Measuring Infrastructure in the Bureau of Economic Analysis National Economic Accounts

Authors Jennifer Bennett, Robert Kornfeld, Daniel Sichel and David Wasshausen*

Contact Jennifer.Bennett@bea.gov

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Abstract Infrastructure provides critical support for economic activity, and assessing its role requires reliable measures. This paper provides an overview of U.S. infrastructure data in the National Economic Accounts. After developing definitions of basic, social, and digital infrastructure, we assess trends in each of these categories and their components. Results are mixed depending on the category. Investment in some important types of basic infrastructure has barely or not kept up with depreciation and population growth in recent decades, while some other categories look better. We also show that the average age of most types of infrastructure in the U.S. has been rising, and the remaining service life has been falling. This paper also presents new prototype estimates of state-level investment in highways, highlighting the wide variation across states. In addition, we present new prototype data on maintenance expenditures for highways. In terms of future research, we believe that deprecation rates warrant additional attention given that current estimates are based on 40-year old research and are well below those used in Canada and other countries. We also believe that additional creative work on price indexes for infrastructure would be valuable. Finally, all of the data in this paper are downloadable, and we hope that the analysis in this paper and the availability of data will spur additional research.

Keywords infrastructure, digital infrastructure, social infrastructure, depreciation rates, service lives, highway, repair and maintenance

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** Bennett, Kornfeld, and Wasshausen, U. S. Bureau of Economic Analysis (BEA); Sichel, Wellesley College and the National Bureau of Economic Research (NBER).* *This paper is part of the National Bureau of Economic Research Economics of Infrastructure Project, supported by the Smith Richardson Foundation The views expressed in this paper are solely those of the authors and not necessarily those of BEA, the Department of Commerce, or NBER. For useful comments and discussions, we thank the editors of this volume, Peter Henry, Shane Greenstein, other participants in the NBER's Economics of Infrastructure Conference in November 2019, and Barbara Fraumeni. We also thank Michael Cusick at BEA for his assistance.*

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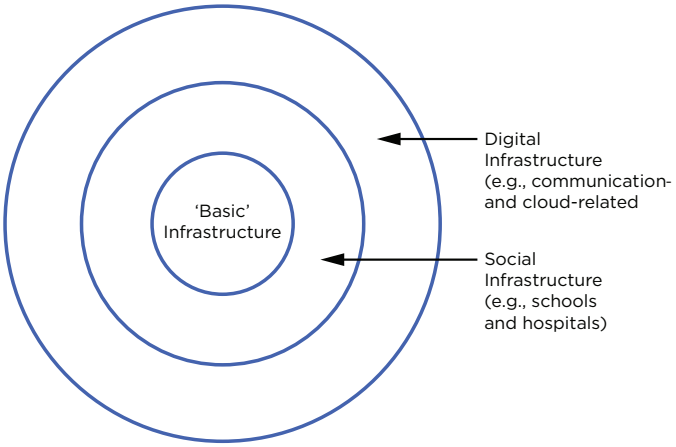
1. Introduction

Infrastructure provides critical support to the economy and contributes importantly to living standards; assessing its role in the economy requires defining and measuring it.[1] That latter task, defining and measuring infrastructure, is the topic of this paper. We focus on the measurement of infrastructure in the U.S. National Economic Accounts (NEAs) to highlight the availability of these data and to gauge trends in recent decades. In particular, we ask if investment in infrastructure by the public and private sectors (and the associated capital stocks) has kept up with key measures, such as population and gross domestic product (GDP).[2] Assessing these trends is particularly valuable given ongoing changes in the nature of infrastructure as networks, connectivity, alternative-energy infrastructure, and digital and intangible infrastructure have become increasingly important and the focus of policy debates.

We begin with the challenging question of the definition of infrastructure. Defining the economic boundaries of "infrastructure" is imprecise and somewhat subjective. We consider three broad categories of infrastructure that can gauge different aspects of infrastructure from a national accounts standpoint. "Basic" infrastructure (for example, transportation and utilities) reflects a traditional definition of infrastructure. From there, we expand that core to include additional economic activity that would potentially be included in infrastructure, including social and digital infrastructure.[3] Chart A below illustrates this idea of basic or core infrastructure surrounded by broader concepts of infrastructure. Moreover, within each of these types, some infrastructure is owned by the public sector and some by the private sector.

Chart A. Basic Infrastructure



1. In a classic paper, Aschauer (1989) argued that government infrastructure was a key determinant of aggregate productivity growth in the United States from 1949 to 1985. While the empirical magnitude of the effect has been a subject of debate (see Fernald 1989), the basic idea stands that infrastructure is an important economic input. Munnell (1992) also highlights the important role of infrastructure.

2. The data developed and discussed in this paper are available in downloadable spreadsheets to enhance opportunities for further research.

3. As noted below, an interesting further extension would include a wide range of intangible infrastructure. Research and development (R&D) and more extensive coverage of software could be contemplated within the current asset boundary of the national accounts, while extensions to a wider set of intangible assets would require expanding the asset boundary in the accounts. For a discussion of public intangibles, see Corrado, Haskel, and Jona-Lasinio (2017).

After providing details on this framework for defining infrastructure, we describe the methodologies and the source data used by the Bureau of Economic Analysis (BEA) to estimate U.S. infrastructure investment, depreciation, and net stocks.

With definitions in hand, we consider different metrics for gauging levels and trends of U.S. infrastructure. In addition to measures for overall infrastructure, we will consider infrastructure by broad category, by detailed type, and by public or private ownership. Our data analysis covers the following topics, with our main conclusions briefly summarized here as well.

