Adjusted probability of being up-to-date with CRC screening. Margins from PCP-Gastroenterologist interaction

		dy/dx	Std. Err.	t	P>t	[95% Conf.	Interval]
2.PCP_quint GI_quart							
	1	-0.004	0.006	-0.69	0.490	-0.016	0.008
	2	-0.004	0.006	-0.69	0.489	-0.015	0.007
	3	-0.004	0.006	-0.69	0.489	-0.015	0.007
	4	-0.004	0.006	-0.69	0.489	-0.015	0.007
3.PCP_quint GI_quart							
	1	0.000	0.006	0.04	0.97	-0.012	0.013
	2	0.000	0.006	0.04	0.97	-0.012	0.012
	3	0.000	0.006	0.04	0.97	-0.012	0.012
	4	0.000	0.006	0.04	0.97	-0.012	0.012
4.PCP_quint GI_quart							
	1	0.021	0.007	3.12	0.002	0.008	0.034
	2	0.020	0.007	3.11	0.002	0.007	0.033
	3	0.020	0.007	3.09	0.002	0.007	0.033
	4	0.020	0.007	3.09	0.002	0.007	0.033
5.PCP_quint GI_quart							
	1	0.022	0.008	2.83	0.005	0.007	0.037
	2	0.021	0.008	2.82	0.005	0.007	0.036
	3	0.021	0.008	2.81	0.005	0.006	0.036
	4	0.021	0.008	2.79	0.005	0.006	0.036

Appendix 11: Output from Stata® showing the odds ratios of being up-to-date with endoscopic screening among men only

Endo50_75	Odds Ratio	Std. Err.	z	P>z	95% Confidence Interval	
1.Age50_64	0.5847	0.0400	-7.85	0.000	0.5114	0.6686
1.Mandate1	0.9694	0.0415	-0.73	0.467	0.8914	1.0541
1.AgeManda~1	1.1720	0.0968	1.92	0.055	0.9967	1.3780
Race4grp						
2	1.2431	0.0474	5.71	0.000	1.1536	1.3396
3	0.9670	0.0381	-0.85	0.394	0.8952	1.0446
4	1.1709	0.2795	0.66	0.509	0.7334	1.8695
Hasdoc	1.7719	0.1175	8.63	0.000	1.5559	2.0179
Edu						
2	1.1306	0.0470	2.95	0.003	1.0421	1.2265
3	1.3315	0.0309	12.32	0.000	1.2722	1.3935
4	1.6602	0.0444	18.93	0.000	1.5753	1.7496
1.Genhealth	0.9825	0.0452	-0.38	0.701	0.8977	1.0753
Income2						
1	0.9904	0.0571	-0.17	0.867	0.8845	1.1089
2	1.2856	0.1136	2.84	0.004	1.0812	1.5286
3	1.3217	0.0826	4.46	0.000	1.1693	1.4939
4	1.3122	0.1198	2.98	0.003	1.0973	1.5694
Smoker						
1	0.8042	0.0626	-2.8	0.005	0.6904	0.9367
2	1.2434	0.0901	3	0.003	1.0787	1.4332
1.Physical	1.0224	0.0260	0.87	0.384	0.9726	1.0747
1.Psa	1.8388	0.1077	10.4	0.000	1.6394	2.0624
iYear2						
2004	1.1035	0.0547	1.99	0.047	1.0013	1.2161
2006	1.3787	0.0796	5.56	0.000	1.2311	1.5440
2008	1.7968	0.1496	7.04	0.000	1.5262	2.1154
_state						
5	0.6788	0.0178	-14.8	0.000	0.6449	0.7146
17	0.6666	0.0242	-11.17	0.000	0.6208	0.7157
22	0.6562	0.0194	-14.27	0.000	0.6193	0.6952
32	0.6982	0.0126	-19.87	0.000	0.6738	0.7233
35	0.8190	0.0188	-8.71	0.000	0.7830	0.8566
41	0.9330	0.0195	-3.33	0.001	0.8956	0.9719

Appendix 12: Output from Stata® showing the odds ratios of being up-to-date with endoscopic screening among women only

Endo50_75	Odds Ratio	Std. Err.	z	P>z	95% CI	
1.Age50_64	0.5531	0.0390	-8.41	0.000	0.4817	0.6349
1.Mandate1	0.9610	0.0501	-0.76	0.446	0.8676	1.0645
1.AgeManda~1	1.0270	0.0702	0.39	0.697	0.8982	1.1743
Race4grp						
2	1.0651	0.0382	1.76	0.078	0.9929	1.1426
3	0.9855	0.0498	-0.29	0.772	0.8925	1.0881
4	0.9837	0.0769	-0.21	0.834	0.8440	1.1466
Hasdoc	1.8723	0.2613	4.49	0.000	1.4242	2.4614
Edu						
2	1.2039	0.0669	3.34	0.001	1.0797	1.3423
3	1.2696	0.0355	8.52	0.000	1.2018	1.3412
4	1.3323	0.0709	5.39	0.000	1.2004	1.4787
1.Genhealth	0.8275	0.0461	-3.4	0.001	0.7419	0.9230
Income2						
1	0.9368	0.0424	-1.44	0.149	0.8572	1.0237
2	1.1331	0.0481	2.94	0.003	1.0426	1.2314
3	1.2952	0.0762	4.4	0.000	1.1541	1.4535
4	1.1525	0.0703	2.33	0.020	1.0226	1.2989
Smoker						
1	0.8432	0.0309	-4.65	0.000	0.7848	0.9060
2	1.2289	0.0365	6.94	0.000	1.1594	1.3025
1.Physical	1.0569	0.0405	1.45	0.148	0.9805	1.1393
1.Mam	2.7218	0.2403	11.34	0.000	2.2893	3.2361
iYear2						
2004	1.1601	0.1026	1.68	0.093	0.9755	1.3796
2006	1.6120	0.0594	12.95	0.000	1.4996	1.7328
2008	1.7093	0.1350	6.79	0.000	1.4643	1.9954
_state						
5	0.8383	0.0244	-6.06	0.000	0.7918	0.8875
17	0.9379	0.0312	-1.93	0.054	0.8788	1.0010
22	0.9610	0.0212	-1.8	0.071	0.9203	1.0034
32	0.7894	0.0208	-8.98	0.000	0.7497	0.8312
35	0.9502	0.0218	-2.22	0.026	0.9083	0.9940
41	1.1313	0.0309	4.51	0.000	1.0723	1.1936

