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TWO HUNDRED YEARS OF HEALTH AND MEDICAL CARE:
THE IMPORTANCE OF MEDICAL CARE FOR LIFE EXPECTANCY GAINS

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Two Hundred Years of Health and Medical Care: The Importance of Medical Care for Life Expectancy Gains
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ABSTRACT

Using two hundred years of national and Massachusetts data on medical care and health, we examine how central medical care is to life expectancy gains. While common theories about medical care cost growth stress growing demand, our analysis highlights the importance of supply side factors, including the major public investments in research, workforce training and hospital construction that fueled a surge in spending over the 1955-1975 span. There is a stronger case that personal medicine affected health in the second half of the twentieth century than in the preceding 150 years. Finally, we consider whether medical care productivity decreases over time, and find that spending increased faster than life expectancy, although the ratio stabilized in the past two decades.

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Introduction

If not nasty and brutish, life two centuries ago was much shorter than now. Since then, life expectancy at birth nearly doubled, and life expectancy at age 65 increased more than 66%.[1] Medical care, two centuries ago, was a small part of the economy. Doctors were loosely trained, the cause of disease was misunderstood, and hospitals were where to die (Starr, 1982). Today, medical care is a major employer, accounts for almost one-fifth of GDP, once fatal diseases are curable, and access to health is fought over. How much medical care contributed to gains in life expectancy is the subject of this paper.

A substantial part of the improvements in health status over the past two centuries was due to improved nutrition and public health. Fogel examined how technological and physiological changes affected mortality, a symbiotic process he termed "technophysio evolution". He showed that the relevant factors in improved health changed over time, and argued that long-term trends in life expectancy are due primarily to environmental factors that enhanced the physiological capital of successive cohorts rather than access to health care (Fogel 2004). At the same time, as health care transformed, new medical advances and therapeutics have undoubtedly contributed to reduced mortality and improved human wellbeing (Cutler, Deaton and Lleras Muney, 2006, Deaton 2004, Cutler

[1] Massachusetts life expectancy at age 65 was 12.3 years in 1890 and 20.5 years in 2014. Sources: Bureau of the Census, United States Life Tables, 1890, 1901, 1910, and 1901-1910, Massachusetts Department of Public Health, Massachusetts Deaths, 2014.

2004). Research on the evolving contribution of medical care to gains in life expectancy over time remains early.

This paper seeks to inform the debate on the evolving contribution of medical care to life expectancy gains by adducing two hundred years of data on health and medical care. Since national mortality data go back only in scattered form, we present national data where available but focus our examination on Massachusetts, where data are available since 1850. Our data on medical care include both medical spending and employment, the latter a good proxy for spending when spending data are not available.

Our analysis has three goals. First, we document gains in life expectancy and changes in medical care over the past two centuries. Using national vital statistics and estimates of life expectancy, we describe changes in mortality in the United States and document the timing of trends and variation across big cities and other urban and rural areas. As the evolution of medical care is related to its potential to affect health outcomes, we then describe the changes in medical care organizations and institutions, and the corresponding increases in medical expenditures and employment, that happened concurrently with the gains in life expectancy.

Second, we consider the role of medical care in the large improvement in health over this time period. Our analysis of the link between medical care and health is not conclusive, as we face the fundamental issue of intertwined development that have has plagued past researchers as well. Still, deriving observations from data from Massachusetts and nationally, we show there is a stronger case that personal medicine affected health in the second half of the 20th century than in the preceding 150 years. Big medicine brought big benefits, especially to the older population, at big cost. In contrast, much of the health advance prior to the mid-20th century was a result of public health improvements, perhaps sometimes supported by physicians but not resulting from clinical therapies for individual patients.

Third, we consider whether medical advances are as productive now as in the past. We do this simply, comparing the change in life expectancy with the change in medical spending in each decade. Life expectancy is increasing, but not as fast as health care expenditures. Since 1935 spending per year of life gained increases. In the past two decades the cost effectiveness ratio has stabilized, but at a very high level.

The first section of the paper describes the concurrent evolution of life expectancy and medical care over the past two centuries. The second section examines the importance of medical care and public health for health improvements. The third section discusses the change in spending per year of life gained over time.

1. Health and medical care: 1800-2016

This section documents gains in life expectancy and changes in medical care that happened concurrently in the United States and in Massachusetts over the past two centuries.

1.1. Two hundred years of health

1.1.1. Life expectancy gains in the United States

Using national vital statistics and published estimates of life expectancy, this section documents the life expectancy gains of the U.S. population, and their distribution across age groups and cohorts, over the past two centuries. The federal government started collecting mortality data in 1900 from ten states. All states reported reliable data by 1933. Fogel and colleagues (e.g., Fogel, 1986 and 2004; Haines, 2001), estimated life expectancy prior to 1900, at age 10 because child deaths were not then consistently recorded. Hacker (2010) extended these estimates to life expectancy at birth. We use Hacker's estimates, understanding that life expectancy at birth is subject to more error than at age 10, but noting that the trends between the various series are relatively similar.

Life expectancy at birth in the United States rose from 43 years in 1800 to 79 in 2014, with the bulk of gains realized during the twentieth century (Figure 1). During the ninetieth century, life expectancy at birth increased modestly, from 43 years to 49 years. In 1800, 43 years was above the level in England and France (36 and 33 years, respectively; Fogel, 2004), likely because the U.S. had more agricultural resources and less urban crowding. In the next half century, life expectancy fell by about 5 years. Prior to public health improvements, urban areas were less healthy than rural areas, and the share of the US population living in urban areas rose from 6% in 1800 to 15% in 1850. By 1880, life expectancy had recovered, and the United States entered the 20th century with life expectancy at birth of just under 50 years.

The major improvements in survival occurred in the 20th century. Life expectancy at birth rose from 49 years in 1900 to 59 years by 1930, to 75 in 1990 and near 80 presently. In the first half of the 20th century, the leading cause of life expectancy gains was reduced mortality from infectious disease. There were less deaths from water-borne (e.g., typhoid fever) and air-borne (e.g., tuberculosis) diseases. In the second half of the century, much more decline was due to decreasing cardiovascular disease mortality, primarily heart attacks and strokes. Age-adjusted cardiovascular disease mortality fell by 73% between 1950 and 2015.

While between 1900 and 1950, mortality rates for younger populations fell enormously, after mid-century, the decline was much more pronounced at older ages. Figure 2 shows mortality rates by age over time from Vital Statistics records. We divide the population by 10-year age group and show annual trends in mortality in four time periods: 1900-1935; 1935-1950; 1950-1990; and 1990-2016. The first period is the time of large-scale improvements in public health, especially clean water and sanitation. The second period involved continued public health innovation as well as the first widespread medical care interventions: sulfa drugs, in the late 1930s and penicillin, in the early 1940s.

Between 1900 and 1950, mortality rates for younger populations fell enormously. Over the entire half century, mortality for infants fell by 80%, mortality for children aged 1-4 fell by 93%, and mortality for children aged 5-14 fell by 84%. By contrast, mortality rates among people aged 45-54 fell by only 43% and mortality among people 65-74 fell by 27%. Corresponding to this was a large increase in life expectancy at birth (20 years between 1900 and 1950), but a much smaller increase in life expectancy at age 65 (about 2 years).[2]

[2] Life expectancy at age 65 are available in Bureau of the Census (1921).

After mid-century, the decline in mortality was much more pronounced at older ages. Infant and child mortality continued to decline (an 80% cumulative decline from 1950 through 2016), but the rates were already so low that further reductions added less to overall life expectancy. Rather, the dominant source of life expectancy gains was reduced cardiovascular disease mortality. Between 1950 and 2016, mortality rates for people aged 65-74 fell by 1.2% annually, compared to 0.4% annually from 1900-1950. The cumulative decline post-1950 was 56%. Life expectancy at birth increased by 11 years between 1950 and 2016, more than half of which was associated with increased survival at ages 65 and older.

To consider the changes in mortality by age in more detail, Figure 3 plots the logarithm of annual mortality rates from 1900-2016 for four age groups: 0-14, 15-44, 45-64, and 65-84.[3] In each case, mortality in 1900 is normalized to 100, so the figures show the relative trend over time. The great flu epidemic of 1918 is clearly visible. As has been widely noted, the highest relative mortality from the flu was in young adults. Mortality for the older two groups – 45-64 and 65-84 – declines only slowly through 1936, before a somewhat rapid decline in the antibiotic era. The period of rapid sustained reduction in mortality in older age groups starts around 1968.

Mortality for the two older cohorts moves roughly in parallel, with a few exceptions. Relative mortality for the population 45-64 fell in the 1910s, where mortality for the elderly population was stable. At the end of the time period, from 1999-2016, mortality for the

[3] We normalize population within each age group using the 1970 population standard. We omit the population aged 85 and older because the average age of this age group is changing most rapidly.

population aged 45-64 has been flat or increasing, as noted by Case and Deaton (2015, 2017), particularly for non-Hispanic whites, especially those with less education.

The era of large mortality improvements for the elderly, from 1968 on, is also an era of large mortality reductions for the near elderly below age 65, though they lag by 5 years. The similarity of mortality for these two groups suggests that the explanation is not something that is specific to the elderly population, as for example the implementation of Medicare in 1966 (see also Finkelstein and McKnight, 2008).

Certain cohorts have higher or lower mortality. Figure 4 shows the time series of the ratio of mortality rates for people in adjacent age groups: 55-64 to 45-54, 65-74 to 55-64, and 75-84 to 65-74 from 1900 to 2016. In the first half of the century, mortality rates were declining more for the younger population; thus, the ratio of mortality for people aged 55-64 was rising relative to people aged 45-54. That trend stopped around 1960, consistent with Figure 3.

The cohort reaching age 55 around 1982 (born around 1927) has significantly higher mortality than the cohort 10 years younger. That higher mortality continues through the cohort passing through that age range in the mid-1990s, roughly, when the cohort born in 1933 reaches age 65. That same cohort also has higher mortality when they are 65-74 and 75-84. The story is not one of selection – a handful of less healthy people who die and leave behind healthier stock. Rather, it seems that an entire generation was rendered vulnerable by being born during and just before the Great Depression (Lleras-Muney and Moreau, 2018).

1.1.2. Timing of trends and geographic variation: evidence from Massachusetts

Massachusetts data include long time series and geographic detail, providing valuable additional information about the timing of trends and mortality for each city and town. This section describes mortality trends in large metropolitan areas, other urban areas and rural areas, and shows that the trends in the three groups of areas are somewhat different in overlapping time periods, particularly since 1990, with a significant reduction in mortality in the Boston SMA, unmatched in other Massachusetts SMAs.

Massachusetts has collected vital statistics since 1851, long before the federal government. The data are tabulated in an Annual Report on the Vital Statistics of Massachusetts. The timing of mortality changes in Massachusetts may not match those of the nation as a whole. Massachusetts was richer and had a greater medical care supply. Still, for the changes in mortality driven by understanding of disease and technological innovation, the differences in timing are likely not too great.

The crude (not age adjusted) mortality rate in Massachusetts, stitched together from various vital statistics reports are reported in Figure 5. Mortality rates in Massachusetts were about 20 per 1,000 (2% annually) from 1851 through the early 1890s. The rate was increasing slightly, though not greatly (0.3% per year). After 1892 mortality rates decreased dramatically, by 1.2% annually from 1892-1938, a cumulative decline of nearly 50%. Then, after a period of relative stagnation in mortality between 1938 and the late 1960s, mortality rates started declining again post-1965, at an annual rate of 0.5% until 2015. This is below the rate of decline in the early 20th century. But the lack of age adjustment is important in this comparison: the crude death rate does not decline as rapidly when mortality reductions occur at older ages, because the marginal survivors add to the number of people at more advanced ages, who have higher mortality rates than younger individuals.

In addition to the long time series, Massachusetts data provide geographic detail on mortality in each of the 350 cities and towns in the State. We assembled data on the number of deaths and population at five-year intervals from 1880 through 2015 (1880, 1885, and so on). We divided cities and towns into three groups: the 25 urban areas having population of 25,000 or more in 1910; the remaining cities and towns that are included in a Statistical Metropolitan Area (SMA) in 1950 (N=107); and the smaller areas that are not included in a 1950 SMA (N=221). Both infectious disease and access to medical care likely differ for those areas near to and far from metropolitan areas.

The prevalence of small towns means that some deaths recorded in one town were from people who lived in another town. Starting in 1945, deaths are tabulated both by occurrence and residence. We use the death rate by place of occurrence prior to 1945 and the death rate by place of residence post-1945. We show data in 1945 both ways on the charts for comparability. Unsurprisingly, death rates in the major urban areas fall and death rates in other areas rise when tabulating deaths by residence as opposed to by occurrence (some people die in hospitals). Because we suspect that very ill people were also moving into cities during the 1935-1945 time period, where we do not have deaths by residence, we do not examine the 1935-45 time period in as much detail.

As Figure 6[4] shows, trends in mortality in the three groups of areas are somewhat different in overlapping time periods[5]. In 1880, mortality was highest in large metropolitan areas and lowest outside of them. The gap was 13% (statistically significantly higher). In the next half century, mortality fell throughout the state, but differentially more and earlier in metropolitan areas. Mortality started declining around 1880 in metropolitan areas, 1890 in towns near metropolitan areas, and 1895 in rural areas. In 1930, mortality rates were equal in major urban areas and rural areas; the lowest mortality rates were in suburban areas that ultimately became part of SMAs. The trends diverged a bit post-1930. This might reflect either true changes or more people receiving medical care in cities, and hence dying there.

After World War II, the trends are somewhat more divergent. Mortality increased in major urban areas between 1950 and 1965, before beginning a lengthy fall. Mortality in semi-urban and rural areas did not rise, but did not decline as rapidly. With the advent of cars and commutes into cities, the distinction between urban and suburban mortality became less relevant. For example, some of the increase in urban mortality between 1950 and 1965 is likely to reflect the movement of people outside of the Boston city limits into nearby suburbs. To address this, our post-World War II analysis focuses on the SMA-level. Within the SMA group, we separate Boston from the other SMAs, since it has the most significant medical presence.

[4] Because there are a number of very small towns with high variance in mortality rates, the data are weighted by population.

[5] Between 1945 and 1950, the change in death rates based on place of occurrence are -3.9%, -3.6%, and -6.0% for the largest urban areas, areas near the largest urban areas, and areas farther from the largest urban areas. Using death rates based on residence, the same changes are -5.1%, -4.3%, and -4.2%.

The recent divergence in trends between the Boston SMA, other SMAs and rural areas of Massachusetts are shown in Figure 7. Mortality throughout the state was relatively flat from 1945-1965. There was a slight increase in the Boston area and a slight decline in rural areas, but the changes were modest. After 1965, mortality began declining throughout the state. The declines were rapid and reasonably uniform through 1990: 23% in the Boston MSA, 20% in other MSAs, and 23% in rural areas. After 1990, there was a significant reduction in mortality in the Boston SMA, unmatched in other SMAs. Mortality rates in the Boston MSA declined by 18% between 1990 and 2015, compared to a rise of 1% in other SMAs and a rise of 7% in rural areas. All three parts of the state experienced increases in mortality between 2010 and 2015, reflecting the widespread opioid epidemic.

Many factors could explain the trends in mortality in Boston and throughout the state, including changes in age or income composition of the residents, along with public health and medical care. As our goal is to assess the importance of medical care in life expectancy gains, the next section describes changes in medical care that occurred concurrently with the described gains in life expectancy.

1.2. Two hundred years of medical care

As the evolution of medical care over the past two centuries is intimately related to its potential to affect health outcomes, this section describes the changes in medical care organizations and institutions, and the corresponding increases in medical expenditures and employment, that happened concurrently with the life expectancy gains documented in the previous section.

1.2.1. Changes in Medical Care Organizations and Institutions

This overview of the organizational and institutional aspects of medical care sets the context for the next section documenting increases in medical expenditures and employment over the past two centuries. Medical institutions have not developed linearly or independently. Even though scientific advances have been major forces, policy and path-dependence have also played major roles.

Medical organization remained rudimentary up to the beginning of the 20th century. Basic transactions between doctors and patients, and ancillary services provided by nurses, druggists and hospitals, composed the small medical part of the economy. Since the early twentieth century, overall economic and social development influenced the organization and institutions of medicine. Scientific advances led to changes in medical technology and organization. Many of the initial discoveries came from Europe (aspirin, antisepsis, bacteria, stethoscopes, vaccination, vitamins, X-rays) but the United States became the main supplier of medical research during the mid and late 20th century. Of the 18 Nobel Prizes in Physiology or Medicine awarded 1901-1920, none went to US researchers. Over the next two decades, four out of twenty-four did, then for the rest of the century, more than half.

Scientific advances led to the regulation of the medical profession, the increasing specialization of doctors, and the rise of ancillary occupations. The Flexner Report (1910) called for reform of medical education based upon European scientific standards, and influenced the regulation of the medical profession. This evolution led to greater division of labor, with the regulation of existing ancillary occupations (e.g., nursing, nutritionists) and the creation of new ones (e.g., audiologist, perfusionist, nurse anesthetist, occupational therapist, radiology technician). Doctors differentiated into a series of specialties and sub-specialties[6].