Investment and capital stocks

- In terms of the composition of infrastructure stocks, the share of gross investment in basic infrastructure out of all infrastructure has fallen since the late 1950s, while the shares of social and digital infrastructure have increased. For net capital stocks, the share of basic infrastructure has fallen while the share of social has risen.
- In terms of ownership, the share of the infrastructure capital stock that is publicly owned (both state and local) has increased since the late 1950s, while the privately- owned share has fallen. An important contributor to the decline in the private share is the huge drop in the investment share of privately-owned railroads.
- Gross real investment in infrastructure has trended up for most types of infrastructure, although patterns are widely mixed across asset types. These data highlight the resources devoted to different types of infrastructure each year and provide a useful overview of trends. These data also are closest to the source data before translation into net investment or capital stock measures (which rely on estimates and assumptions about depreciation).
- Regarding trends in the budget resources devoted to infrastructure, gross real investment per capita has gently drifted up since the early 1980s. However, depreciation has absorbed a rising share of that investment and real net investment per capita has barely risen.
- Growth rates of real net capital stocks per capita also provide a metric for assessing how well infrastructure investment has kept up. This metric is particularly interesting because of its connection to measures of the contribution of capital to productivity growth. For this metric, the real net stock of basic infrastructure per capita has been soft for a long time, running below a 1 percent pace. For social infrastructure, this metric rose at more than a 2 percent pace during the 2000s, but since the financial crisis its growth rate has been around just 1 percent. The growth rate of the real net stock of digital infrastructure per capita has been much higher than that of other types of infrastructure though it has been quite volatile. It is difficult to draw strong conclusions from these charts, though infrastructure investment certainly has, in general, not been growing rapidly (with the exception of digital infrastructure, some categories of electric power, medical equipment, and a few other categories).

State-level data. As interesting as national measures of infrastructure are, infrastructure is built in a specific region and has specific benefits for that region. In addition, the geographic distribution of infrastructure obviously carries considerable political salience. However, the national accounts do not, in general, include information on regional breakdowns of infrastructure. To get some visibility into the geographic distribution of infrastructure, we present new prototype measures on highway investment by state.[4] These estimates show that investment per capita and as a share of GDP has varied dramatically across states. Interestingly, the state-by-state rankings have tended to be relatively stable since 1992 (when our state-level data begin).

Depreciation rates, service lives, and the age of the infrastructure stock. This paper also reviews the methodology and estimates used for calculating depreciation rates, service lives, ages, and remaining service life for infrastructure assets. Regarding depreciation, the rates used in the national accounts for infrastructure assets were developed about 40 years ago. In addition, even at that time, the information set used for developing estimates of depreciation was relatively thin. It is an interesting question as to whether depreciation rates have changed over that period, although international comparisons raise the possibility that new research would generate different estimates.

On the age of the stock and remaining service life, the average age of the publicly-owned basic and social infrastructure stock in the United States has increased quite noticeably in recent decades and remaining service life of infrastructure assets has been falling. Moreover, average ages of stocks in the United States are often above those in Canada and have followed a different trend. While ages have increased in the United States, the average age of comparable types of infrastructure in Canada has decreased during the past 10 years.

Maintenance expenditures. Regarding depreciation and maintenance, a host of interesting issues are raised by the fact that maintenance expenditures and new investment can sustain the service flow from some types of infrastructure for many years.[5] To push forward on issues related to maintenance expenditures; we present new prototype data for maintenance expenditures for highways. These maintenance expenditures have amounted to about 15 percent of gross investment in highways, running a bit below that chart from the late 1990s through about 2011 and above that chart since then.

Prices. This paper also reviews trends in price deflators and quality change for infrastructure assets. Prices of infrastructure increased more rapidly than GDP prices in the first part of the sample (1947–1987), but more slowly than GDP prices since 2000. Since 2010, overall infrastructure

4. We use the term prototype here to denote that neither these estimates, nor the methods used to prepare them, have been approved by BEA for official publication. The same qualification applies to new data on maintenance expenditures described below.

5. See Diewert (2005) for a model in which maintenance expenditures sustain the service flow from an asset.

prices have changed little, a pace noticeably below that for GDP prices. The softness in infrastructure prices since the financial crisis reflects a stepdown in rates of increase for basic and social infrastructure. Within social infrastructure, prices for health care infrastructure have fallen since 2010, owing largely to declines in quality-adjusted prices for medical equipment.

Our final conclusions focus on methodology and directions for future research. First, as we highlight below, estimates of depreciation rates warrant a fresh look. Second, price deflators for some categories of infrastructure are based on cost indexes, which may not fully reflect quality improvements and productivity gains. Third, we note that in some cases, relevant data are not granular enough to isolate digital infrastructure assets of interest, suggesting that greater granularity would be valuable. Fourth, we believe that development of additional data on regional estimates and for maintenance expenditures would be valuable. Finally, we believe much could be gained from additional international comparisons. The UK Office for National Statistics is actively engaged in international comparisons of infrastructure across Europe and has issued a series of interesting reports presenting their results.[6] Of course, we are not the first to make these methodological observations, and the problems are challenging. Some creativity and novel data likely are the key to progress in these areas.

This paper is organized as follows. Section 2 describes our definitions of basic, social, and digital infrastructure, and section 3 describes the methodologies and data used by BEA in its estimates of infrastructure investment, net capital stocks, depreciation rates, and prices. Section 4 turns to analysis of the data, highlighting both recent and longer-term trends. At the beginning of section 4, we provide a roadmap of the different metrics we examine and the broad questions our analysis speaks to. Section 5 concludes and offers our thoughts on directions for future research.

Please note that most of the tables and charts referred to in this document are located in the appendix.

6. These reports prepared by United Kingdom's Office for National Statistics are available online here: First article, July 2017; Second article, August 2018; Third article, May 2019.

2. Defining infrastructure

Defining infrastructure is not a precise science and is prone to subjective analysis. Henry Cisneros, former Secretary of Housing and Urban Development, defined infrastructure capital as the structures and equipment that comprise "the basic systems that bridge distance and bring productive inputs together" (Cisneros 2010). These systems or elements of them often are shared and can have characteristics of public goods—for example, the interstate highway system—though infrastructure also can be excludable and rival public goods (for example, a toll road suffering from congestion).

One preliminary issue for implementing any definition of infrastructure is deciding whether to categorize by type of asset or by private industry or by government function. In this paper, we categorize by asset type; for example, we consider specific assets providing transportation rather than the total capital stocks used in various industries providing transportation services. We believe this classification provides sharper focus for analyzing recent trends in infrastructure by keying in on specific assets that may have grown rapidly or slowly relative to other economic trends. In addition, this asset-type approach lines up more closely with available estimates of depreciation rates and prices in the NEAs.

Turning to our specific definitions, our 'basic' measure of infrastructure is largely consistent with Cisneros' concept. In particular, we define "basic" infrastructure to include those asset- types, both structures and equipment, related to power, transportation, water supply, sewage and waste disposal, and conservation and development (dams, levees, sea walls, and related assets). Expanding our definition from basic (or core) infrastructure, we consider social infrastructure, including assets such as public safety facilities, schools, and hospitals. Our final expansion from basic infrastructure brings in digital infrastructure, assets that enable the storage and exchange of data through a centralized communication system.