Appendix 13: Output from Stata® showing the odds ratios of being up-to-date with FOBT among men only

Fobt2yr	Odds Ratio	Std. Err.	z	P>z	95% Confidence Interval	
1.Age50_64	0.6932	0.0404	-6.29	0.000	0.6185	0.7770
1.Mandate1	1.0455	0.0588	0.79	0.428	0.9364	1.1674
1.AgeManda~1	1.0873	0.1011	0.9	0.368	0.9061	1.3048
Race4grp						
2	1.3617	0.1541	2.73	0.006	1.0908	1.6999
3	0.7093	0.0974	-2.5	0.012	0.5419	0.9284
4	1.0739	0.1429	0.54	0.592	0.8274	1.3938
Hasdoc	1.5375	0.2823	2.34	0.019	1.0728	2.2035
Edu						
2	1.4757	0.1615	3.56	0.000	1.1908	1.8287
3	1.5662	0.1406	5	0.000	1.3135	1.8674
4	1.6657	0.1481	5.74	0.000	1.3994	1.9827
1.Genhealth	0.9139	0.0565	-1.46	0.145	0.8097	1.0315
Income2						
1	0.7891	0.0893	-2.09	0.036	0.6322	0.9851
2	0.6752	0.0756	-3.51	0.000	0.5421	0.8410
3	0.7246	0.0343	-6.8	0.000	0.6603	0.7951
4	0.7467	0.1202	-1.81	0.070	0.5447	1.0237
Smoker						
1	1.1342	0.0661	2.16	0.031	1.0117	1.2716
2	1.1938	0.0302	7	0.000	1.1360	1.2546
1.Physical	1.2440	0.0698	3.89	0.000	1.1145	1.3887
1.Psa	4.2807	0.4521	13.77	0.000	3.4803	5.2651
iYear2						
2004	0.9151	0.0212	-3.84	0.000	0.8745	0.9575
2006	0.6040	0.1007	-3.03	0.002	0.4357	0.8373
2008	0.5343	0.0277	-12.09	0.000	0.4827	0.5915
_state						
5	1.4127	0.0248	19.66	0.000	1.3649	1.4623
17	1.4568	0.0352	15.58	0.000	1.3895	1.5275
22	1.6899	0.0524	16.92	0.000	1.5902	1.7957
32	1.4013	0.0175	27.02	0.000	1.3674	1.4360
35	1.6003	0.0337	22.35	0.000	1.5357	1.6677
41	1.8717	0.0184	63.85	0.000	1.8360	1.9080

Appendix 14: Output from Stata® showing the odds ratios of being up-to-date with FOBT among women only

Fobt2yr	Odds Ratio	Std. Err.	z	P>z	95% Confidence Interval	
1.Age50_64	0.5721	0.0607	-5.26	0.000	0.4647	0.7044
1.Mandate1	0.8354	0.0821	-1.83	0.067	0.6891	1.0129
1.AgeManda~1	1.0330	0.0787	0.43	0.669	0.8898	1.1993
Race4grp						
2	0.9865	0.0214	-0.63	0.529	0.9455	1.0292
3	1.0229	0.0674	0.34	0.731	0.8990	1.1638
4	1.0147	0.1396	0.11	0.916	0.7749	1.3287
Hasdoc	1.6930	0.3124	2.85	0.004	1.1792	2.4307
Edu						
2	1.1683	0.0560	3.25	0.001	1.0636	1.2834
3	1.2448	0.0566	4.82	0.000	1.1387	1.3608
4	1.3111	0.0557	6.38	0.000	1.2064	1.4248
1.Genhealth	0.8086	0.0243	-7.06	0.000	0.7623	0.8577
Income2						
1	1.1707	0.1359	1.36	0.175	0.9324	1.4699
2	1.1708	0.1113	1.66	0.097	0.9719	1.4106
3	1.0792	0.1663	0.49	0.621	0.7979	1.4597
4	1.2204	0.0986	2.46	0.014	1.0416	1.4298
Smoker						
1	0.8832	0.0359	-3.06	0.002	0.8156	0.9564
2	1.0651	0.0225	2.98	0.003	1.0219	1.1102
1.Physical	1.1349	0.0703	2.04	0.041	1.0052	1.2813
1.Mam	2.4100	0.4894	4.33	0.000	1.6187	3.5880
iYear2						
2004	0.9073	0.0840	-1.05	0.293	0.7568	1.0877
2006	0.7911	0.0601	-3.08	0.002	0.6816	0.9181
2008	0.6658	0.0801	-3.38	0.001	0.5259	0.8429
_state						
5	0.9311	0.0193	-3.44	0.001	0.8940	0.9698
17	0.9204	0.0347	-2.2	0.028	0.8548	0.9910
22	1.2354	0.0313	8.35	0.000	1.1756	1.2983
32	1.1557	0.0291	5.76	0.000	1.1001	1.2141
35	0.9701	0.0257	-1.14	0.253	0.9210	1.0219
41	1.4503	0.0347	15.54	0.000	1.3838	1.5198