The technological advances requiring capital investments and the increasing division of labor requiring coordination of specialized groups of workers both called for central organizations. Hospitals played this role even as they remained under the control of legally and economically independent medical staffs. Physician control over governance faded in recent years as hospitals became larger, accumulated outpatient facilities, linked into large health systems, increased full time staff, and reduced the ranks of independent medical staff members.

Paying more employees and buying more expensive equipment forced hospitals to find more stable and expansive sources of funding. In response to the Great Depression, Blue Cross pre-payment and insurance pools were established. Shortly thereafter, doctors established Blue Shield plans to facilitate collection of fees. During World War II, private insurance companies entered this arena. Yet as private health insurance expanded, it became more and more evident that the neediest groups, the old, the poor and the disabled, would lack coverage unless government stepped in. Medicare and Medicaid filled the gap. By the end of the century, government had become the

[6] Boards of surgery (1913), ophthalmology (1916), radiology (1923), internal medicine (1936) and other fields were established, eventually including family medicine (1969) emergency medicine (1979) genetics and genomics (1980) and clinical informatics (2011).

largest source of “personal” health insurance and, the main producer of standards for physician payment[7].

Changes in the size, scope and complexity of medical practice shifted the division of labor (from generalist to specialist), locus of payment (from individual to group), geographic reach (from local to national), and regulatory framework controlling medical institutions (from voluntary to mandatory/legal). During the 1920s and 1930s, the local county medical society was the primary institution regulating the medical profession. Hospital privileges depended upon the approval of a local peer group, and payments came from patients residing in the community. By the 1950s, two associations of local associations, the American Medical Association (AMA) and the American Hospital Association (AHA), had become dominant national political forces, yet standards of practice and payments remained local. This changed through the impulse of federal legislation, with the creation of the NIH in 1938, the Hill Burton Act of 1946, the Health Professions and Education Act of 1963, the Social Security Amendments of 1965 to create Medicare and Medicaid, and the Affordable Care Act (ACA) of 2010. The organization and financing of medical care became increasingly national. Expert judgments from national specialty boards, and accrediting organizations such as JHACO (the Joint Commission) slowly replaced local community standards.

In spite of these evolutionary changes, the U.S. health care system remains fragmented and wasteful due to overtreatment, failures of care coordination, failures in

[7] The earlier Blue Cross hospital rate-setting and Blue Shield “Usual, Customary and Reasonable” (UCR) physician payment standards were displaced by prevailing Diagnosis Related Groups (DRG) and Resource-Based Relative Value Scale (RBRVS) standards, administratively regulated.

execution of care processes, administrative complexity, pricing failures, fraud and abuse (Berwick and Hackbarth, 2012). Almost 10% of the population is still uninsured. Groups of lobbyists representing many specialties, various ancillary professions, rural or urban hospitals, private insurance, pharmaceutical companies and specific disease advocates, now contest control over money in Washington DC.

Voluntary professional control, charitable financing for care of the poor, non-profit community hospitals and local insurance plans faded as the rise of a "medical-industrial complex" resulted in "the monetarization of medical care" (Relman, 1980; Ginzberg, 1984). Professional obligations on physicians to volunteer at clinics and use sliding fee scales could not cover an expansion of expenditures from 2.5% to 15% of GDP. Blue Cross and Blue Shield could not retain community rating when confronted by selective group enrollment from private insurance companies. Hospitals' non-profit community orientation eroded under debt loads and patient selection. Voluntarism largely dissipated except in safety net institutions by the turn of the 21st century.

Changes in medical expenditures and employment mirrored these changes in medical care organizations and institutions. The next section documents the quantitative magnitude of these changes.

1.2.2. The growth of the medical care sector

Medical care employment mirrored the growth of health spending, although most of employment growth has been in non-physician personnel. Piecing together information on the size of the medical system over the past two centuries is challenging since national statistics did not keep track of the medical sector separately until the early twentieth century. Data about medical spending and employment were assembled and described in detail by Getzen (2017), and are summarized in Table 1 and Appendix A.

Medical spending and medical spending growth are presented in Figures 8 and 9. Figure 8 shows medical care as a share of GDP. Figure 9 shows the 15-year moving average of growth rates. Medical care employment as a share of total employment is presented in Figure 10. Table 1 contains summary statistics in decadal intervals. Available data for the last two hundred years suggest that medical expenditures followed an S-shaped growth curve: variable but slowly rising before 1900, increasing to average +1% in excess of real per capita income for the next half-century, surging to more than +3% above GDP in the post-World War II era, and eventually moderating.

Medical care accounted for about 2% of GDP in 1800, 2.2% in 1850, and 2.5% in 1900. These estimates suggest that the growth of medical care exceeded the growth of the economy as a whole by only 0.2% annually (± 0.5%) over the 19th Century.

Spending began to accelerate before 1900 in the more developed areas. Between 1880 and 1900, medical care rose from 0.8% of total employment to 1.2% of total employment. Medical care spending was rising steadily by the 1920s, though major variations on the order of two-fold to ten-fold across states and regions make generalization of a national trend problematic.

Medical care rose rapidly as a share of the economy in the Great Depression, but some of this is a transitory artifact since medical spending fluctuates less than other sectors of the economy. Overall, excess growth of medical costs averaged about +1% per year from 1900 to 1950.

Following World War II, particularly after 1955, medical costs surged. From 1955 to 1970, medical spending grew more than +3% more rapidly than incomes. Expansion continued to be strong for the next twenty-five years (+2.7% excess 1970-1995) but has moderated toward +1.5% or less in the decades since. The post-1955 trend is not linear. Macroeconomic stagflation caused a temporary dip in the health share of GDP in 1973 but the overall rate of growth remained relatively high for the next twenty years.

The growth of medical care employment has mirrored the growth of spending, mostly in non-physician personnel. Physicians accounted for 0.8% of the total U.S. workforce in 1850, falling to 0.5% in 1900 and 0.3% in 1950, before rising to 0.6% in 2000 and about 0.7% today. While physicians made up two-thirds of the health workforce in 1880, they were less than one-tenth in 1990, with more than 11 other health workers for each physician employed.

Establishing reliable sub-trends for shorter periods is difficult. Data are thin and not reliable before 1900. Since there was little expansion during the 19th century, this absence does not greatly complicate the analysis of trends. From 1900 to 1955, medical care spending varied considerably across years and regions. The Great Depression and World War II complicate the analysis of health expenditures over this period. Whether the growth in health spending was more or less rapid after the onset of the Great Depression depends upon the perspective taken. The 1929 shock is so large that calculated excess growth rates are +1.2% for 1900-1929 and 0.8% for 1929-1955, but +1.4% and +0.5% for 1900-1930 and 1930-1950. However, since income growth was so much more rapid in the later period, relative growth in real per capita spending rather than share of GDP gives the opposite result, 2.9% vs. 3.5% for 1900-1930 and 1930-1955 respectively.

Analyzing the Great Depression, World War II, and Korean War era, Seale asserted that “the proportion of the gross national product in a nation devoted to medical care tends to remain constant,” and “a persistent rise in real per capita GNP will tend to result in a very gradual increase” (Seale, 1959) (see Figure 11).

To some extent, Seale’s econometrics were flawed. Changes in inflation rate take up to three years to work through the health care system and real income shocks are distributed over five years or more (Getzen, 1992, 2000, 2017). As a result, Seale may have underestimated growth rates in the 1940s. The decline in the health share of GDP between 1950 and 1955 is partly attributable to lagged effects from the 1949 and 1954 recessions. Still, the conclusion of a modest and inertial response to macroeconomic disruptions was generally appropriate at least prior to 1960.

Even with much better annual data, post-1960 delineation of sub-trends is challenging. Four recent papers demarcate a number of eras in health expenditures growth over the last fifty years (Chandra, Holmes, and Skinner 2013; Catlin and Cowan, 2015; Chen and Goldman, 2016, Horenstein and Santos, 2018). Using essentially the same time-series, they each divide the time span at different places and into a differing number of eras.

Examining changes in health expenditures at particular institutions provides another perspective. Meyer, et al. (2012) present 200 years of health and mortality at Massachusetts General Hospital (MGH), based on the hospital’s annual records.

Spending per person at MGH was relatively stable at about $1,000 (in 2010 dollars, adjusted using the CPI) from 1820-1910. Costs increased mildly from 1910 through 1960, before increasing quite rapidly after 1960. Spending per case, in real terms, increased nearly 7-fold between 1960 and 2010, much more than in the prior 150 years.

2. How central is medical care to life expectancy gains?

We consider the role of medical care in the large improvement in health over the past two centuries. Deriving observations from national and Massachusetts data, we show there is a stronger case that personal medicine affected health in the second half of the 20th century than in the preceding 150 years.

2.1. The infectious disease era: 1800-1935

A significant body of research has examined the cause of reduced mortality in the early part of the 20th century. The consensus is that public health improvements explain the bulk of the decline in mortality in this era, including both water (Cutler and Miller, 2005) and sewage treatment (Alsan and Goldin, 2018). In this section, we analyze whether medical care explains some of the residual mortality using data from big U.S. cities and all cities and towns in Massachusetts.

2.1.1. Evidence from U.S. big cities

To extend the analysis of Cutler and Miller (2005), we consider whether cities with greater medical care supply had larger trend reductions in mortality over the 1900-1936 time period. We find that areas with more physicians per population had a slightly smaller decrease in mortality, and that there is little correlation between medical care supply and the timing of clean water interventions.

The push for public health improvements began shortly after the germ theory of disease became widely accepted in the late 19th Century. Public health officials could finally explain how and why many people became sick and propose remedies for disease. Since the remedies were often expensive – big treatment facilities and new sources of water – the exact timing of the public health interventions varied across cities.

Cutler and Miller (2005) use data on mortality by city and year matched with data on clean water interventions to examine how clean water affected mortality. Their sample includes 13 cities, each with data from 1900-1936. They estimate that 35% of the mortality reduction over this period was a result of clean water interventions.[8]

To analyze whether medical care explains some of the residual mortality, we augment the analysis of Cutler and Miller to include two measures of medical care supply, taken from the 1910 Census: the number of physicians and surgeons per 100,000 people (we condense this to "physicians"); and the number of trained nurses per physician.[9] We adopt these variables as proxy measures of medical care supply over the entire time period. We consider whether cities with greater medical care supply had larger trend reductions in mortality over the 1900-1936 time period. The models are of the form:

[8] There is a slight error in Cutler and Miller. They divide the change in mortality due to clean water measured in log points by the percentage point change in overall mortality. That share is 43%. Using the change in mortality in log points in the denominator leads to a revised finding that 35% of total mortality can be explained by clean water technologies.

[9] At the time, a distinction was made between trained nurses, who are the precursors to todays registered nurses, and untrained nurses, who often functioned as baby nurses or to otherwise aid the infirm. More developed medical care systems were likely to have more trained nurses.

$$\ln(m_{c,t}) = \beta_1 \, Filter_{c,t} + \beta_2 \, Chlorine_{c,t} + \beta_3 \, (Filter_{c,t}*Chlorine_{c,t}) + \qquad (1)$$

$$\beta_4 \, MDsupply_c * I_t + \beta_5 \, Nurse/MD_c * I_t + \delta_c + \mu_t + \Sigma \, \lambda_k \ln(m_{c,t-k}) + \varepsilon_{c,t}$$

In equation (1), c denotes cities and t denotes years. The dependent variable is the logarithm of city mortality in year t. This measure of mortality is related to whether the city filters or chlorinates the water as of time t, and the interaction between the two.[10] One would expect the main effects β_1 and β_2 to be negative (cleaning the water lowers mortality) and the interaction term β_3 to be positive (the marginal contribution of a second method of water cleaning is smaller than the first). β_4 and β_5 show the trend in mortality for cities with more medical care personnel; I_t is a time trend. Controls include city and year dummy variables ($\delta_c + \mu_t$) and five lags of mortality. [11]

Appendix Table A1 shows information about the two measures of medical care supply for a larger sample of 38 cities. In 1910, the average city had 281 physicians per 100,000 people. The higher end generally consisted of smaller cities: Los Angeles (414) and Kansas City (410), for example. Cities like Boston (280), Chicago (209), and New York (185) were average. Smaller numbers of physicians were found in smaller East Coast areas such as Jersey City (92) and Fall River, MA (109). On average, there were 0.81 trained nurses per physician. Nurse supply was inversely correlated with physician supply (ρ=-0.40). Los Angeles had many physicians but few trained nurses (0.62 per

[10] Alsan and Goldin (2018) note that sewer treatment is important as well. However, only two cities treated their sewage during this time period, so we do not explore this issue with these data.

[11] Cutler and Miller include a few additional variables. First, they include a city-specific time trend. Since our medical care supply variable is point in time and is interacted with the time trend, we cannot include a general city-specific time trend. Cutler and Miller also include the logarithm of city population. We omit this since the data on population were not readily available. Finally, Cutler and Miller include dummy variables for whether the city started filtering or chlorinating the water within five years as a test of the timing of the intervention. We omit these terms.

physician). Fall River had more trained nurses per physician than average (0.95 per physician).

The first two columns of Table 2 show the relationship between public health improvements, medical care supply, and overall mortality. The first column mirrors the specification of Cutler and Miller, with similar results: filtering the water supply reduces mortality. The effects of water chlorination are negative but not statistically significant, and the interaction term between filtration and chlorination is positive.

The second column adds measures of medical care supply interacted with the time trend. Areas with a larger number of physicians per 100,000 people had a less negative trend in mortality than areas with fewer physicians. The effect is statistically significant but small in magnitude. The cross-city standard deviation of physicians per 100,000 people is 76. A one standard deviation increase in physician supply raises overall mortality by an additional 0.1% each year. The estimate on trained nurses per physician is also positive and of similar magnitude (0.1% annually), but not statistically significant.

Including the measures of medical care supply has relatively little impact on the coefficients on water treatment. The coefficients decline slightly, but generally not by a large amount. In this sample of 13 large cities, there is little correlation between medical care supply and the timing of clean water interventions.

These results may be specific to big cities. To examine whether medical care supply explains different mortality trends across large metropolitan areas, other urban areas and rural areas, we turn to Massachusetts data.

2.1.2. Evidence from Massachusetts

This section relies on extensive data on water and sewer treatment, and medical care supply for each of the 350 Massachusetts cities and towns. First, we examine whether areas with more medical care supply set up water and sewer systems before other areas, and find modest evidence that more physicians lead to more public health interventions. Second, we examine the relationship between public health measures, medical care supply and mortality where our analysis does not support a large impact of medical care supply on mortality in the pre-antibiotic era.

Alsan and Goldin (2018) gathered data on water and sewer treatment dates for some cities and towns in Massachusetts: those around the Boston area that joined the Metropolitan Water District and Metropolitan Sewerage District, which cleaned the drinking and wastewater respectively for cities around Boston; and a selection of large cities outside of the Boston area. We extend these data to the entire state.

To understand our measures, it is helpful to understand the water situation in Massachusetts. Massachusetts cities and towns receive water through lakes, rivers, streams, reservoirs, wells, springs, and ponds. For many cities, these sources are unpolluted – for example, underground reservoirs. Thus, even today, not all cities and towns treat their water.

When natural sources become polluted, there are two options. First, reservoirs can be created to store clean water from rainfall and melting snow. This was the strategy for many areas, including Boston and Springfield, MA. Such a reservoir was typically created by a special water system, which had to lay pipes for large-scale water transport.

Thus, our first measure of public health intervention is whether the city or town has a water system. Depending on the purity of the water, there may be a need for filtration, chlorination, or other methods. Our second measure of public health intervention is whether the community treats the water in any such way. We do not distinguish among methods because the need for particular methods varies across areas.

The data on water treatments and sewage systems are assembled from archival material and previous literature (see Appendix B). We were able to identify when a water system starts for 260 cities and towns in Massachusetts (out of 351), and when water treatment starts for 186 of them. To our knowledge, this is the most comprehensive historical database on water systems and water treatment ever assembled across cities and towns at the state level. Data on sewage systems are more difficult to obtain. Inventories of sewage include only sparse data on when the systems started. We therefore form sewage system information only for the largest 25 cities in the state – those with over 25,000 residents in 1910. Appendix B describes these data in more detail.

Appendix Table A2 shows the dates on which the 25 largest cities adopted water and sewer systems, and started treating the water. The first water systems date from the early 1870s, with systems put in place in Fitchburg (1872), Holyoke and Waltham (1873), and Fall River and Springfield (1874). At the time, these were bustling industrial cities. Water treatment occurred later. The first water treatment facility was in 1893. Sewer systems date from the early 1890s. Boston and surrounding areas had the first sewer systems.