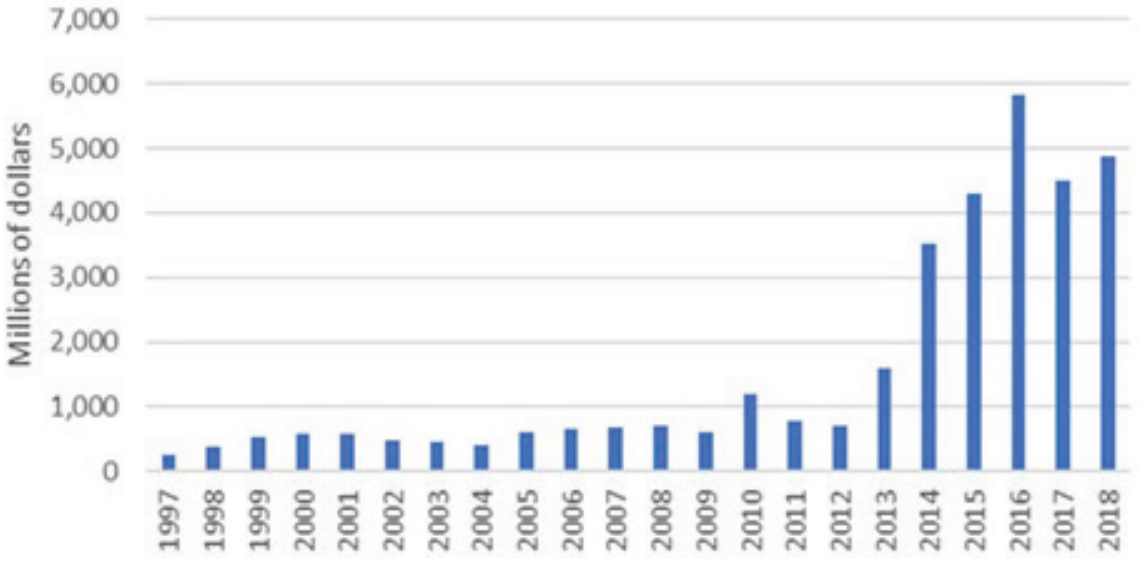
Digital infrastructure is particularly challenging to define, both because much of it represents new and evolving technologies and because, in some cases, the national account data are not sufficiently granular to separately identify assets of interest. Moreover, deciding what portion of specific assets to allocate to digital infrastructure raises challenging issues. For example, the equipment and software providing wireline and wireless access to the internet could, in principle, be counted as part of cloud computing infrastructure and therefore included in a measure of digital infrastructure. However, these assets are also used for other purposes. Perfectly dividing these assets and sorting out these issues may be impossible.

Despite these difficulties, we forge ahead and propose a definition of digital infrastructure, with the understanding that it likely will evolve as additional research and data work allow further refinement. Our definition includes pieces that are identifiable in the national accounts and that we believe would unambiguously be considered infrastructure. In particular, we include all

private communication structures—for example, cell towers—as well as computers, communications equipment, and software owned by the broadcast and telecommunications industries (North American Industry Classification System (NAICS) 515 and 517) and by the data processing, internet publishing, and information services industries (NAICS 518 and 519).[7] This latter category should include the equipment and software within data centers.

The assets described in the last paragraph cover an important part, but by no means all, of what would be thought of as the infrastructure supporting the internet and cloud computing. One important category that is missing is the structures component of data centers. (As described above, we believe we are capturing the equipment and software within data centers.) As strange as this may sound, these structures likely fall within the "office" category of commercial construction but are not currently broken out as a separate line item so cannot be directly quantified. Nevertheless, collateral evidence points to extremely rapid growth in these types of structures. As shown in the chart below, office construction for establishments classified in NAICS 518 and 519 (data processing, hosting, and related services and other information services) surged dramatically after 2012, timing that is roughly consistent with a boom in data center construction. While this category includes office structures unrelated to data centers and that we would not want to include in our definition, the surge strongly suggests that data centers are a big growth category. With some further work, it may be possible to isolate the data center piece of this category and include it in a definition of digital infrastructure.

Chart B. Office Buildings Construction, Owned by NAICS 518 and 519



7. Our definition of digital infrastructure explicitly excludes servers owned by private firms outside of NAICS 518 and 519. If such a firm in the auto industry, for example, transitioned most of its computing from private servers to Amazon Web Services, then the private server that is being transitioned away from (and not replaced) would be out of scope in our definition while the server run by Amazon would, in principle, be in scope in our definition. The logic of this outcome is that the firm is transitioning from utilizing a privately used asset to a shared digital "infrastructure" asset.

Returning to the big picture, note that one category of infrastructure that we largely omit is intangible infrastructure (except for selected software). Within the framework of the national accounts, we did not develop a methodology for splitting R&D into infrastructure and noninfrastructure components. In principle, this split could be done. Moreover, if the asset boundary in the national accounts were expanded to include a wider set of intangible assets, then it would be possible to include a wider set of intangible infrastructure in a definition.[8]

To provide some quick intuition for the size of our defined categories, the right three columns of table 1 report net capital stock shares for types of basic, social, and digital infrastructure (and components) out of total infrastructure for 1957, 1987, and 2017.[9] These shares demonstrate the declining role of basic infrastructure and the greater role of social and digital infrastructure over the past 60 years. Table 2 provides detailed examples for the components of infrastructure.

8. See Corrado, Haskel, and Jona-Lasinio (2017) for an examination of public intangibles.

9. We report shares starting in 1957 even though our data reach back earlier. We begin in 1957 to avoid volatility related to the aftermath of the second World War.

3. Source data and methodology used for estimating investment, net capital stocks, and depreciation

The data for this paper are from BEA's capital accounts, also known as the fixed assets accounts (FAAs).[10] BEA produces the U.S. National Income and Product Accounts (the NIPAs, or national accounts) and is perhaps best known for the estimates of current production income—gross domestic product (GDP) and gross domestic income (GDI).[11] As part of its work to produce GDP and GDI, BEA also produces the FAAs, which provide estimates of depreciation and capital stocks for many types of private and government fixed assets used in production. These data exist from 1925 to the present.