Information on physician supply comes from an AMA directory of physicians in Massachusetts in 1906. The numbers are consistent with the Census data on overall physician supply in Massachusetts in 1900 and 1910[12], but provide physician distribution throughout the state. We express physician supply as the number of doctors per 100,000 people. The number of trained nurses was measured in the 1900 census, only available for towns with over 25,000 people in that year. For other areas, we infer the number of nurses per physician by spreading the remainder of nurses across areas. We use the average ratio observed in rural areas for all rural areas, the average ratio observed in Rhode Island for all cities that, although in Massachusetts, belong to the Providence, RI metropolitan area, and a similar ratio for Pittsfield (which is right below the 25,000 population threshold) and Gloucester (which is right above the 25,000 population threshold). Appendix Table A2 also shows the number of physicians per 100,000 and trained nurses per physician, where we have exact data. The most physicians were in Boston and Brookline, right outside of Boston. Boston had 2.2 times more physicians per 100,000 residents than the average in the rest of Massachusetts (321 versus 143 physicians per 100,000 residents).

We start by examining whether areas with more medical care supply set up water and sewer systems before other areas. Our sample is the 25 big cities noted above. For these cities, the decision to set up a water supply involved discussion of costs and benefits. For smaller towns near the large cities, the decision is likely to have been in concert with the large cities they are near, for example because of regional water systems.

[12] 5,372 physicians are listed in the AMA directory in 1906 versus 5,497 in the 1900 census and 6,227 in the 1910 census.

Figure 12 plots the relationship between the year of public health measures addressing water and sewage and the number of physicians per 100,000 people in 1906. Panel (a) considers the formation of a water system as the measure of treatment, panel (b) considers the year that the water began being treated, and panel (c) shows the measure of sewage treatment.

Cities with more physicians had somewhat earlier dates of sewer systems (ρ = -0.35), significant at the 10% level. Cities with more physicians had somewhat earlier dates of water treatment (ρ = -0.22) but later dates of forming water systems (ρ = 0.11); neither statistically significant. There is thus modest evidence that more physicians led to more public health interventions, but the evidence is not very strong.[13]

Indeed, the outliers tell the story as much as the regression. The first water treatment facility in the country, in Lawrence, Massachusetts, begun in 1893.[14] Springfield also had an early water treatment system, filtering the Ludlow River as early as 1909. In contrast, Boston did not treat its water until 1930.

The history of these areas suggests some of the driving forces. The State Board of Public Health in Massachusetts developed an interest in clean water shortly after its establishment in 1869 and especially after its reconfiguration as an independent organization in 1886. The Board was led by Henry Walcott, a physician and longtime public health official. One of the board members was a hydrologist named Hiram Mills,

[13] We also considered multivariate analysis, relating public health measures to physicians per 100,000, the population in 1910 (to reflect the ease of providing public goods) and the death rate in 1880 (as a measure of need). Physicians per 100,000 was not related to public health measures in any of these specifications. The same is true if we expand the sample for water treatment to all cities and towns that ultimately set up a water system or treated the water supply.

[14] There were earlier water pumping stations, as in Philadelphia. See Blake (1956).

who earned the sobriquet “Father of American Sanitary Engineering.” An employee of the Essex Company in Lawrence, his experiments on water purity and filtration were conducted at the Lawrence Experiment Station. He worked in concert with engineers and biologists at nearby MIT, including William Sedgwick a physician and biologist who later became president of the American Public Health Association.

Being downstream from Lowell, MA, Lawrence had high water pollution and high mortality. Thus, it followed naturally for Lawrence to be first to filter the water. Springfield also had relatively unsafe water, as determined by state testing. After consultation with the State and outside engineers hired by the city, Springfield decided in 1908 to switch from the Ludlow Reservoir to the Little River watershed as its primary water supply. In the interim before the switch was ready, the city decided to filter the Ludlow Reservoir. It kept filtering the water even after the change in source. Public health officials and engineers thus worked in concert to bring clean water and sanitation to cities in Massachusetts, not particularly based on the local mix of physicians.

The remaining columns of Table 2 show the relationship between public health measures, medical care supply, and mortality. Columns (3) and (4) focus on the 25 largest cities in Massachusetts. Column (3) relates the logarithm of mortality to whether the city has a water and sewer treatment, and the interaction of those two.[15] Cities with a water and sewer system each have lower mortality. The effect is .07 log points for a water system and .06 log points for a sewer system. The interaction between water and sewer systems is positive: the two together have less impact than the two separately.

[15] Alsan and Goldin have annual data, where our data are every five years. In addition, they focus on infant mortality; our analysis uses all age mortality.

This is different from Alsan and Goldin, who find that water and sewer systems are complements for infant mortality. The reason for the difference between these results is not entirely clear.

The next two columns expand the analysis to all 260 cities and towns which ultimately established a water system. As these areas have a need for public health measures, the impact of public health improvements should be most apparent there. Because we do not have sewer system information for all cities and towns, we focus only on water systems in our analysis of public health. Establishing a water system lowers mortality, estimate of 0.03 log points. The coefficients on physician and nurse supply remain positive. Thus, our analysis of Massachusetts data does not support a large impact of medical care supply on mortality in the pre-antibiotic era. The next section examines the impact of medical care on mortality in the era of big medicine.

2.2. The era of big medicine: 1935-2016

2.2.1. Previous evidence and national data

Medical technology expanded gradually over time. Surgical advances were ongoing in the 19th century, often developed during war (e.g., safer amputations) and aided by discoveries such as ether anesthesia in the 1840s. Still, the overall impact of medical advance on mortality through the 1930s was slight, as discussed above.

The story shifts around 1935. In the 1930s and 1940s, the major medical advances were in medications to treat infectious diseases. Sulfa drugs became widely available starting in 1937, and penicillin was mass produced in the mid-1940s. Several recent papers have examined the impact of sulfa drugs on mortality (Thomasson and Treber, 2008; Jayachandran et al., 2010). They take advantage that sulfa drugs treat some infectious diseases (most importantly maternal mortality, pneumonia, and scarlet fever) but not others (e.g., tuberculosis). Thus, there is a natural control for other economic and medical factors influencing mortality. They estimate that the advent of sulfa drugs reduced mortality by 2-3% in total between 1937 and 1945. Overall mortality in this time period fell by 16%, so sulfa drugs accounted for 10-20% of the overall decline in mortality.

Such an analysis is not possible for penicillin, since there is no natural control for deaths from infectious diseases that penicillin does not treat. Some studies clearly show that penicillin was important in mortality reduction. For example, 50,000 US soldiers died from respiratory infection in World War I. Only 1,265 did in World War II, despite many more men in battle (Hager, 2007). On the other hand, a study in Sweden and Finland found no change in mortality trend after the introduction of penicillin, suggesting that other trends might explain the reduction in mortality over this time period (Hemminki and Paakkulainen, 1976) at least up north.

Figure 13 shows age-adjusted mortality rates for five causes of death from 1900-2015, adjusted to the 2000 population standard. While mortality from pneumonia and influenza fell throughout the first half of the 20th century, there is a change in trend in the late 1930s and 1940s. Figure 14 shows the change in trend in more detail, plotting the logarithm of influenza and mortality rates over time. Three periods of mortality decline are apparent. Between 1900 and 1936, mortality fell by 1.5 log points annually. The decline was 8.3 log points annually from 1935-1950, before returning to a decline of 1.6 log points annually between 1950 and 2015.[16]

After 1950, the bulk of the recent decline in mortality was from heart disease, and to a lesser extent cerebrovascular disease (stroke) and cancer. Between 1900 and the early 1960s, age-adjusted heart disease deaths doubled. Starting in the early 1960s – around 1963– mortality began a prolonged decline. Heart disease mortality nowis below any point in the 20th century. Falling mortality from heart disease and stroke mirrors the rise in medical spending on the aged. Taken together, the two suggest a large role for medical treatment in improved health. Cutler, Rosen, and Vijan (2006) examined the sources of improved health between 1960 and 2000. They estimated that about half of the improvement in survival was a result of medical advance; a bulk of the remainder was due to lifestyle changes such as the reduction in smoking. Ford et al. (2007) examined the specific causes of declining heart disease deaths between 1980 and 2000. They estimated that half of the reduction in heart disease deaths was a result of medical technologies, and half was due to changes in risk factors independent of treatments. Cutler (2008) examined the trend in cancer mortality, shown in Figure 13. He estimated that 35% of the reduction in mortality resulted from improved screening (especially colonoscopy), 23% from behavioral changes, primarily reduced smoking, and 20% from improved therapies, principally pharmaceutical.

Improved health over this time period appears to be a response to the availability of new treatments as opposed to people being better insured (i.e., to the supply-side, not

[16] The issue is not specific to the 2000 population standard. The change in trend is found using the 1940 age standard as well. See also Armstrong et al. (1999).

the demand-side). Finkelstein and McKnight (2008) examined whether the reduction in mortality starting in the 1960s is attributable to Medicare. They concluded that was not the case: mortality declined for the near-elderly population that was not eligible for Medicare in addition to the elderly population that was eligible.

A more difficult question is whether these supply-side changes were driven by expansions of insurance coverage, or whether they came from the accumulation of knowledge. Medicare by itself is clearly not the entire story; the reduction in heart disease mortality predates Medicare by a few years. Acemoglu et al. (2006) examined whether pharmaceutical innovation was driven by the increase in the number of elderly with insurance; they concluded that it was not. That said, expensive technology might not have been as widely adopted without a strong insurance base to pay for it.

2.2.2. Evidence from Massachusetts

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Using Massachusetts data, we examine how physician supply during the era of big medicine differentially affected mortality in specific local areas. Massachusetts has a Medical Mecca (Boston) and then the rest of the State. To the extent that medical advances happen first or more extensively in more technologically advanced areas, we expected to see that in our data. We find that medical care supply has no effect on mortality in the earlier time period but has a significant impact on mortality in the later time period.

Figure 7 shows mortality trends in the post-World War II era in the Boston MSA and the rest of the state. Mortality began declining in Massachusetts after 1965. This is consistent with the national trend noted above. Through 1990, there was a uniform decline throughout the state; the change was 23 log points in Boston, 20 log points in other SMAs, and 22 log points in rural areas. After 1990, mortality declined much more in Boston than in the rest of the state. Indeed, with the recent upsurge in mortality from drug overdoses, mortality outside of the Boston SMA was higher in 2015 than in 1990, while it declined by 18 log points in the Boston SMA.

The central question we consider is whether this differential decline in mortality in the Boston SMA is a result of the greater number of physicians in the area. We use the panel of mortality rates in each area from 1965 through 2015, matched with data from the 1960 Census on the number of physicians in each SMA. The 1960 census provides the total number of physicians for the State and for all statistical metropolitan areas with more than 100,000 population. Remaining doctors are spread in proportion of population across rural areas, and smaller urban areas.

Following the lines of equation (1), we relate the logarithm of mortality per 100,000 people to the number of physicians per 100,000 in the SMA in 1950 interacted with the year trend. In addition, we include several other variables designed to capture medical care supply: the distance to the nearest major city in an SMA interacted with the year trend, the distance to Boston interacted with the year trend, and a dummy for whether the area is the major city in an SMA interacted with the year trend. We also include the share of the population age 65 or older and median family income in the SMA. When we estimate models for the mortality rate in the entire population, including the elderly population share controls for the share of people at high risk of dying. All regressions also control for area and year dummy variables.

Table 3 shows the results of the regression analysis. The first column estimates models for the logarithm of deaths per 100,000 people over the entire 1965-2015 time period. The coefficient on the number of physicians per capita is negative and statistically significant at the 10% level. As explained below, this result is somewhat misleading because it does not account for age differences across areas, which are correlated with the death rate.

Three-quarters of deaths in the US occur among elderly people. Thus, an informative measure of mortality rather than deaths per capita is deaths per elderly person. The second column shows the results explaining deaths per person aged 65 and older. The coefficient on medical care supply falls markedly and is much smaller than its standard error. Hence there is little evidence that access to medical care plays a role in mortality over the entire 1965-2015 time period, but it appears to have had an effect during recent years.

The third and fourth columns examine the relationship between deaths per elderly person and physician supply in two subperiods: 1960-1990 and 1990-2015. Medical care supply has no effect on mortality in 1960-1990 but has a significant effect on mortality in 1990-2015. The coefficient implies that mortality declined by .005 log points every five years for a 1 standard deviation increase in physician supply (50 physicians per 100,000), or .025 log points over the entire time period.

The final five columns of Table 3 examine different causes of mortality, looking to see which ones are most responsive to medical care. The largest effects are for influenza/pneumonia and cancer. Influenza and pneumonia are amenable to medical care but have been for some time. It is not clear why they should differ in trends over this time period between areas with more and fewer physicians, though influenza vaccination rates for people age 65 and older increased dramatically over the second time period and there could well be differential trends in vaccination practices. The relative decline in cancer deaths comes from lung cancer and some other cancers, but not breast cancer. Additional detail could examine which cancers are affected most by physician supply.

3. Are additional years of life expectancy coming at increasingly higher cost?

This section analyzes changes in age distribution of spending and considers whether medical advances are as productive now as in the past.

3.1. Changes in age distribution of spending

Combining three data sources, we observe that the ratio of medical spending for the elderly to adults grew from 1953 to 1988 and decreased from 1988 to 2012 (Figure 15 and Table 4). After 1990, the rate of spending growth was faster for the young than the old. The relative increase in medical spending for the elderly through the 1980s is consistent with the expansion of medical knowledge and technology. The recent reduction in the relative growth of medical spending for the elderly is not as easily explained as the increase in relative spending.

There are relatively few data on medical spending for particular population groups. Most of the spending estimates previously described are from providers: adding together revenue received by hospitals, physicians, and so forth. These data do not naturally permit a decomposition into spending by age. Periodically, however, micro surveys allow researchers to estimate spending by individual and age group.

Even data on spending from population surveys are complicated by inconsistencies in measurement, particularly regarding the inclusion of institutional long-term care and home health. Some surveys treat long-term care as medical care, while other treat it as housing, and thus outside the medical system. As spending on these services has grown over time, analytic complications have increased.

We analyze data on the distribution of medical spending by age from three sources that use consistent methods to cover extended spans of time. Meara, White and Cutler (2004) present data on medical spending by age for 1963-2000. Centers for Medicare and Medicaid Services (CMS) (2017) presents data for 2002-2012. The 1953 estimate from Cutler and Meara (1998) is based on the National Opinion Research Center (NORC) survey conducted by Anderson (1956) and therefore differs somewhat from later estimates but was included so as to provide a better sense of spending patterns for the decades prior to the development of Medicare and expansion of insurance coverage.[17] Note that age-specific spending ignores the roughly 15% of medical spending not directly

[17] Other sources for data on spending by age include Cooper, Worthington and McGee (1973), Fisher (1980), Waldo et. al. (1984, 1989); Keehan et. al. (2004); Hartman et al. (2009); and Lassman et. al. (2014).

attributable to individual patients, for example research, health insurance administration, overhead, construction, and public health.

Figure 15 shows relative medical spending on the elderly population in comparison to the non-elderly population over time. In 1953, estimates suggest that per capita spending on the elderly was 70% greater than per capita spending on the non-elderly. Shortly after health spending as a share of GDP began to accelerate in the late 1950s, a major reallocation of national expenditures toward the older population began. In 1963, spending on the elderly was 140% higher than for the non-elderly. This increased to 250% in 1970 and 440% in 1987. As a percentage of GDP, the amount spent for the elderly tripled over the twenty-year span from 1967 to 1987 (1.5% to 4.6%) while the amount for the population age 0-64 increased by less than half (from 4.5% to 6.0%). Since the data are per capita, these relative spending changes were due to technology and policy, including Medicare and other reimbursement rules, not demography.

After 1990, the rate of spending growth was faster for the young than the old, bringing the relative expenditure ratio down to +230% in 2012. In the past decade, Medicare spending on the elderly has been essentially constant in real terms (Keohane et al., 2018).

The relative increase in medical spending for the elderly through the 1980s is consistent with the expansion of medical knowledge and technology noted above. Conditions such as cardiovascular disease and cancer were relatively untreatable prior to the mid-1950s. Subsequently, developing technologies allowed both conditions to be treated more effectively. One consequence was higher spending.

To take one example, consider care for people with heart attacks (Cutler, 2003). In 1950, there was little effective therapy for heart attacks. The standard treatment was bed rest. Technological advances supported increasingly effective therapies such as coronary artery bypass grafting (grafting a new blood vessel to bypass the occluded arteries, developed in the 1950s and 1960s), administration of medications that dissolved the clot (thrombolytic therapy, adopted widely in the 1980s), control of arrhythmias, and insertion of balloons and wire mesh tubes to open blocked arteries (stents, developed in the 1980s and 1990s). These therapies are all effective in reducing mortality after a heart attack. Mortality in the month after a heart attack has declined by 75% since 1950 (Cutler, 2003). But they are also expensive. Medicare spending is over $10,000 per heart attack, in many cases much more. Since the incidence of heart attacks rises with age, the technological revolution in treatment of heart attacks affected spending for the elderly more than for the non-elderly.

The recent reduction in the relative growth of medical spending for the elderly is not as easily explained as the increase in relative spending. There has been continuation of medical technology development. For example, coronary revascularization procedures have continued to diffuse, and there have been significant and expensive advances in treatments for cancer (new chemotherapies) and orthopedic problems (hip and knee replacements), among other areas. Some of the relative reduction in spending for the elderly is a product of the diffusion of these technologies into the non-elderly population as well, e.g., elective hip and knee replacements for people with severe arthritis. But this is not the entire story. In addition to the reduction in the relative spending of people over age 65, there has been a slowdown in the real growth rate of spending for the elderly. The explanation for this is unknown.

3.2. Changes in returns to spending

In this section, we examine whether additional years of life expectancy come at increasingly higher cost. Between 1935 and 1955, spending on medical care relative to income remained nearly constant despite large increases in life expectancy. Since then, the cost per year of life has increased in every subsequent decade, although the rate of increases appears to have flattened out in the last two decades.

A central question about the era of big medicine is whether the return to medical care is falling – do additional years of life expectancy come at increasingly higher costs? We cannot answer this question in detail, but we can provide some evidence, following the methodology of Cutler, Rosen, and Vijan (2006). Those authors calculated the incremental cost per year of life for decadal intervals from 1960-2000. They assumed that medical spending was responsible for half of mortality improvements in all decades. They matched up the implied changes in medical spending with changes in expected lifetime medical spending over the same intervals.

Using similar methods, we calculate the increase in real, per capita medical spending (in 2016 dollars) in each 10 year period starting in 1935, and divide that by the increase in life expectancy at birth over the equivalent decade (see Figure 16). This is a scaled version of a cost per year of life due to medical care and will be directionally accurate assuming that medical care accounted for the same share of mortality improvements in each decade. Between 1935 and 1955, very little was spent despite large increases in life expectancy. The cost per year of life has increased virtually every decade since then, though it seems to have flattened out in the past two decades.

The analysis in Figure 16 may understate or overstate the return to medical spending. Recent increases in spending might have led to quality of life improvements more than life expectancy gains. Quality of life has improved over time, likely due in some part to medical advance (Chernew et al., 2017). We are not able to adjust for quality of life changes in our data. And even if medical care is responsible for the same share of longevity improvements over time, the most costly interventions might not lead to the greatest longevity improvements. For example, it might be that medical spending is increasingly directed towards unproductive end-of-life care, while cheap medications may be the source of mortality reductions.

Necessarily, our conclusions about changes in the return to medical care are speculative. But they suggest some reason for concern about the rise of medical expenditures in the post-World War II era.

Discussion and conclusion

Fogel wrote about the theory of "technophysio evolution". In the United States, one sees it in action. The U.S. entered the 19th century an agricultural economy transitioning into industry. By contemporary standards, the U.S. was poor, but by standards of the day, it was rich. Life expectancy at birth was a robust 44 years, even without much of a functional medical care system.

The beginnings of industrialization were harmful for health, as in Europe. Crowded cities, low wages, and poor sanitary practices took their toll. Not until about 1880 did health recover from the beginnings of the industrial revolution.

From 1880 on, both life expectancy and medical spending grew, sometimes in concert but often not. The initial improvements in health owe much to medical science if not to therapeutics. In particular, public health measures such as handwashing, cleaner water, and sewers saved millions from diarrhea and infectious diseases. In cross-area analysis, we find little evidence that formal medicine added to the role of public health. Physicians were involved in the public health revolution, but so too were engineers and biologists.

Medicine came of age in the interwar years. Sulfa drugs and antibiotics were developed in the 1930s and 1940s, and they prolonged the mortality reduction of earlier decades. The period from 1935 to 1950 saw the most rapid decline in infant and child mortality of any time period since 1900. It is unclear how much of this change would have happened without antibiotics, but blood banking and advances in surgical techniques were among the host of distinct and incremental improvements that added to life expectancy while the health share of GDP increased only slightly.

In the 140 years from 1800 through 1940, medical spending doubled as a share of the economy, from 2% to 4% of the economy. Expenditures were still only 4.3% of GDP in 1955. They doubled again in the next 25 years and quadrupled by 2010.

Big medicine brought significant health benefits. Heart disease mortality declined for the first time since records were kept. Deaths declined everywhere but – at least in Massachusetts – more so in Boston than elsewhere in the state.

Nearly a century into the era of Big Medicine, there is a new revolution brewing, or perhaps three: a genetic revolution showing why common diseases occur and how they might be treated; an information revolution allowing clinicians to follow patients and their illnesses and individualize treatments; and a financial revolution in how medical care is paid for. It remains to be seen how these three revolutions will match Fogel's technophysio revolution in scale and scope.

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Appendix A : Data on Medical Spending and Employment

The first data on medical spending are from the early 20th century. Lough (1935) estimates spending on medical care for selected years from 1909 to 1931. He concludes that medical spending was about 3-4% of GDP then. The far more comprehensive 28 volume report by the Committee on the Costs of Medical Care (CCMC, 1932) estimates medical spending of 3.4%-3.8% of GDP from 1925-1930, and speculates that total health spending accounts for "about 4% of national income" for "any normal year." That is consistent with Lough, though the CCMC report shows wide variation across the 10 counties included in their detailed surveys and little recognition of how abnormal the 1929 economy would later seem. The CCMC report served as the framework for subsequent national health accounting efforts by the Social Security Administration, the Health Care Financing Administration, and currently the Centers for Medicare and Medicaid Services (CMS) Office of the Actuary (Fetter 2006, CMS 2016). The annual National Health Expenditures Account (NHEA) estimates since 1960 are generally accepted as valid.

We assume the CCMC data for 1925-30 are approximately right for the US as a whole. We use the Lough data to backcast medical care as a share of GDP to 1900, using approximate growth rates by decade: 0.8% annually for 1900-1910; 1.5% for 1910-1920 and 1.8% from 1920-1925.

As few medical spending data are available prior to 1900, estimates of spending during the 19th Century must for be extrapolated from census occupational data. The decennial U.S. census collected occupational data from 1850 to 1990, after which data are available from the Current Population Survey (CPS). Generally, expenditure and employment data have moved in tandem since 1900 (see Table 1), providing reasonable grounds for extrapolation of spending shares back to 1850.

The health share of total employment is about 0.8% for 1850-1880 and rises to 1.2% in 1900. We trend from 1850 to 1900 using these data. Before 1850, no national data on employment are available. We assume continuation of the very modest employment trend observed from 1850-1880. While this is a large period of time for such an assumption, it is roughly consistent with Lindert and Williamson's (2013) compilation of occupational data in 11 city directories from 1772 to 1806.

From 1960 on, our data on employment in the health sector come from the Bureau of Labor Statistics (BLS).[18] We use data from the BLS Handbook (2003) for 1960-1980 and from BLS (2017) from 1990. The latter series slows slightly higher health care employment than the former: 7.5% in 1990 using the newer series v. 7.1% using the older series.

[18] The BLS began collecting data on employment in the health sector in 1958.

Appendix B: Data on Water and Sewage in Massachusetts

Data on water treatments come from different sources for the Boston Metropolitan area and the rest of Massachusetts. For the Boston Metropolitan area, the water systems depend on a metropolitan authority that changed over time: the Metropolitan Sewerage Commission (1889-1901), the Metropolitan Water Board (1895-1901), the Metropolitan Water and Sewerage Board (1901-1919), the Metropolitan District Commission (MDC) (1919-1985) and, from 1985 to present, the Metropolitan Water Resources Authority (MWRA). Early data (1890-1915) are from Alsan and Goldin (2015), data for the 1920s and 1930s come from the Metropolitan District Commission (MDC) annual reports, data from the 1930s to present come from historical data included in the Metropolitan Water Resources Authority (MWRA) Master Plan (2006).

Data for the rest of Massachusetts come from censuses of water plants published in academic journals and by public agencies. Johnson (1917), Gillepsie (1924) and Streeter (1931) provide surveys of early purification and filtration plants in Massachusetts. The inventory of water and sewage facilities in the United States[19] published in 1945 by the U.S. Public Health Service provides detailed information by city and town, including water source types and treatment details. From 1954 to 1968, the U.S. Public Health Service produces every other year a survey of Municipal Water Facilities for municipalities of 25,000 population and over. In 1963, a cooperative State Federal report presents an

[19] Inventory of water and sewage facilities in the United States, 1945. A cooperative inventory by the sanitary engineering divisions of state health departments and the U.S. Public Health Service.

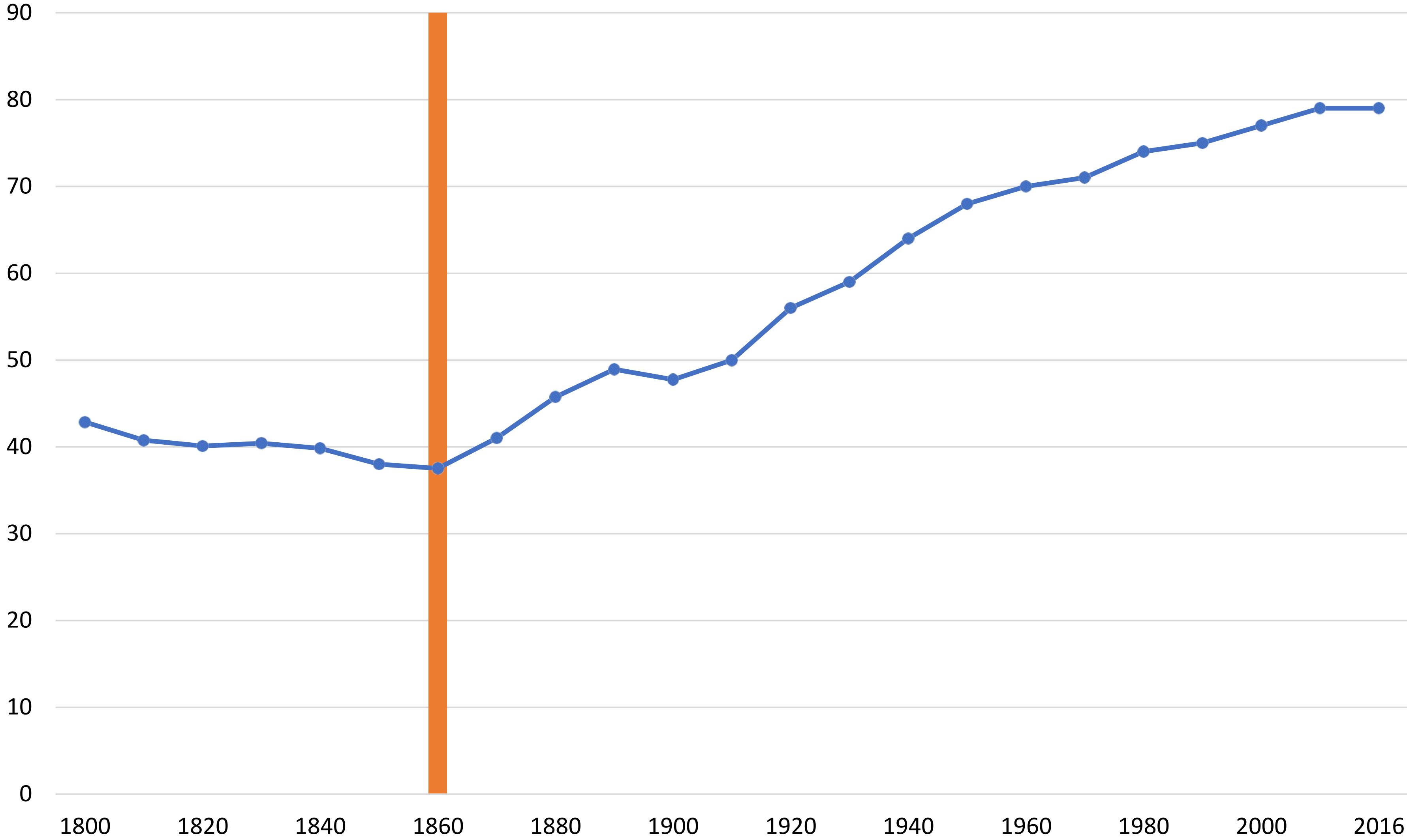
exhaustive inventory of Municipal Water Facilities for all cities and towns (not limited to larger cities).

Data on sewage systems come from some of the same sources as well as other sources. For the Metropolitan district, we use the data from Alsan and Goldin supplemented with information from MDC and MWRA. For the rest of Massachusetts, we use the inventory of water and sewage facilities in the United States published by the U.S. Public Health Service in 1945 as well as data from Municipal Waste Facilities Inventories published every other year by the Public Health Service from 1957 to 1968. When no start date for the sewer system is available in any of these directories, we used web searches to look for the operation date of local waterworks.