More specifically, private and government gross investment (also known as capital investment or gross fixed capital formation) in the NIPAs and FAAs refers to additions and replacements to the stock of fixed assets without deduction of depreciation.[12] Fixed assets are produced assets that are used repeatedly in production for more than one year. Fixed assets include structures (buildings and other generally immobile assets such as cables, pipelines, and roads), equipment (such as computers and communications, industrial, and transportation equipment), and intellectual property (software, research and development, and entertainment originals). The FAAs report investment (as a component of GDP) as well as economic depreciation or consumption of fixed capital (as components of GDP and GDI). Economic depreciation is defined as the decline in the value of stock of these fixed assets due to normal physical deterioration and obsolescence. The FAAs also report net capital stocks of fixed assets, reflecting the accumulation of previous investment less accumulated depreciation. These statistics are reported in nominal and in inflation-adjusted (real, or chain) dollars for over 100 types of government and private fixed assets, for the entire economy, for about 70 industries, and for several "legal forms of organization," such as corporations, partnerships, sole proprietorships, and nonprofits.

The FAAs' comprehensive national statistics on investment, depreciation, and capital stocks are widely cited and have several purposes. Net investment—investment less depreciation—is a useful measure of the extent to which investment adds to the capital stock rather than merely replacing stock lost to depreciation.

10. BEA's main webpage is www.bea.gov. For the FAAs, see https://apps.bea.gov/iTable/index_FA.cfm

11. GDP, a measure of current period production, is the sum of personal consumption expenditures (spending by households and nonprofits), gross private domestic investment, the change in private inventories, net exports of goods and services, and government consumption expenditures and gross investment. GDI, which is theoretically equal to GDP but can differ because of measurement challenges, equals the sum of employee compensation, corporate profits, the income of sole proprietors and partnerships, net interest and some other income sources from current production. For more information see the NIPA handbook.

12. Estimates of fixed investment in the FAAs and in GDP are very similar; minor differences are presented at https://apps.bea.gov/iTable/index_FA.cfm, see "Relation of the NIPAs to the Corresponding Items in the FAAs."

The FAAs are used in several ways. In the Integrated Macroeconomic Accounts (IMAs), produced jointly by BEA and the Federal Reserve Board (FRB), the value of stocks of fixed assets are entries in the balance sheets of major sectors of the U.S. economy, such as households, government, and nonfinancial corporations. Rates of return of capital investment and q ratios presented by BEA and others are based on BEA's estimates of net stocks.[13] The FAAs also are used for the estimates of multifactor productivity (MFP) produced by the Bureau of Labor Statistics (BLS) and BEA's industry-level production account.[14] Finally, and most germane to this paper, because a subset of the assets in the FAAs are within our definition of infrastructure, these data can be used to gauge investment and capital stocks of different types of infrastructure and to examine their long-term trends.

3.1 Methodology

In the FAAs, inflation-adjusted (real) net stocks and depreciation of fixed assets, including infrastructure, are calculated for each type of asset using the perpetual inventory method (PIM). Under the PIM, the real net stock of each asset type in a year equals last year's real net stock plus the cumulative value of real fixed investment through that year, less the cumulative value of real depreciation through that year, less "other changes in the volume of assets" (mainly damage from major disasters). Real economic depreciation (consumption of fixed capital (CFC)) for most assets is estimated as a fixed percentage of the net stock (geometric depreciation).[15] The PIM can be expressed as:

$$K_{jt} = K_{j(t-1)} (1 - \delta_j) + I_{jt} (1 - \delta_j / 2) - O_{jt}$$

where:

K_{jt} = real net stock for year *t* for asset type *j*

δ_j = annual depreciation rate for asset type *j*

I_{jt} = real investment for year *t* for asset type *j*

O_{jt} = other changes in volume of assets for year *t* for type *j* (often small or zero)

13. See the NIPA handbook for more information on the uses of CFC in the NIPAs. For a description of the IMAs, see Yamashita (2013). The IMAs can be found here. Rates of return may be calculated as net operating surplus (a measure of business income net of depreciation) as a share of the stock of fixed assets. q ratios are calculated as the ratio of financial-market valuation of corporate assets to the current-cost value of fixed assets. BEA produces an annual article on rates of return of fixed investment and q ratios; see Osborne and Retus (2018) here.

14. For estimates of and background on the BLS MFP estimates, see here. Note that these estimates rely on BEA's investment data but BLS estimates its own measures of capital stocks, which are generally similar to BEA's FAAs but use slightly different depreciation rates. For the BEA industry-level production account, see here.

15. Investment in the current year is depreciated using half the annual depreciation rates, under the assumption that investment occurs throughout the year. Price indexes used for investment and depreciation reflect the average price of the asset over the investment period, whereas price indexes used for stocks reflect the price of the asset at the end of the period. BEA constructs end of period prices using moving averages of the average period prices.

The PIM can be rewritten as

$$K_{jt} = K_{j(t-1)} + I_{jt} - O_{jt} - M_{jt}$$

where:

$$M_{jt} = K_{j(t-1)}\,\delta_j + I_{jt}\,\delta_j / 2$$

= real depreciation for year t for asset type j
(also known as CFC)

Real estimates of fixed investment are, for almost all assets, obtained by dividing estimates of nominal investment by a price index. The prices used for the FAAs are generally the same prices used for estimates of fixed investment in GDP. Once the real net stocks are estimated using the PIM, current-cost net stocks are estimated by multiplying real net stocks by corresponding end-of-year price indexes (we refer to this as "reflating"). For example, the current-cost estimate of the net stock for 2018 is an estimate of the replacement cost or market value of the stock at the end of 2018. Similarly, current-cost depreciation or CFC is estimated by reflating real CFC with corresponding average year price indexes. At the end of 2018, the estimated current-cost value of total private and government net stocks of fixed assets was about $63 trillion, and depreciation was about $3.3 trillion.

The accuracy of these estimates depends, as the equation implies, on the accuracy of estimates of investment, depreciation, and prices. The FAAs may, for example, overstate net stocks if the NIPAs overstate fixed investment or understate depreciation. For many types of structures, annual depreciation rates can be well below 5 percent, so that the current stock includes slices of investment from decades earlier and errors in depreciation rates can result in significant biases in the amount of older assets included in the net stock.