List of Figures and Tables

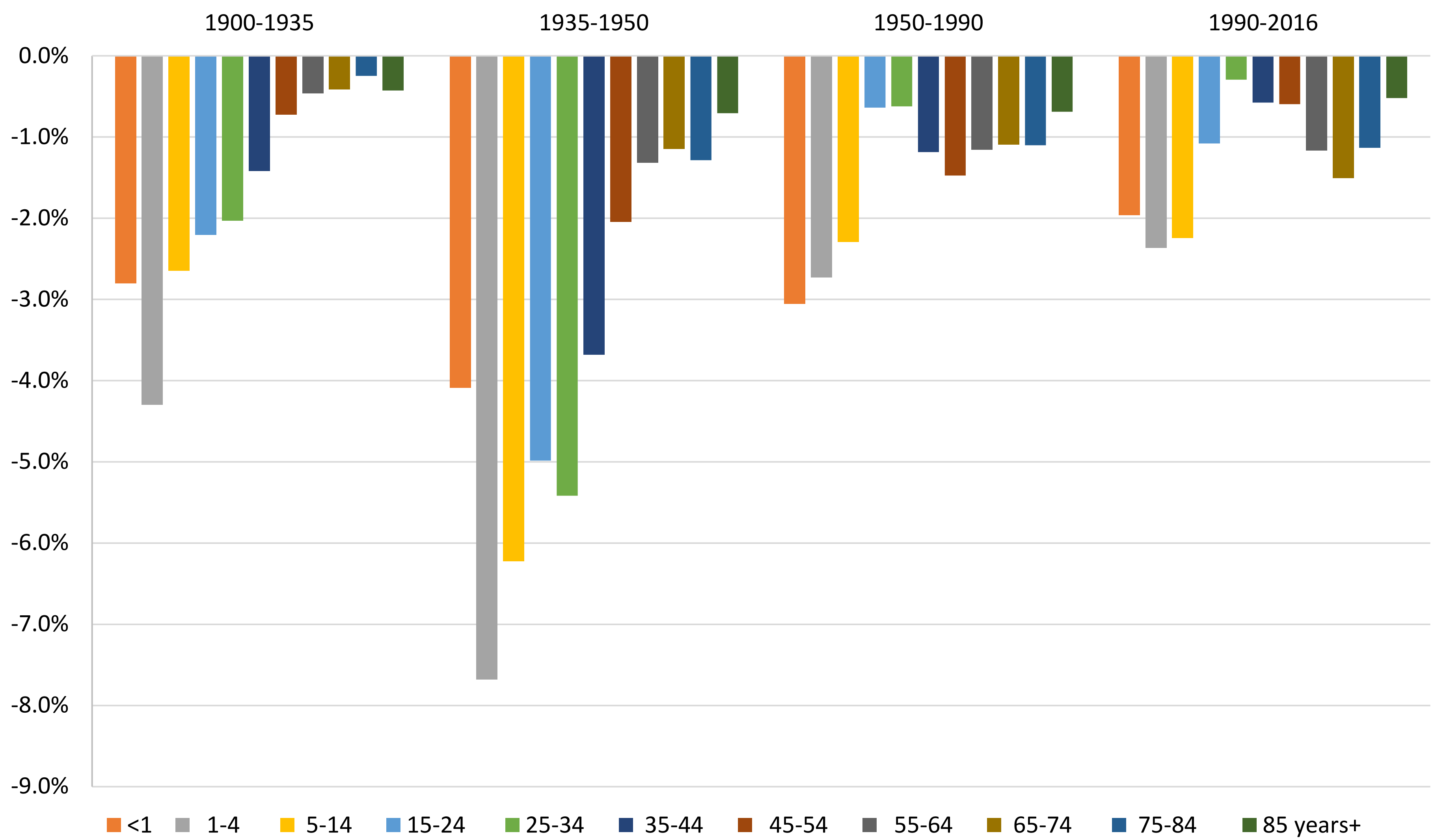
Appendix tables

Figure 1: Life Expectancy at Birth in the United States, 1800-2016

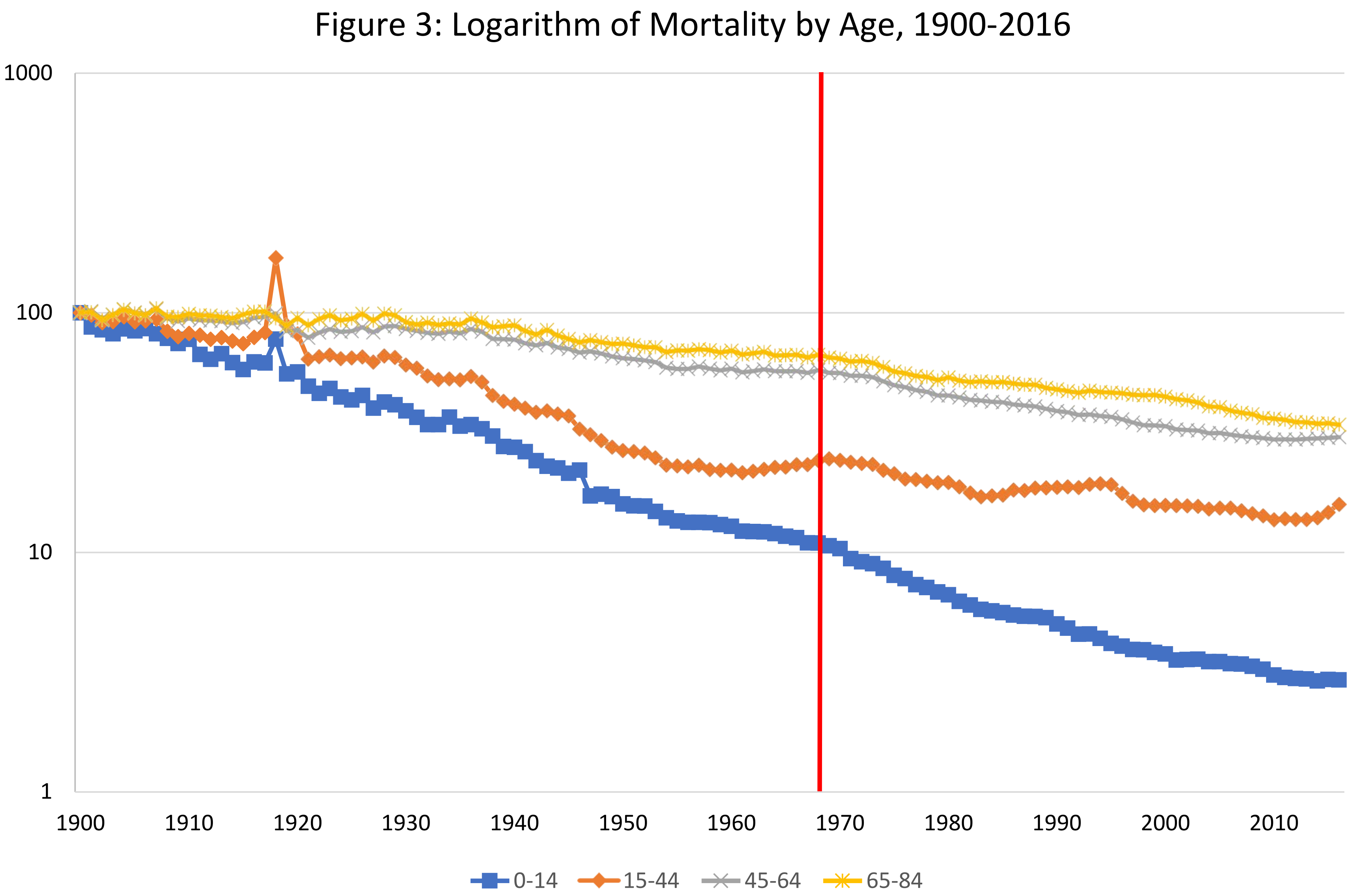


Source: Hacker, based on Fogel and Haines.

Figure 2: Change in Mortality by Age and Time Period

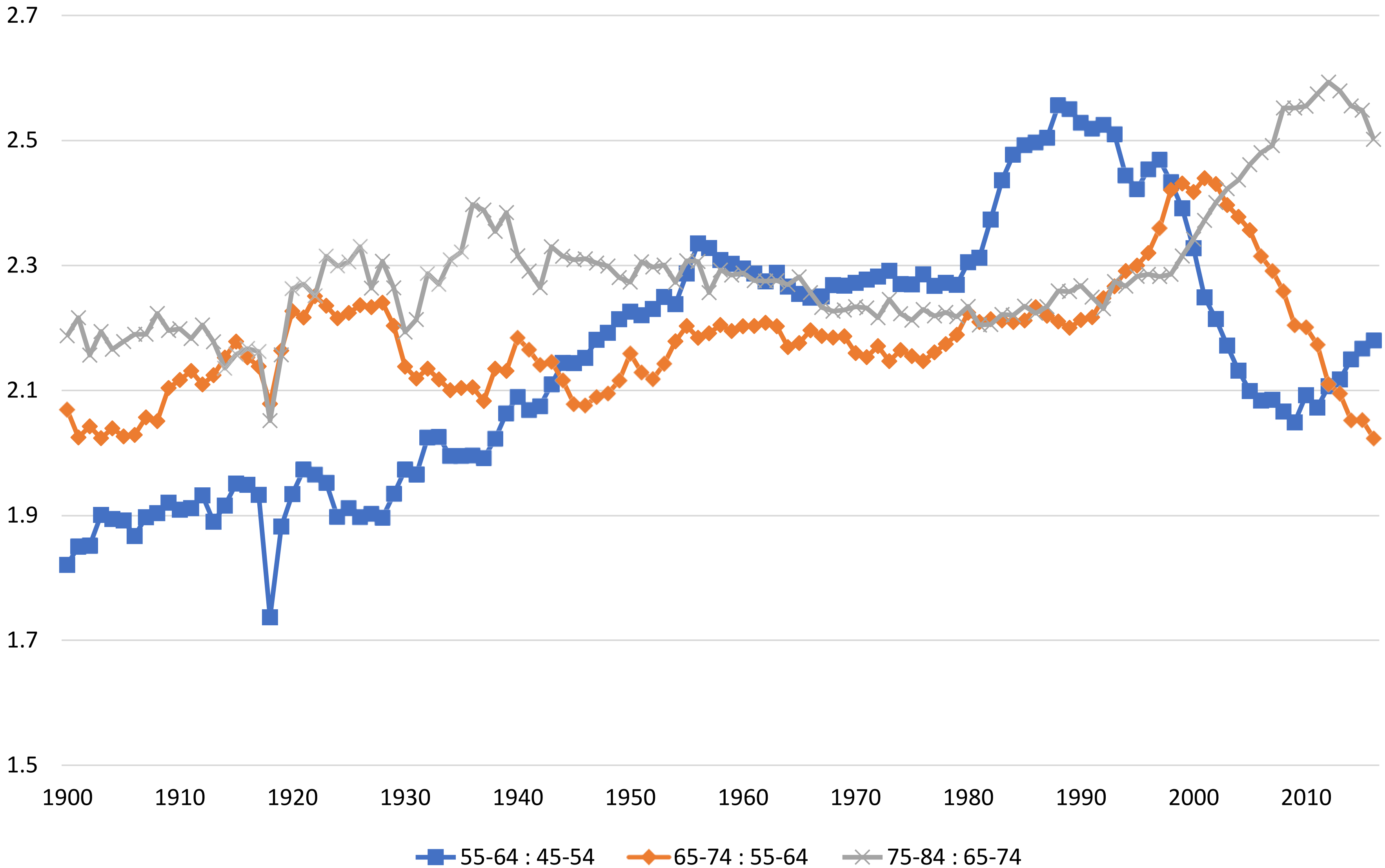


Source: Data are from the National Center for Health Statistics.



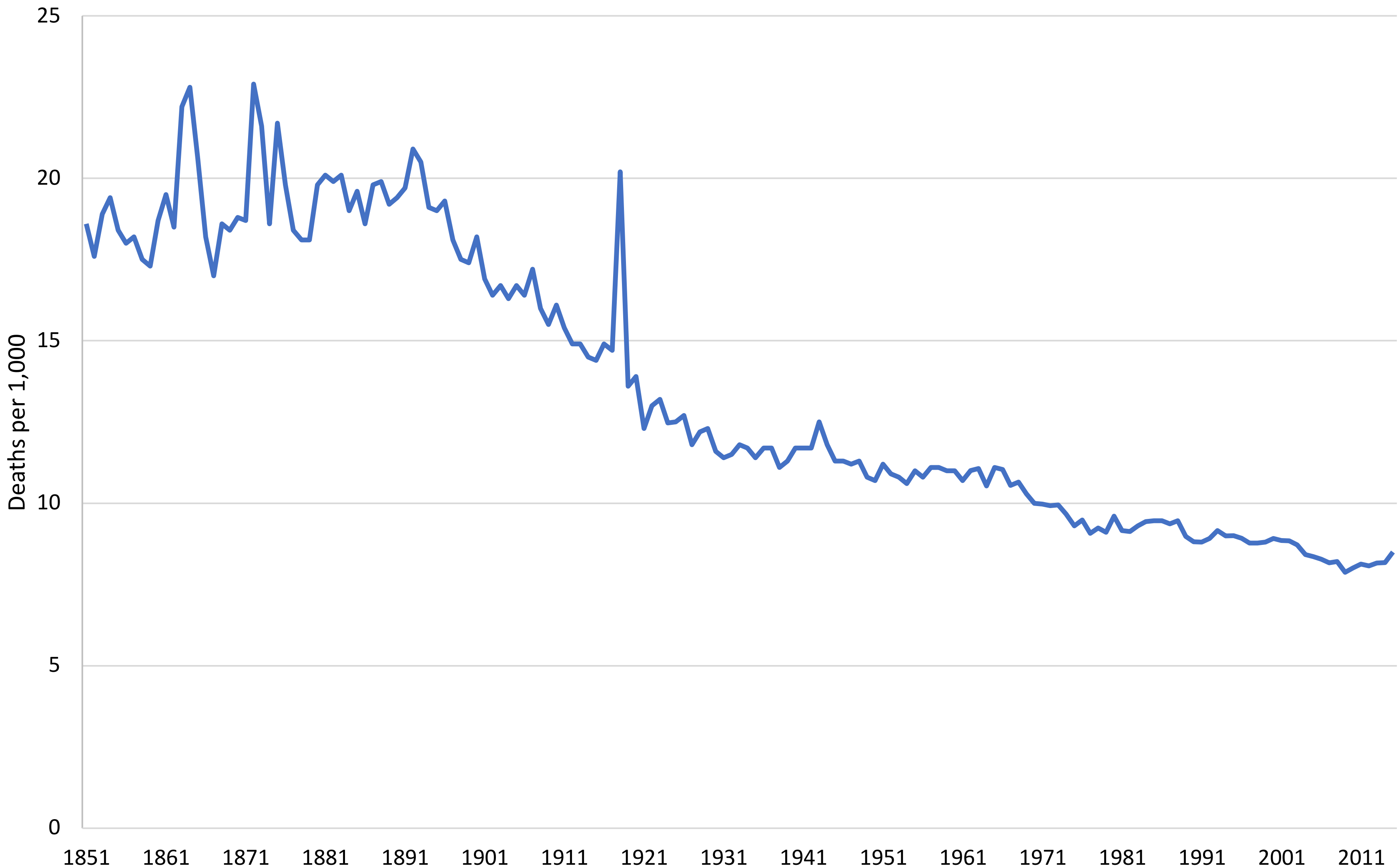
Source: Data are from the National Center for Health Statistics.

Figure 4: Ratio of Mortality Rates for Adjacent Age Groups, 1900-2016

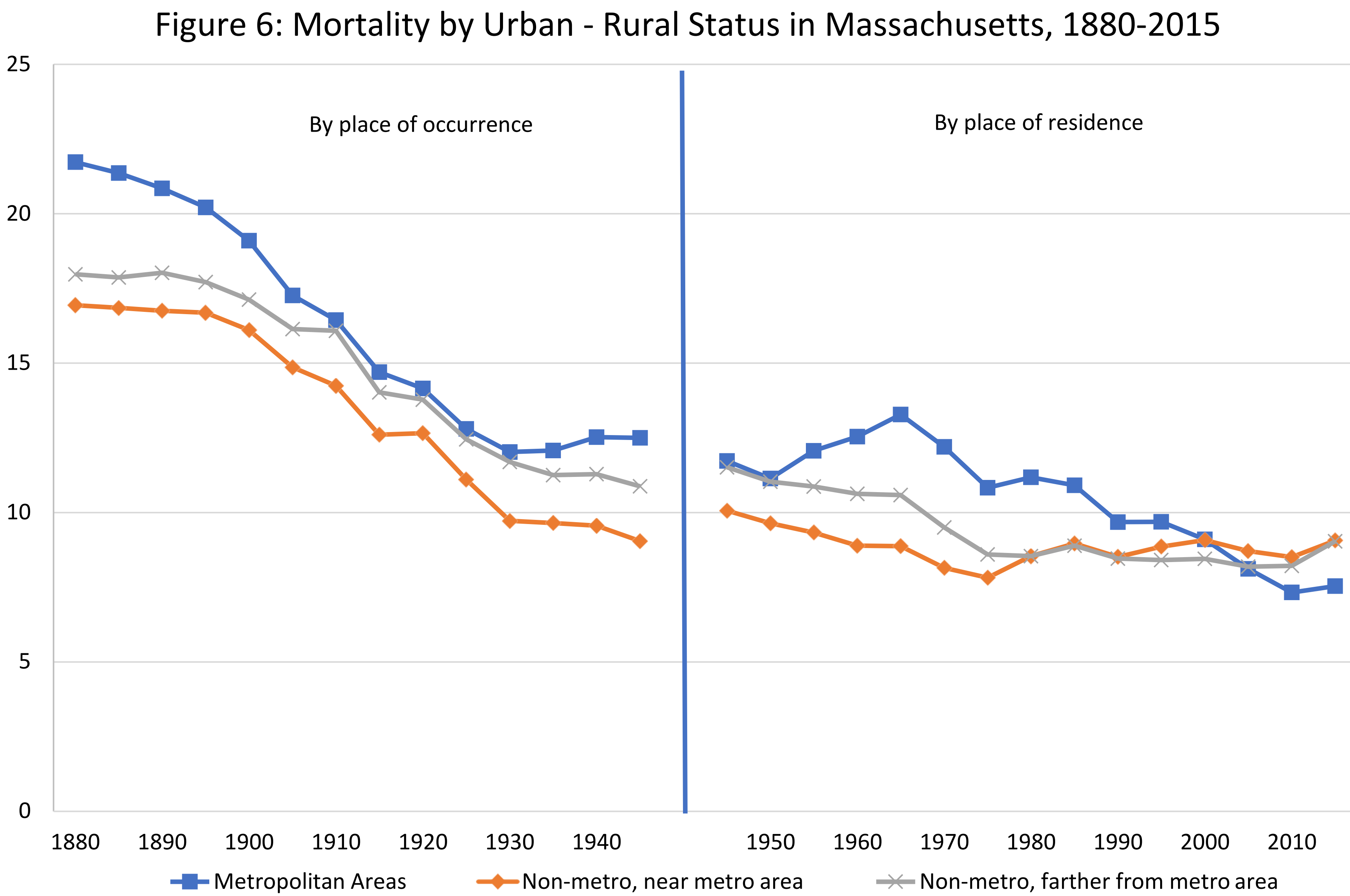


Source: Data are from the National Center for Health Statistics.