Regarding the role of prices, estimates of both real and current-cost net stocks of assets in any year are sensitive to changes in these prices and to any errors in price measurement. For example, if price indexes fail to accurately capture quality change and are biased, then real investment would be misstated and therefore estimates of real stocks built up from these investment flows would be biased. In addition, given the reflation procedure used to estimate current-cost net stocks, mismeasurement of prices also will bias estimates of the current-cost stocks.[16]

16. The effects of price mismeasurement on real investment and current-cost stock reflation generally will not be exactly offsetting. The effect on real net stocks via real investment reflects mismeasurement of prices in past years, while the effect on current-cost stocks via reflation reflects mismeasurement of prices in the single year of prices used for reflation.

Despite these challenges, the FAAs provide perhaps the best available comprehensive estimates of investment and stocks of U.S. infrastructure-related assets. The rest of this section of the paper describes the methodology for estimating fixed investment, depreciation rates, and prices in greater detail.

3.2 Data sources for investment

In BEA's FAAs, the current-dollar fixed investment statistics that serve as the foundation for the net stock estimates are generally the same as the fixed investment statistics that are part of BEA's estimates of GDP. These estimates rely on a wide and comprehensive range of source data. Most infrastructure assets in this paper are classified as structures. For structures, current-dollar investment in private and federal government nonresidential fixed investment is primarily based on detailed value-put-in-place (VIP) data from the Census Bureau's monthly survey of construction spending.[17] Investment in state and local government structures is largely based on the 5-year Census of Governments (COG) and the annual Surveys of State and Local Government Finances (GF), with the Census VIP data used to extrapolate estimates for the months and years before the next round of GF data are available.[18]

In these surveys of investment in structures, the value of construction put in place is defined as the value of construction installed at the construction site during a given period, regardless of when the overall project was started or completed, when the structure was sold or delivered, or when payment for the structure was made. For an individual project, construction costs include materials installed or erected, labor (both by contractors and in-house), a proportionate share of the cost of construction equipment rental, the contractor's profit, architectural and engineering services, miscellaneous overhead and office costs chargeable to the project on the owner's books, and interest and taxes paid during construction. This "sum of costs" estimate of investment does not reflect the eventual selling price of the asset, which may be above cost in a strong market or below cost in a weak market.

The category "construction" includes the following items:

- New buildings and structures;
- Additions, alterations, conversions, expansions, reconstruction, renovations, rehabilitations, and major replacements (such as the complete replacement of a roof or heating system);
- Mechanical and electrical installations, such as plumbing, heating, elevators, and central air conditioning equipment; and
- Site preparation and outside construction of fixed structures or facilities.

17. For more information on the Census Bureau's construction statistics, see https://www.census.gov/construction/c30/definitions.html.

18. For more information on NIPA measures of fixed investment, see the "NIPA Handbook of Concepts and Methods of the U.S. National Income and Product Accounts" chapters 6 and 9.

Construction costs and BEA's estimates of fixed investment in structures exclude the cost of land and the cost of routine maintenance and repairs. Investment reflects only the construction of new assets and excludes the purchase of already existing assets.[19]

Our definitions of infrastructure also include some equipment and software categories. For private equipment, such as computers and communications, medical, and electrical transmission and distribution equipment, BEA's estimates are prepared using the commodity-flow method. This method begins with a value of domestic output (manufacturers' shipments) based on data from the quinquennial Economic Census and the Annual Surveys of Manufacturers. Next, the domestic supply of each commodity—the amount available for domestic consumption—is estimated by adding imports and subtracting exports, both based on the Census Bureau's international trade data. The domestic supply is then allocated among domestic purchasers—business, government, and consumers—based on Economic Census data. Investment in equipment by state and local governments is also based on the commodity-flow method, relying on these same data sources and the COG and GF data. Investment in equipment by the federal government is based on data from federal agencies.

Estimates of investment in private purchased software are based on industry receipts data from the Economic Census and Census Bureau's Service Annual Survey. The estimates for own-account software are measured as the sum of production costs, including the value of capital services (which includes depreciation). The estimates are based on BLS data on occupational employment and wages, on Economic Census data, and on BEA-derived measures of capital services. For the estimates of infrastructure for the digital economy, the share of investment allocated to the relevant subset of industries we identified above is based on industry shares of purchases of fixed investment reported by the Census Bureau's Annual Capital Expenditures Survey and the Information and Communication Technology Survey.

3.3 Capital improvements versus maintenance and repairs

One of the challenges of measuring fixed investment is distinguishing between capital improvements (which are part of investment) and maintenance and repairs (which are not). The *2008 System of National Accounts* (*2008 SNA*)[20] defines fixed assets as produced assets that are used repeatedly or continuously in production processes for more than one year. Moreover, fixed

19. One complication to the exclusion of sales and purchases of existing assets is the transfer of assets between the private-sector and the government. For example, if the government sells a building to a private business, that transaction would count as an addition to the private-sector capital stock and a subtraction from the government's capital stock. BEA estimates the net value of these purchases/sales using data from other government sources.

20. The *2008 SNA* refers to an agreed upon set of international standards for the NEAs. For more information on the 2008 *System of National Accounts*, see https://unstats.un.org/unsd/nationalaccount/sna2008.asp.

investment (gross fixed capital formation in the *2008 SNA*) may take the form of improvements to existing fixed assets that increase their productive capacity, extend their service lives, or both.

Distinguishing between capital improvements and maintenance and repairs can be particularly difficult in practice, and the *2008 SNA* (Para. 10.45, 200) acknowledges that "the distinction between ordinary maintenance and repairs that constitute intermediate consumption and those that are treated as capital formation is not clear cut." Quoting the *2008 SNA* further, ordinary maintenance and repairs are distinguished by two features:

- They are activities that must be undertaken regularly in order to maintain a fixed asset in working order over its expected service life. The owner or user of the asset has no choice about whether to undertake ordinary maintenance and repairs if the asset in question is to continue to be used in production.
- Ordinary maintenance and repairs do not change the fixed asset's performance, productive capacity, or expected service life. They simply maintain it in good working order by replacing defective parts with new parts of the same kind.