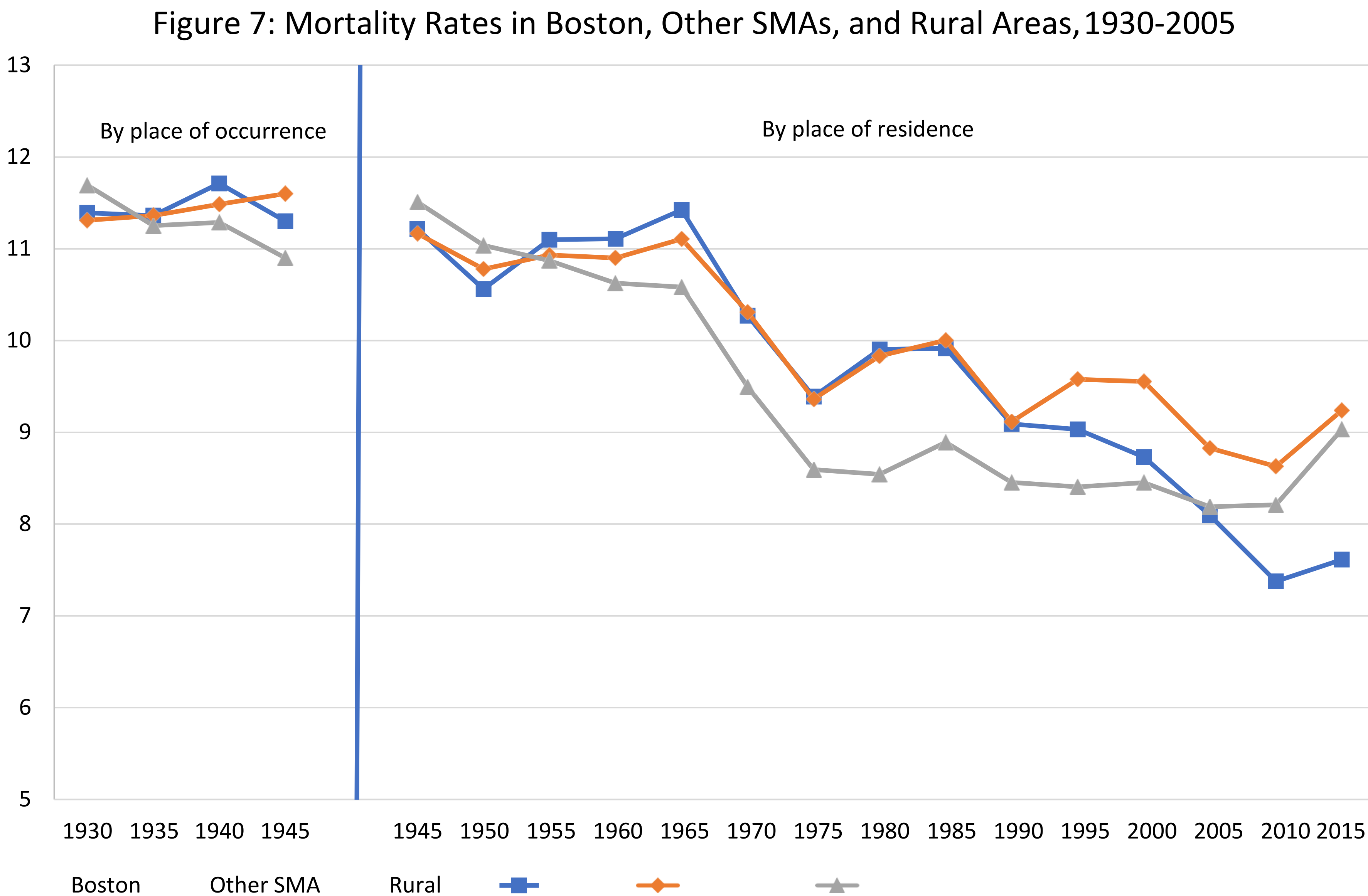
Figure 5: Crude Death Rate in Massachusetts, 1851-2015



Source: Commonwealth of Massachusetts, Secretary of State, Annual Report on Vital Statistics of Massachusetts, various issues.

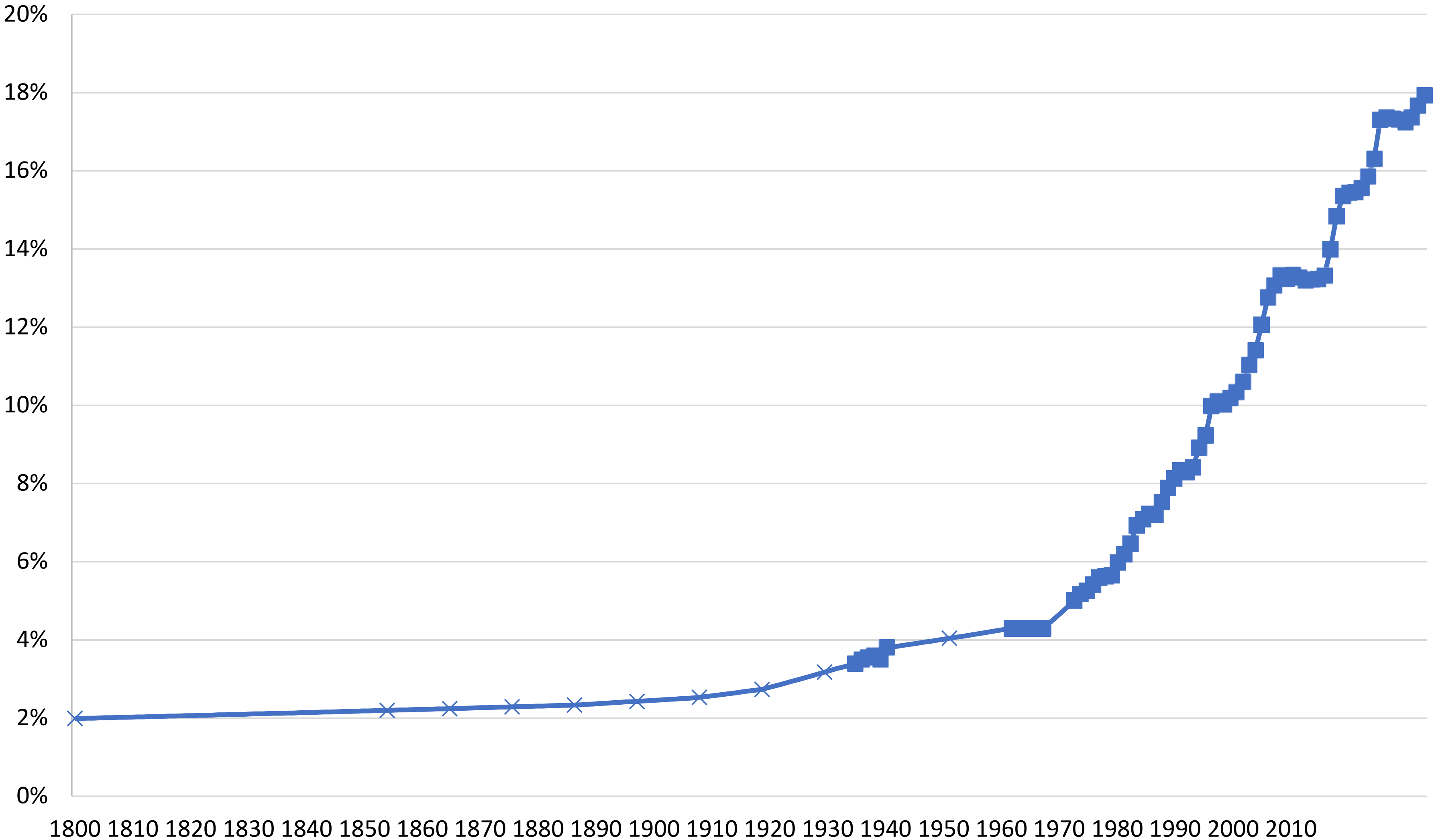


Source: Commonwealth of Massachusetts, Secretary of State, Annual Report on Vital Statistics of Massachusetts, various issues. Prior to 1945, data are deaths by occurrence; post-1945, data are deaths by residence.



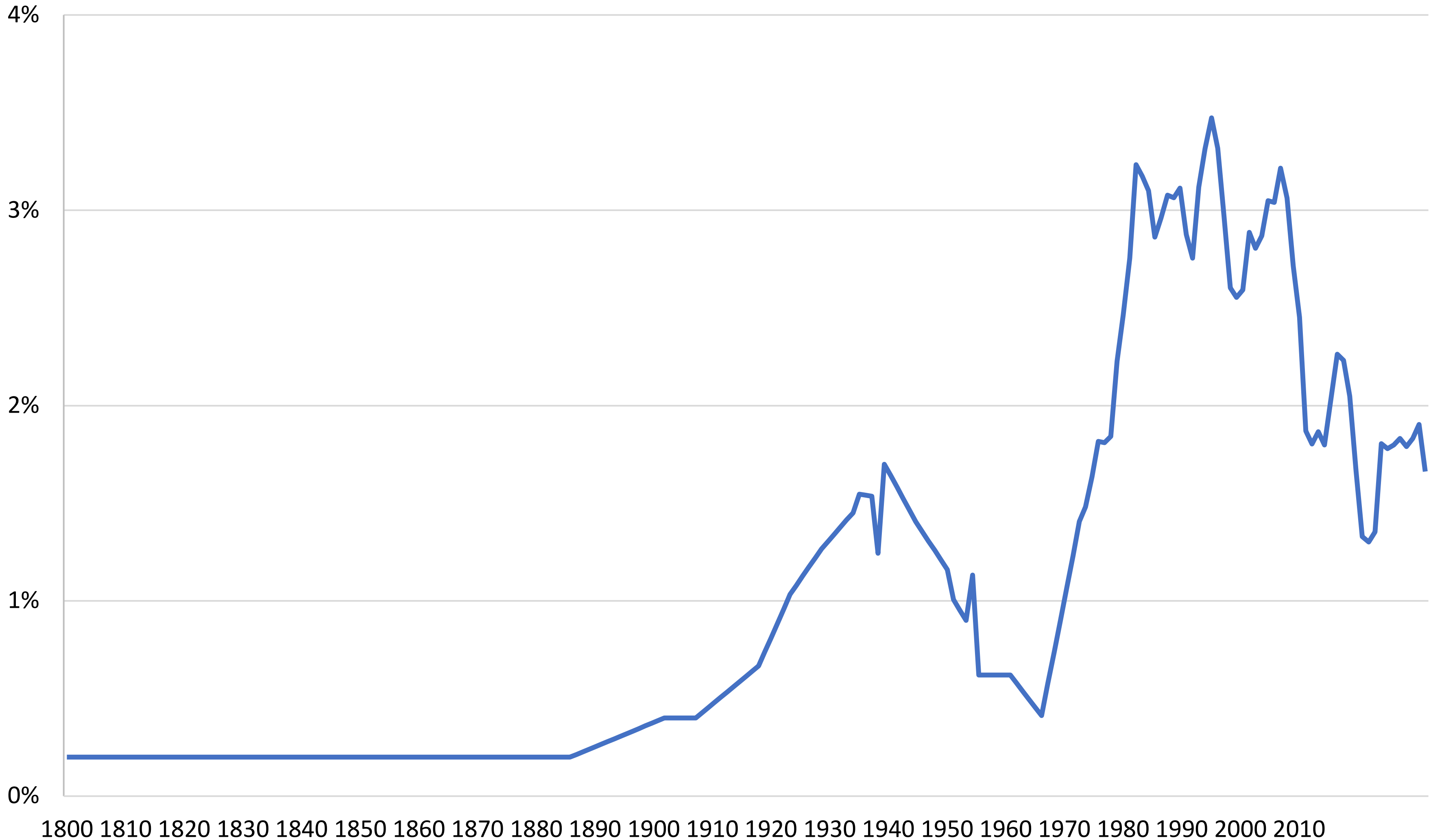
Source: Commonwealth of Massachusetts, Secretary of State, Annual Report on Vital Statistics of Massachusetts, various issues. Prior to 1945, data are deaths by occurrence; post-1945, data are deaths by residence.

Figure 8: Medical Spending as a Share of GDP, 1800-2016

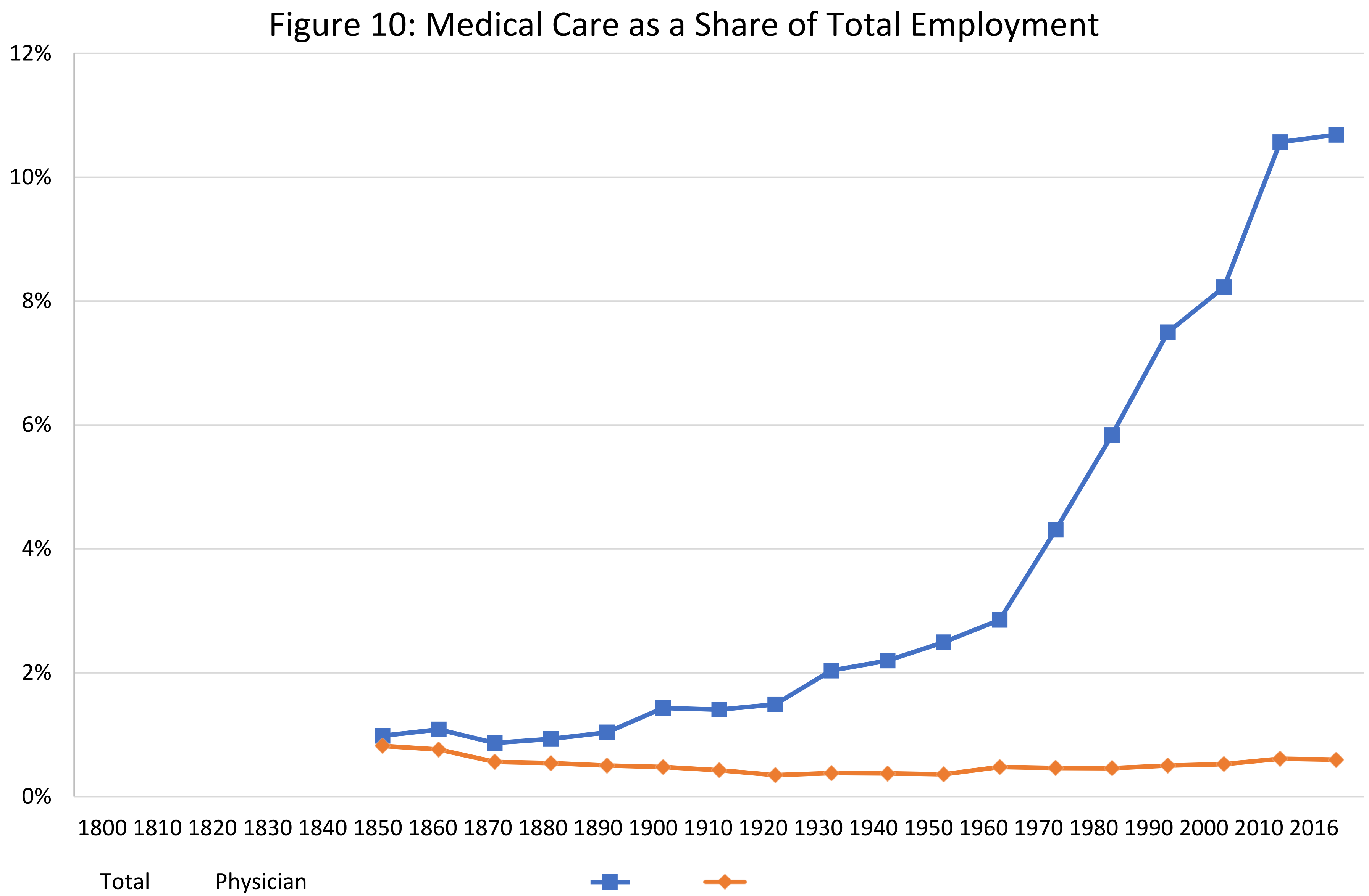


Note: Data sources are described in the text. □ indicates actual data on medical spending as a share of GDP. x indicates extrapolation from Census employment data.

Figure 9: Fifteen Year Moving Average of Medical Spending Growth Above GDP Growth



Note: Data sources are described in the text.



Note: Data for 1850-1950 are from U.S. Census. Data for 1960-2016 are from BLS (2003, 2017).

Figure 11: Seale's Estimates of Medical Spending as a Share of GDP, 1929-1957

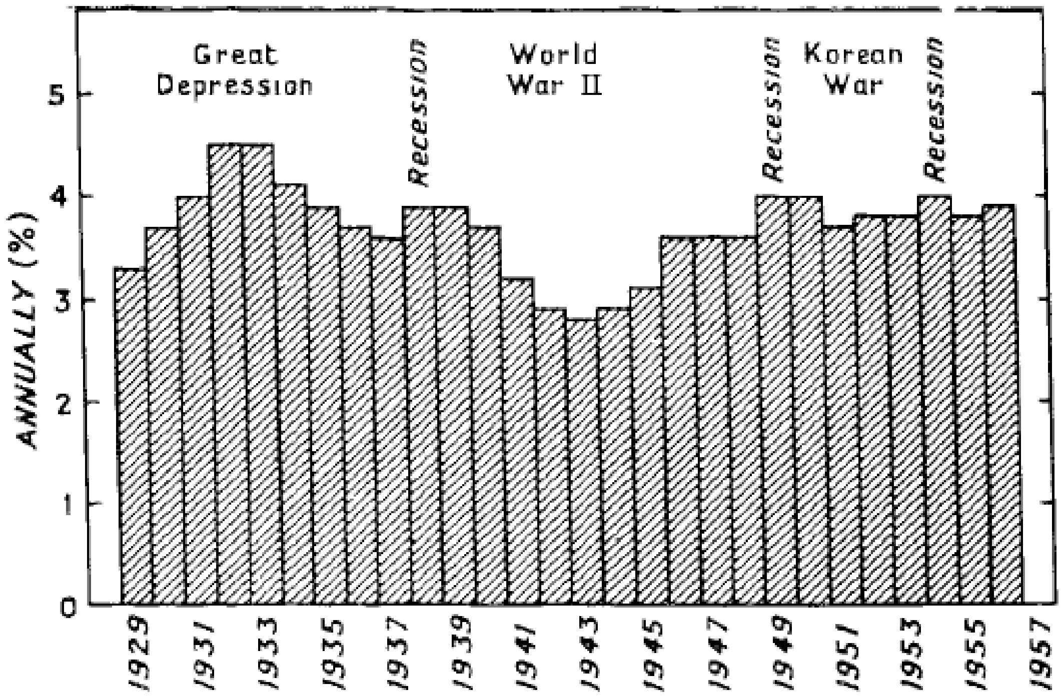
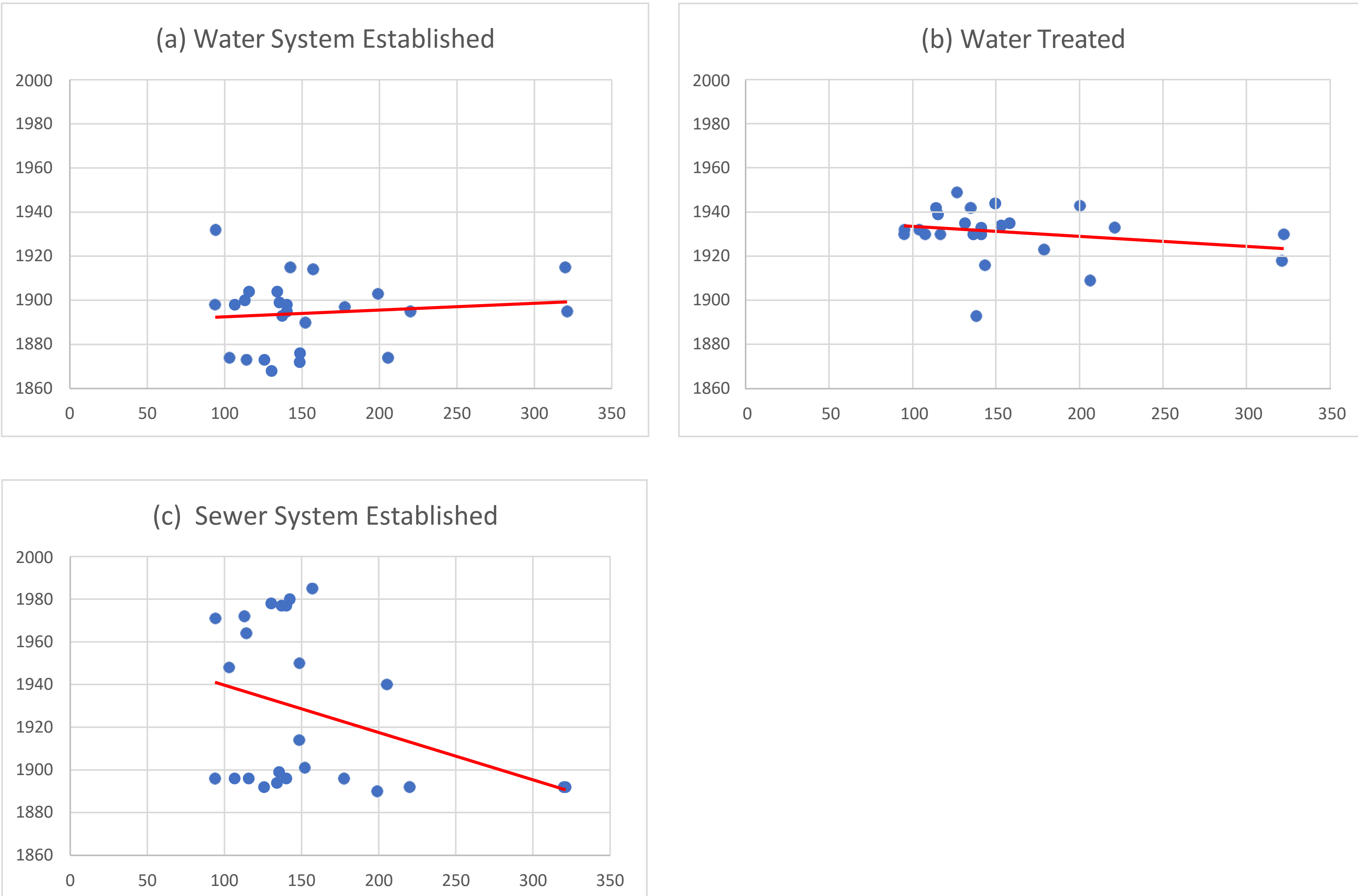
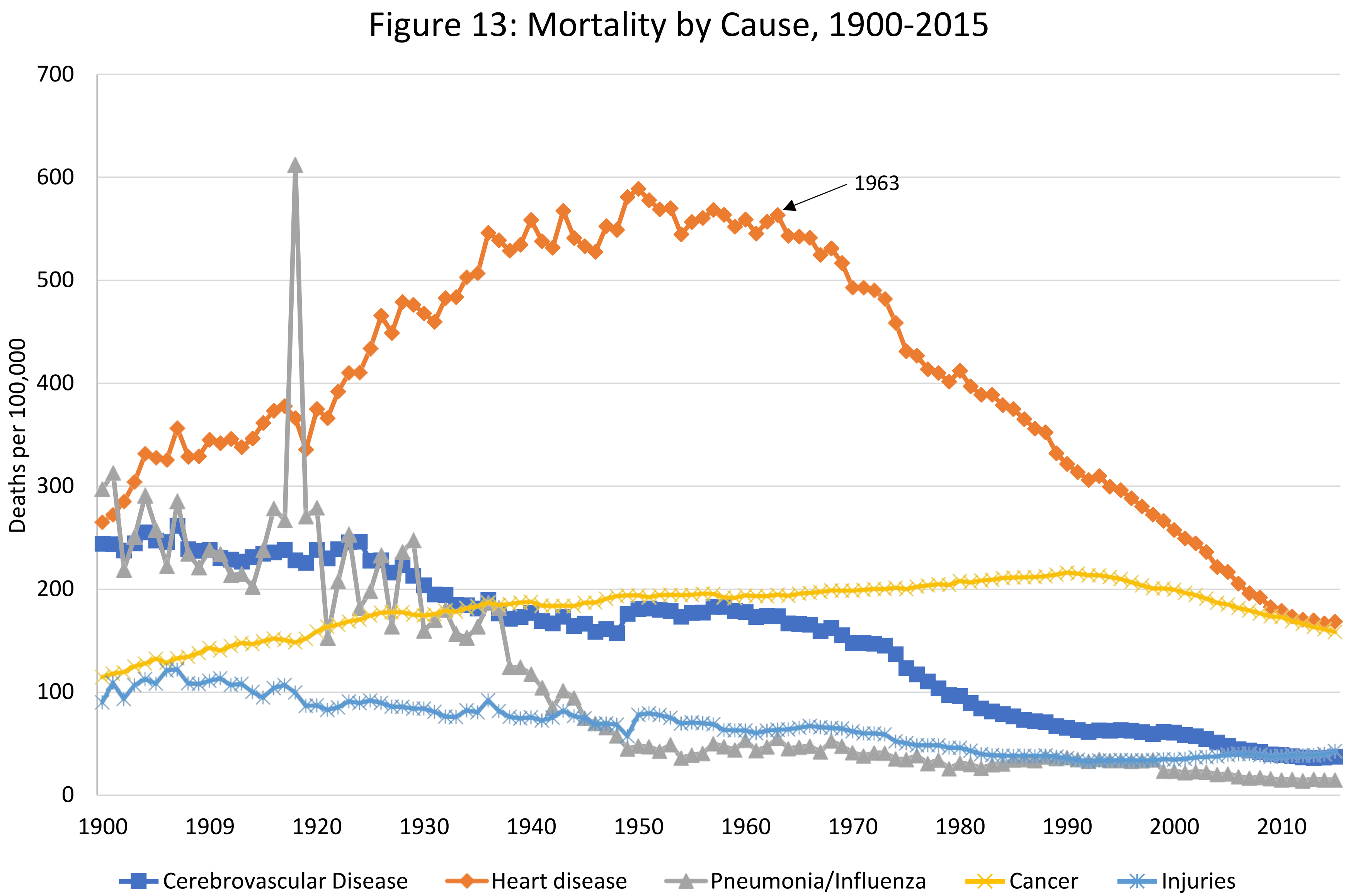


Fig. 2—National expenditure on medical care expressed as a percentage of gross national product, U.S.A., 1929–56.

Source: J.R. Seale (1959), page 555.

Figure 12: Dates of Water and Sewage Treatment vs. Physicians per 100,000, 1906





Note: Data are age adjusted to the 2000 population standard.

Figure 14: Natural Logarithm of Influenza/Pneumonia Mortality

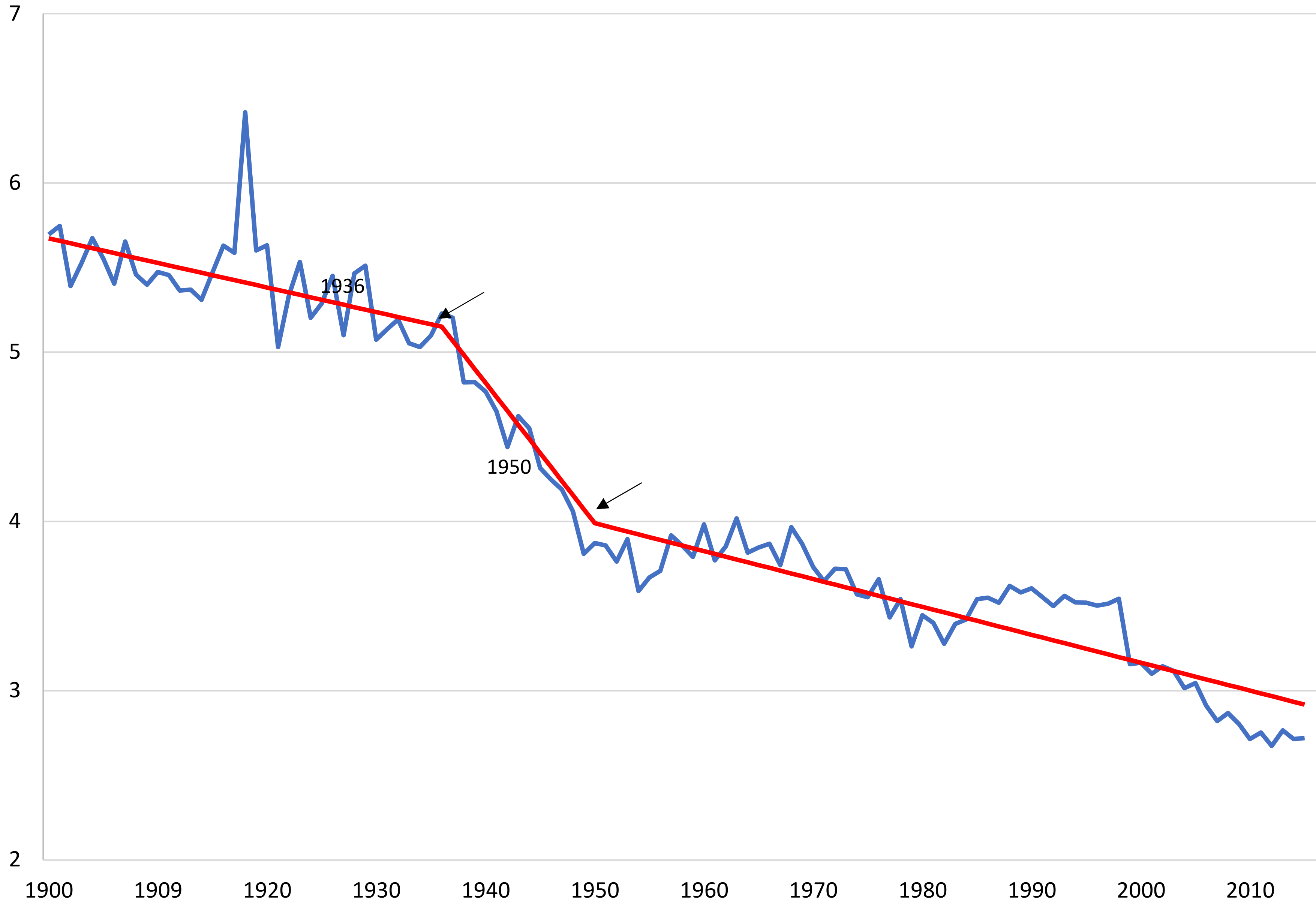
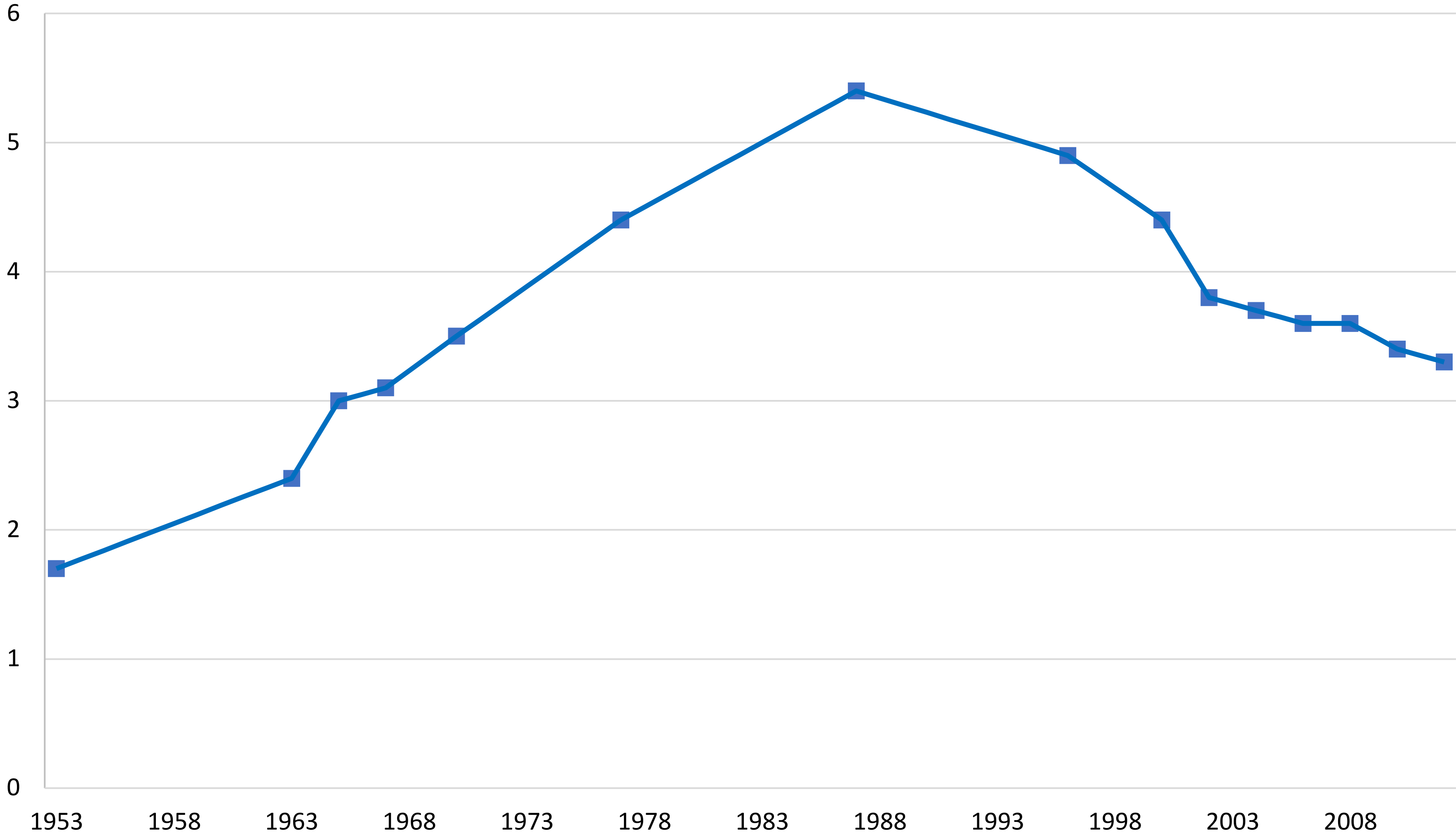


Figure 15: Ratio of Medical Spending for the Elderly to Adults, 1953-2012



Note: Data for 1953 are from Cutler and Meara (1997). Data for 1963-2000 are from Meara, White, and Cutler (2004). Data for 2002-2012 are from CMS (2017).