On the other hand, improvements to existing fixed assets that constitute fixed investment must go well beyond the requirements of ordinary maintenance and repairs. They must bring about significant changes in the characteristics of existing assets and may be distinguished by the following features:

- The decision to renovate, reconstruct, or enlarge a fixed asset is a deliberate investment decision that may be taken at any time, even when the good in question is in good working order and not in need of repair. Major renovations of ships, buildings, or other structures are frequently undertaken well before the end of their normal service lives.
- Major renovations, reconstructions, or enlargements increase the performance or productive capacity of existing fixed assets or significantly extend their previously expected service lives, or both. Enlarging or extending an existing building or structure constitutes a major change in this sense, as does the refitting or restructuring of the interior of a building or ship or a major extension to or enhancement of an existing software system.

The definitions of fixed investment in new construction, improvements, and maintenance and repairs from BEA and the Census Bureau are generally consistent with the definitions prescribed in the *2008 SNA* and, as best as possible, classify capital improvements as investment and maintenance and repairs as current spending. As noted, these criteria are sometimes difficult to implement in practice. Currently, the Census Bureau's nonresidential construction statistics do not separately report spending for new construction or for improvements, complicating efforts to

separately track these expenditures. Nevertheless, we develop estimates of maintenance and repair expenditures for highways, and these are discussed below.

3.4 Price measures

As noted, BEA's estimates of real infrastructure investment (quantities) are derived by deflating nominal investments with corresponding price indexes. BEA's price indexes are chosen to be as consistent as possible with the categories of current-dollar investment, reflecting prices of new investment and improvements and excluding prices of maintenance and repairs and land.

Given the heterogenous nature of many of the infrastructure-related structures (for example, bridges, tunnels, power plants, and hospitals), constructing accurate, constant- quality price indexes for these types of assets presents challenges. Where possible, BEA uses producer price indexes (PPI) published by BLS. However, for many of the infrastructure asset-types, PPIs do not exist and BEA instead uses combinations of input-cost measures and output-cost measures from trade sources and government agencies in an effort to capture productivity and quality changes.[21] Naturally, cost indexes are a second-best approach for estimating prices as they potentially exclude changes in productivity and margins. For infrastructure-related structures, key source data for price indexes are as follows:

- Electric power structures: Weighted average of Handy-Whitman construction cost indexes for electric light and power plants and for utility buildings;
- Other power structures: Handy-Whitman gas index of public utility construction costs;
- Communications structures: AUS Consultants Incorporated telephone plant cost index;
- Highways: Federal Highway Administration composite index for highway construction costs;
- Water transportation: Handy-Whitman water index of public utility construction costs;
- Health care structures: PPI for healthcare building construction;
- Educational and vocational structures: PPI for new school construction;
- Land transportation structures, railroad: Weighted average of (1) BLS employment cost index for the construction industry, (2) Bureau of Reclamation construction cost trends for bridges and for power plants, (3) PPI for material and supply inputs to construction industries, and (4) PPI for communications equipment; and
- Air transportation, land transportation other than rail, all other structures: Unweighted average of Census Bureau price index for new one-family houses under construction and the unweighted average of the Turner Construction Co. building-cost index.

21. For more information, see Lally (2009).

For most equipment categories that we include in infrastructure, BEA relies on detailed PPIs and import price indexes (IPIs) from BLS. These measures control for quality change just as in the noninfrastructure parts of the NEAs. Note that for our purposes of capturing digital infrastructure, the prices for computers, communications equipment, and medical equipment are quality adjusted based on recent research. The price for communications equipment uses the FRB quality-adjusted price indexes for data networking equipment, voice network equipment, data transport equipment, and a weighted composite of wireless networking equipment and cellular phone equipment, in addition to several PPIs and IPIs. The price for medical equipment and instruments uses BEA's own quality-adjusted price indexes for medical imaging equipment and for medical diagnostic equipment, along with several PPIs and IPIs.

The price measures for software also reflect recent research on quality adjustment. The price index for prepackaged software is based on the PPI for software publishing except games, and quality adjustments by BEA. The price index for custom and own account software is a weighted average of the prepackaged software price and of a BEA input-cost index. The input cost index is based on BLS data on wage rates for computer programmers and systems analysts and on intermediate input costs associated with the production of software. This input cost index also reflects a modest adjustment for changes in productivity based on BEA judgment.

3.5 Depreciation rates and service lives

Intuitively, depreciation is an easy to understand concept, capturing the loss in value as a tangible (or intangible) asset ages. In practice, the measurement of depreciation can be complicated by differences in concepts, terminology, and implementation, as reflected in active debates over the years.[22]

The basic underlying idea is that, over time, an asset's value typically will decline reflecting depreciation and revaluation. Depreciation is the loss in value arising from aging, and revaluation is the change in value arising from all factors other than aging. Fraumeni (1997) nicely illustrates the distinction with an example of the price over time of a used car. Differences in the price for a 1-year-old car of a specific make and model in 2018 and of the same make and model car in 2019, when the vehicle is now 2 years old, reflects depreciation. Differences in the price of a 1-year-old car of a specific make and model in 2018 and the same make and model of 1-year-old car 2019 reflect revaluation. (Perhaps gas prices changed making a vehicle more or less attractive to buyers.)

For the NEAs, BEA conceptualizes depreciation as the consumption of fixed capital or a cost of production. Specifically, BEA defines depreciation as "the decline in value due to wear and tear,

22. See Fraumeni (1997) and Diewert (2005) for an introduction to, and discussion of, the issues.

obsolescence, accidental damage, and aging."[23] Assets withdrawn from service (retirements) also count within BEA's definition of depreciation. This definition draws in the pure concept of depreciation described in the prior paragraph as well as a part of revaluation (specifically, obsolescence related to factors other than age).

Prior to 1997, depreciation in the NEAs was calculated on a straight-line basis. Starting in that year, BEA adopted geometric depreciation rates for most assets, including most infrastructure assets. This choice and the estimates adopted were influenced heavily by the work of Hulten and Wykoff (1981a and 1981b) and their analysis of age-price profiles. Their work pointed to geometric depreciation for most assets and provided estimates of depreciation rates.[24]

3.6 Alternative ways to prepare capital measures

While BEA's measures of capital for infrastructure-related assets are high quality and largely follow international guidelines, there are alternative methods that would likely yield different results. As described in section 3.1 above, BEA uses the perpetual inventory method to derive net stocks. For this method to yield high quality, accurate measures, the price indexes, nominal investment estimates, and depreciation profiles must all be high quality. An alternative to the perpetual inventory method that is also used by BEA for selected assets is the physical inventory method. The physical inventory method applies independently estimated prices to a direct count of the number of physical units of each type of asset. The physical inventory method is a more direct approach, but it does require robust, detailed statistics on prices and number of units of new and used assets in the stock of each vintage available. Preparing measures of net stock using this method typically is extremely costly and time consuming. BEA currently uses this method only for automobiles and light trucks, using detailed data on motor vehicle prices and units purchased from private vendors.

Some other alternative measures of capital stock and the services that it provides are estimated by other government agencies. BLS estimates a capital services index, and a corresponding productive capital stock, that is used as a measure of capital input in the estimation of multifactor productivity.[25] The BLS measure of capital services is designed to measure the flow of services provided by capital assets in the production process, similar to the flow of labor hours. BLS estimates the capital service flow using data on investment, rates of deterioration and depreciation of capital, and data on the income of firms utilizing capital.

23. Katz and Herman (1997).

24. BEA deviates from geometric depreciation for assets for which empirical studies have provided evidence of nongeometric depreciation.

25. See BLS Handbook of Methods, Chapter 11 Industry Productivity Measures. https://www.bls.gov/opub/hom/inp/home.htm

Although BLS uses formulas for deterioration that are not strictly consistent with formulas used by BEA for depreciation, the investment, income, and service-life data used by BLS are similar to the estimates presented by BEA, resulting in depreciation rates that are generally consistent with BEA's estimates. Exploring alternative measures of capital services provided by infrastructure-related assets and their effect on multifactor productivity, rates of return, and q ratios is a rich field for future research.[26]

Additional alternative methods exist specifically with respect to how to depreciate these assets. Several models of depreciation are available, including geometric depreciation, straight-line depreciation, and one-hoss shay.[27] As noted above, BEA primarily uses geometric depreciation rates although alternative methods are used for selected assets.

26. See Diewert (2005) for a discussion of some alternatives.

27. For information on differing measures of depreciation under alternative assumptions, see Diewert (2005).

4. Data trends and analysis

In this section, we highlight broad trends in the data and discuss underlying details and methodological questions that are particularly interesting for infrastructure assets. For our main categories of infrastructure—basic, social, and digital—many metrics are available, including gross and net investment in both real and nominal terms, net capital stocks in real and nominal terms, and measures of depreciation. Each of these variables can also be scaled by population, GDP, or some other variable. These different metrics are useful for answering different questions. We are particularly interested in several broad questions and these guide our choice of metrics to present in the paper.

Because we consider several metrics, the following roadmap highlights the subsections that discuss different metrics and focus on different broad questions.

- ***Section 4.1.*** *What are recent and long-term trends in investment for different types of infrastructure?*
- ***Sections 4.1 and 4.2.*** *Has the infrastructure stock kept up with growth in the U.S. population?*
- ***Section 4.3.*** *What do we know about infrastructure investment by state?* The short answer is not so much; to begin to fill this lacuna, we provide new prototype measures of investment in highways by state for 1992, 2002, 2012, and 2017.
- ***Section 4.4.*** *How do U.S. estimates of depreciation rates and service lives compare with those in other countries?* This analysis provides one way of gauging whether U.S. estimates of depreciation and service lives of infrastructure would benefit from additional research.
- ***Section 4.5.*** *What is the age profile of infrastructure?*
- ***Section 4.6.*** *What do we know about the interplay between stocks of infrastructure and maintenance and repair expenditures?* This is a difficult question to answer. To provide some basic insights, we present new prototype estimates of maintenance and repair expenditures for highways.
- ***Section 4.7.*** *What has happened to prices of infrastructure?*

4.1 Investment in infrastructure

Investment

We begin by focusing on trends in real investment. Gross investment highlights the resources (in inflation-adjusted dollars) set aside each year for infrastructure. Net investment indicates how much actually is being added to capital stock each year after accounting for depreciation. We begin with investment measures because these charts represent the raw data that feed into estimates of

net investment and capital stocks; accordingly, these estimates provide a broad overview of the national accounts infrastructure data. (For a broad overview of the data from another perspective, the first three columns of table 1 report real net capital stocks for basic, social, and digital infrastructure and their components for 1957, 1987, and 2017.)

As shown in chart 1 in the appendix, on a ratio scale, real gross investment in total infrastructure rose to about $340 billion in 1968, declined somewhat afterward, and then began to rise again in the mid-1980s, to nearly $800 billion in 2017.[28] Real investment generally dipped or flattened out during recessions. The overall pattern exhibited by total infrastructure investment is roughly mirrored for real investment in many (but not all) other broad categories of infrastructure.

Real investment in basic infrastructure exhibited a similar pattern to the pattern seen for the total category as shown in chart 1. It peaked in the late 1960s, at about $230 billion, and fell in the 1970s and early 1980s. It did not rise appreciably above its late-1960s level until the early 2000s and it has remained fairly flat since then.

Real investment in social infrastructure investment also peaked in the late 1960s at about $100 billion. It fell afterward, resumed rising in the 1980s to about $240 billion in 2008, then fell with the crisis but rose to pre-crisis levels by 2017. Real investment in digital infrastructure displayed a different pattern. It has increased more rapidly than the other categories, with the faster growth particularly notable from the mid-1990s to the present.

To illustrate these broad trends another way, chart 2 shows nominal gross investment shares for basic, social, and digital infrastructure for 1957, 1987, and 2017. Gross investment has shifted away from basic since 1957 towards social infrastructure and more recently, towards digital. Despite this shift in investment shares, chart 3 shows that the shift in nominal net capital stocks has been somewhat less dramatic, with a much smaller rise in the net stock share of digital infrastructure than is evident in investment shares. This pattern reflects the fact that while gross investment has risen dramatically for digital infrastructure, depreciation for these assets is high and thus, stock accumulation has not been as noticeable.

We now turn to a more detailed analysis of trends in real investment in infrastructure.

Basic infrastructure

Trends in the basic category are mainly determined by trends in transportation and power (chart 4). Investment in transportation infrastructure, and in highways and streets (by far the biggest part

28. Fair (2019) also examined trends in infrastructure, highlighting a slowdown after the early 1970s.

of transportation investment) show similar patterns (chart 5). Investment in highways and streets have mostly risen since the end of World War II, reaching $94 billion in 1968, and then fell afterward to about $52 billion in 1982 (except for a brief increase in the late 1970s). Investment in highways then generally rose through 2001, declined through 2013, and since then has risen slightly. Chart 6 provides detail on investment in other components of transportation infrastructure.