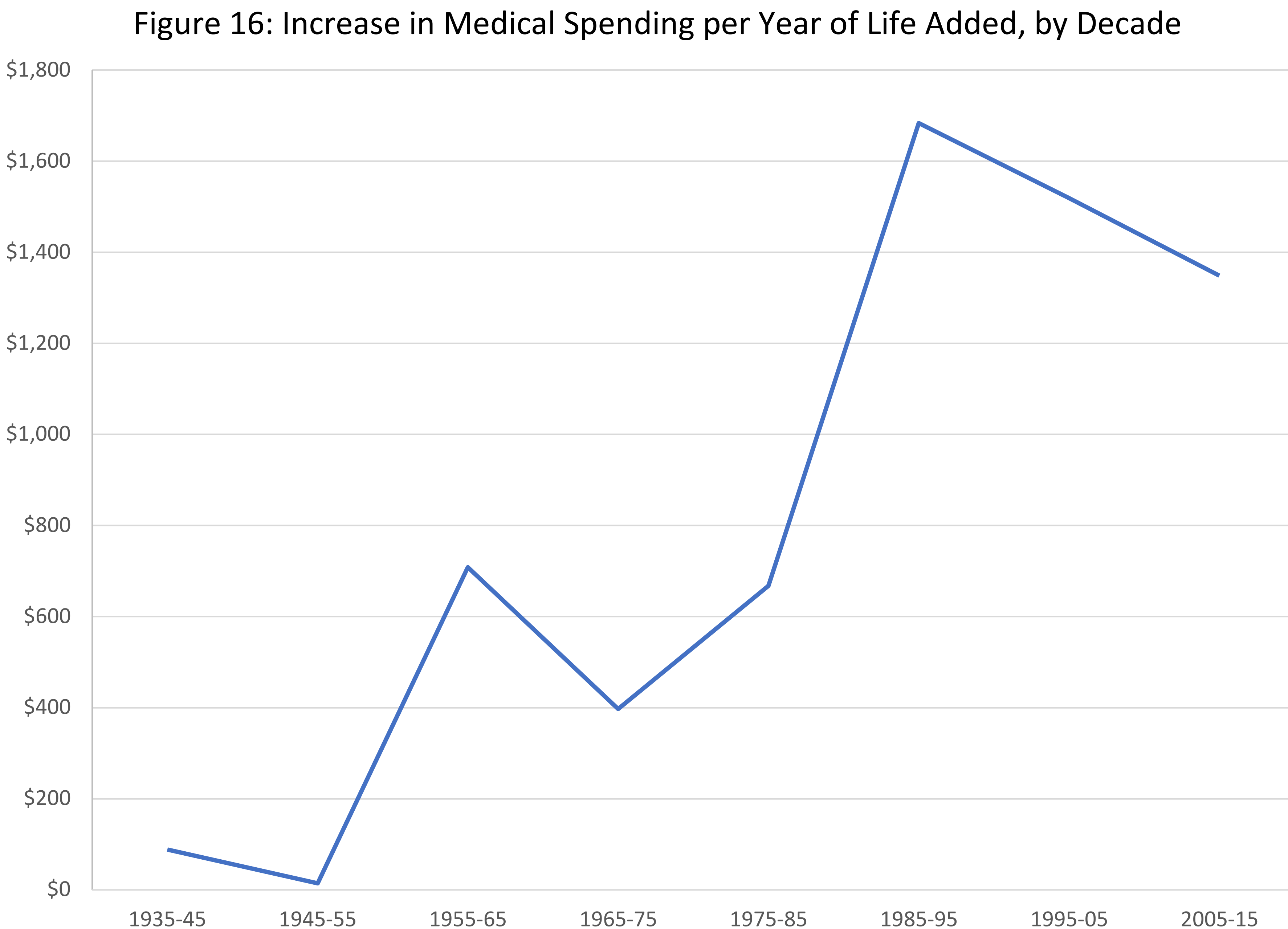


Figure 16: Increase in Medical Spending per Year of Life Added, by Decade
$1,800
$1,600
$1,400
$1,200
$1,000
$800
$600
$400
$200
$0
1935-45
1945-55
1955-65
1965-75
1975-85
1985-95
1995-05
2005-15

Table 1: Health Expenditures and Employment, and Population Health

	Spending		Employment			Population	
Year	**NHE/GDP (%)**	**Per capita GDP ($2009)**	**Health/total employment**	**Physicians/ 100K**	**Staff/ physician**	**Percent urban**	**Life expectancy at birth**
1800	2.0	$1,769	-	-	-	6	*43*
1850	2.2	$2,516	*0.8*	1.8	0.1	15	*38*
1880	2.3	$4,175	*0.8*	1.7	0.5	20	*46*
1900	2.5	$5,356	*1.2*	1.7	1.4	40	49
1910	2.7	$6,325	*1.3*	1.7	1.9	46	50
1920	3.2	$6,881	*1.5*	1.4	2.7	51	56
1930	3.8	$7,854	*1.8*	1.3	3.9	56	59
1940	3.9	$9,595	*2.0*	1.3	4.4	57	64
1950	4.2	$14,381	*2.5*	1.3	5.8	64	68
1960	5.0	$17,273	3.1	1.3	7.4	70	70
1970	6.9	$23,149	4.6	1.5	9.2	74	71
1980	8.9	$28,388	6.3	1.9	10.6	74	74
1990	12.1	$35,874	7.5	2.4	11.1	78	75
2000	13.3	$44,518	8.2	2.6	11.7	79	77
2010	17.4	$47,790	10.6	2.7	12.9	81	79
2016	17.9	$51,420	10.7	3.1	12.3	82	79

Sources: National Health Expenditure: Shares 1960-2016 are from CMS (2018). 1950 is from Reed & Hanft (1966) linked to the CMS series at 1960 by adjustment x1.02 using relative values. 1940 is a linear extrapolation between 1950 and 1930 is an estimate based of a variety of sources including CCMC (1932), Seale (1959), and Cooper, Worthington and McGee (1973) with adjustment for distortion created by sharp recession in 1929 (see Getzen 2018 for details). Hough (1935) is used to establish growth trends to extrapolate back from 1930 to 1910. Based on Census employment trends Getzen extrapolates backward using cumulative annual growth rate estimates of 0.8% for 1900-1910, 0.4% for 1880-1900, and 0.2% for 1850-1880, and extends backward at the same 0.2% rate to 1800 relying on the Lindert city occupational totals as an endpoint. **Real GDP per capita:** U.S. Bureau of Economic Analysis (2017) Current-Dollar and "Real" Gross Domestic Product for 1929-2016 and online Table Ca11 in *Historical Statistics of the United States* (Carter et al., 2006) (HSUSm) for 1790-2000 and inflated to from 1996 dollars to 2009 dollars using BEA deflator. Resident population in millions from HSUSm-Table Ca14 (identical to Aa7). **Urbanization:** HSUSm-Aa699-715 for 1790-1999 and "percent urban" for 2000 and 2010 at (Census, 2018). **Physicians** from U.S. Decennial Census occupations 1850-1990 in HSUSM-Ba1218 & Ba1222 for 1970-2000 from Health, United States, 1993 Tables 108 and 109, and Health, United States, 2015 Table 83. **Health Employment:** 1990 - 2016 from BLS "Current Employment Statistics Survey" data series CEU6562000101 and for 1960-1990 the comparable SIC 808 "Health" series from BLS Handbook of U.S. Labor Statistics, 2003, Table 2-1 (adjusted x1.07 to link with the current NAIC series). For earlier years U.S. Decennial Census 1850-1970 in HSUSM-Table Ba1033-1439 (occupations categorized as "health employment" by author), and for 1970-2000 and Edwards (1943). Health employment estimates in the older BLS SIC series are somewhat smaller than in the current NAIC series, which began in 1990, and also differ from census occupational totals 1960-1990. Staff per MD is total health employment (minus physicians) divided by number of physicians. Note that various vintages or versions the "same" data series often show different values for the same year. **Life Expectancy:** For 1900 – 2016: NCHS Vital Statistics Reports 66 #4 "United States Life Tables, 2014" August 2017, and NCHS data brief #293 "Mortality in the United States, 2016." For 1800-1880, Hacker (2010), Table 8; Haines "Vital Statistics" and Table Ab644 in HSUSm.

Table 2: Cross-City Evidence on Medical Care, Public Health and Mortality

	National, 1900-1936		Massachusetts, 1880-1935			
			25 Largest Cities		260 Cities/Towns	
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)
MDs/100K population * year	---	0.00002*	---	0.00003*	---	0.00002**
		(0.00001)		(0.00001)		(0.00001)
Trained nurses / MD * year	---	0.004	---	0.006*	---	0.005**
		(0.006)		(0.002)		(0.001)
Water filtration	-0.042*	-0.041**	---	---	---	---
	(0.020)	(0.018)				
Water chlorinaction	-0.008	0.003	---	---	---	---
	(0.011)	(0.019)				
Water filtration * chlorination	0.046**	0.03	---	---	---	---
	(0.014)	(0.020)				
Water System	---	---	-0.071**	-0.065**	-0.033**	-0.047**
			(0.017)	(0.018)	(0.015)	(0.016)
Sewer System	---	---	-0.058*	-0.053*	---	---
			(0.023)	(0.018)		
Water System * Sewer System	---	---	0.137**	0.089*	---	---
			(0.037)	(0.038)		
Lag 1 mortality	0.538**	0.524**	---	---	---	---
	(0.066)	(0.060)				
Lag 2 mortality	0.026	0.017	---	---	---	---
	(0.077)	(0.081)				
Lag 3 mortality	0.264**	0.250**	---	---	---	---
	(0.101)	(0.094)				
Lag 4 mortality	0.05	0.038	---	---	---	---
	(0.039)	(0.043)				
Lag 5 mortality	-0.130**	-0.156**	---	---	---	---
	(0.049)	(0.055)				
N	410	410	300	300	4199	4199
R^2	0.95	0.951	0.86	0.878	0.788	0.797

Note: All regressions include city and year dummy variables. Standard errors are clustered at the city level in the national data and the SMA level in the Massachusetts data. * p<0.10, ** p<0.05

Table 3: Medical Care and Mortality Post-World War II

	ln(All Deaths)			
Independent Variable	Deaths per 100,000, 1965-2015	Deaths per 100,000 Elderly, 1965-2015	Deaths per 100,000 Elderly, 1965-1990	Deaths per 100,000 Elderly, 1990-2015
MD/100K * year	-0.000021**	-0.00001	0.000009	-0.000041**
	(0.000005)	(0.000008)	(0.000008)	(0.000015)
Share of Elderly Population	0.060**	-0.021**	-0.026**	-0.024**
	(0.005)	(0.004)	(0.002)	(0.009)
Income per capita in SMA	-0.000008**	-0.000006	-0.000011	-0.000002
	(0.000003)	(0.000004)	(0.000011)	(0.000004)
Distance to major SMSA city * year	-0.000036	0.000049	0.000140*	0.000033
	(0.000040)	(0.000040)	(0.000077)	(0.000053)
Distance to Boston * year	0.000032*	0.000050**	-0.000004	0.000089*
	(0.000015)	(0.000020)	(0.000031)	(0.000049)
Major city * year	-0.002856**	-0.001445	-0.001458	-0.004254**
	(0.000891)	(0.000840)	(0.001099)	(0.001359)
Rural area * year	-0.006304**	-0.005843*	-0.00621	-0.005093
	(0.002220)	(0.002819)	(0.003760)	(0.002987)
N	3835	3835	2090	2093
R^2	0.837	0.724	0.716	0.669

	ln(Deaths per 100,000 Elderly), by cause, 1990-2015							
		Cancer						
Independent Variable	Heart Disease	All	Breast Cancer	Lung Cancer	Other Cancer	Stroke	COPD	Influenza/ Pneumonia
MD/100K * year	-0.000024	-0.000065**	-0.000042	-0.000075*	-0.000055**	0.000076**	-0.000019	-0.000148*
	(0.000025)	(0.000013)	(0.000085)	(0.000038)	(0.000013)	(0.000029)	(0.000026)	(0.000073)
Share of Elderly Population	-0.017	-0.037**	-0.001	-0.057	-0.021**	-0.020	-0.031**	0.002
	(0.012)	(0.009)	(0.015)	(0.032)	(0.008)	(0.013)	(0.011)	(0.022)
Income per capita in SMA	-0.000002	-0.000011*	-0.000038	-0.000001	-0.000009	0.000011	-0.000003	0.000017
	(0.000007)	(0.000005)	(0.000021)	(0.000006)	(0.000007)	(0.000008)	(0.000013)	(0.000023)
Distance to major SMSA city * year	0.000184	0.000082	0.000457**	0.000162	0.000120**	0.000074	0.000240*	0.000231
	(0.000129)	(0.000049)	(0.000170)	(0.000093)	(0.000041)	(0.000048)	(0.000122)	(0.000278)
Distance to Boston * year	0.00006	0.00003	-0.000155	0.000097	0.000055**	0.000237**	0.000116	0.000145
	(0.000070)	(0.000029)	(0.000149)	(0.000063)	(0.000021)	(0.000064)	(0.000068)	(0.000197)
Major city * year	-0.003272*	-0.002202	0.012467**	-0.008893	0.002756	0.000696	-0.003648	0.00077
	(0.001764)	(0.002248)	(0.004169)	(0.005254)	(0.002451)	(0.001831)	(0.002603)	(0.003505)
Rural area * year	-0.003599	-0.010703**	-0.022989	-0.005335	-0.007868	0.017981**	-0.00624	0.003711
	(0.006641)	(0.004647)	(0.016308)	(0.005409)	(0.005893)	(0.006228)	(0.010665)	(0.020262)
N	2022	2019	1178	1506	1655	1744	1703	1547
R^2	0.708	0.484	0.443	0.510	0.405	0.493	0.452	0.500

Note: All regressions are weighted by city/town population and include city/town dummy variables and year dummy variables. MD/100K is measured at the SMA level.
* (**) Statistically significant at the 10% (5%) level.

Table 4: Personal Health Care Spending per capita by Age

Year	age 0-64	age 65+	Ratio 65+ / 0-64	% Pop age 65+	% Spending $$ age 65+
1953	67	110	1.7	8.5%	13.0%
1963	129	304	2.4	9.4%	20.0%
1965	158	472	3	9.5%	24.0%
1967	171	528	3.1	9.8%	25.0%
1970	238	823	3.5	10.8%	30.0%
1977	453	2002	4.4	12.2%	38.0%
1987	1088	5849	5.4	12.7%	44.0%
1996	2123	10308	4.9	12.4%	41.0%
2000	2676	11815	4.4	12.5%	39.0%
2002	3521	13537	3.8	12.4%	35.0%
2004	4062	15112	3.7	12.4%	34.0%
2006	4577	16434	3.6	12.5%	34.0%
2008	4998	17786	3.6	12.8%	34.0%
2010	5381	18544	3.4	13.1%	34.0%
2012	5781	18988	3.3	13.5%	34.0%

Source: Author calculations based on Meara, White and Cutler (2004); CMS NHE Age and Gender Tables (2017) and other sources.

Table A1: Medical Care Personnel in 1910

City	MDs / 100K	Trained Nurses per MD
Atlanta	326	0.92
Baltimore**	214	0.92
Boston	280	0.93
Buffalo	190	0.97
Chicago**	209	0.58
Cincinnati**	221	0.77
Cleveland**	171	0.85
Columbus	261	0.99
District of Columbia	323	0.36
Denver	392	0.63
Detroit**	203	0.63
Fall River	109	0.95
Indianapolis	306	0.54
Jersey City**	92	0.78
Kansas City	404	0.55
Los Angeles	414	0.62
Louisville**	284	0.63
Memphis**	278	0.77
Mikwaukee**	158	0.68
Minneapolis	230	0.72
New Haven	183	1.00
New Orleans**	187	0.88
New York	185	0.91
Newark	143	1.09
Omaha	301	1.08
Paterson	128	0.81
Philadelphia**	232	0.80
Pittsburgh**	194	0.87
Providence	192	1.24
Richmond	204	1.46
Rochester	194	0.91
St Louis**	247	0.71
St Paul	197	1.23
San Francisco	310	0.97
Scranton	151	1.12
Syracuse	234	1.08
Toledo	223	0.66
Worcester	204	1.34
Average	**218**	**0.81**
Standard Devn	**76**	**0.23**

Table A2: Medical Care Personnel in Massachusetts

city	Population, 1910	Date of Public Health Measures: Water System	Water Treatment	Sewer System	Supply per 100,000: Doctors, 1906	Nurses, 1900
Boston	670,585	1895	1930	1892	321	481
Worcester	145,986	1903	1943	1890	199	537
Fall River	119,295	1874	1932	1948	103	137
Lowell	106,294	1915	1916	1980	142	220
Cambridge	104,839	1897	1923	1896	178	299
New Bedford	96,652	1900	1942	1972	113	267
Lynn	89,336	1914	1935	1985	157	336
Springfield	88,926	1874	1909	1940	205	363
Lawrence	85,892	1893	1893	1977	137	197
Somerville	77,236	1898	1930	1896	140	303
Holyoke	57,730	1873	1939	1964	114	267
Brockton	56,878	1904	1942	1894	134	332
Malden	44,404	1904	1930	1896	116	306
Haverhill	44,115	1895	1933	1977	140	334
Salem	43,697	1868	1935	1978	130	387
Newton	39,806	1895	1933	1892	220	485
Fitchburg	37,826	1872	1944	1914	148	251
Taunton	34,259	1876	1944	1950	149	425
Everett	33,484	1898	1930	1896	106	.
Quincy	32,642	1899	1930	1899	135	.
Chelsea	32,452	1898	1930	1896	94	279
Pittsfield	32,121	1890	1934	1901	152	.
Waltham	27,834	1873	1949	1892	126	.
Brookline	27,792	1915	1918	1892	320	.
Chicopee	25,401	1932	1932	1971	94	.

Note: Data are presented for the 25 metropolitan areas with 25,000 or more people in 1910.