Investment in all forms of power-related infrastructure (chart 4) rose to $84 billion in 1973, fluctuated over the next 25 years, and then began rising more noticeably in the late 1990s. Electric power is the largest category, with its details plotted in chart 7. Overall investment in electric power peaked at about $67 billion in 1973, fluctuated unevenly through the late 1990s, and rose very unevenly again, reaching a level of $124 billion by 2016. Investment in electric power structures (other than wind and solar) displays similar trends. The increase in electric power investment since 2000 comes partly from investment in wind and solar electric power structures, which rose sharply since the early 2000s, though its pace of increase has slowed more recently.

Investment in petroleum and natural gas structures and its components (chart 8) are considerably smaller than investment in electric power. Investment in private petroleum pipelines exhibited a sharp peak in the mid-1970s with the energy crisis, and then rose in the mid-2000s as the use of fracking took off. Investment in private natural gas pipelines has been volatile but the underlying trend has been relatively flat since the 1960s.

Water, sewer, and conservation and development (dams, levees, sea walls, and related assets) make up a relatively small share of basic infrastructure. Conservation and development (chart 9) peaked in 1966, then declined, and has remained quite modest in recent years. This will be an interesting category to watch as efforts to mitigate climate change gain traction. Water treatment rose rapidly through the late 1960s, fell back, rose by fits and starts through the early 2000s, and has moved lower since then. Sewer investment rose unevenly through the early 1990s, fell until 2000, and bounced around since then, ending at a level about equal to where it was in the early 1970s. The flat trends during the past two decades in water and sewer seem broadly consistent with the narrative of decaying systems in many municipalities.

These different trends in investment have led to shifts in the composition of capital stocks of basic infrastructure over time (table 1). Generally, net stocks of most types of infrastructure have risen over time because, even with periods of flat and declining investment, stocks tend to increase because depreciation rates for these assets (mostly structures) are low. One notable exception is railroad transportation; the United States had substantial stocks of rail assets at the end of World War II but has had limited additional investment since then as the nation turned to roads, airplanes, and other forms of transportation. As a result, net stocks of railroad assets decreased

markedly over these decades. Over time, the largest increases in real net stocks of basic infrastructure were in highways and streets, electric power structures and equipment, and water and sewer.

These changes in the composition of basic infrastructure also imply changes in the public- private mix of ownership. Trends in the ownership mix depend on trends in total stocks by asset type and on ownership patterns for each type of asset. For many assets, the ownership mix is stable. Highways, water, and sewer assets are mostly or entirely owned by state and local governments. Air and water transportation assets are also mostly owned by state and local governments, and the private share has declined over time. The conservation and development share is mostly federal, although the state and local share grew over time. Power and railroad assets are, on the other hand, mostly or entirely owned by private companies.

Putting these pieces together, the state and local government share has risen over time while the private share has declined, as reported in table 3. The biggest change in ownership occurs for transit investment, with the state and local government share rising over time, and the private share falling. This pattern reflects the decline in stocks of private railroad assets, the shift in transit from private to state and local governments, and the growth in mostly-public air transportation infrastructure. All told, in 2017, state and local governments owned 62 percent of basic infrastructure, while the federal government owned 4 percent and private companies owned 34 percent.

Social infrastructure

Trends in social infrastructure are mainly determined by trends in health, education, and public safety (chart 10). Health related infrastructure investment rose steadily over time, with occasional pauses in recessions; after the financial crisis, investment continued to rise, reaching about $152 billion in 2017. Most of the rise in health investment resulted from increases in investment in equipment, as shown in chart 11, although increases in investment in hospitals and other structures also played a role. The increases in real equipment spending partly reflect BEA's quality adjusted, declining prices for medical equipment.

Investment in education-related infrastructure (chart 12) has followed long up and down waves, rising through the late 1960s, falling back through the early 1980s, rising again through the early 2000s, and then generally drifting lower. The trends mainly result from trends in investment in K-12 school structures by state and local governments, and presumably reflect demographic and budgetary trends. State and local government investment in higher education peaked in 1973, fell afterward, resumed rising in the early 1980s, but has flattened out since then. Private education investment (all grades) reached $11 billion in 1968, then fell and resumed rising in the late 1970s, but began moving lower, on balance, in the early 2000s.

Public safety, a much smaller part of social infrastructure, rose through the 1990s to $11 billion in 1998, but then declined afterward (chart 13). This decline resulted mostly because of declines in investment in correctional facilities by state, local, and federal governments, and by private companies.

Real net stocks of social infrastructure rose substantially over these years, and most of the increase occurred because of increases in education (especially K-12) and health-related stocks (equipment and structures, table 1).

For social infrastructure, the share of privately owned net stock grew over time while the share of state and local government owned stock fell (table 3). The main driver of this shift is the growth of the stock of health infrastructure, which is mostly owned by the private sector.

Digital infrastructure

Investment in digital infrastructure rose from about $25 billion annually in the 1980s to almost $250 billion in 2017 (chart 14). The sharp increase in digital infrastructure since the 1990s arose because of increases in investment in private communications equipment in NAICS 513 and 514 as well as investment in software and computers in these industries. These increases in real investment partly reflect work by BEA and others to quality-adjust the prices of these assets. Interestingly, the pattern of investment in communications structures since the 1990s has been more mixed. This category—which accounted for a modest share of digital investment—includes cell towers but also includes old-fashioned telephone switching structures. Over these decades, the equipment and intellectual property shares of digital infrastructure have increased, while the structures share has fallen.

While the net stocks of these digital assets have increased substantially over time, as one would expect (table 1), the increase in the net stocks and the net stock shares of equipment, software, and computers is perhaps not as rapid as one might expect because depreciation rates for these assets are far higher than the rates for structures. Note that the assets we have classified as digital infrastructure have always been entirely private (table 3).

Net investment per capita

Gross investment gauges the resources devoted to infrastructure in a particular year. However, in terms of how much this investment is augmenting the stock of infrastructure, we must account for depreciation; a sizable slice of infrastructure investment is just covering depreciation. (Recall that to count as investment rather than as maintenance and repair, spending must be for significant improvements rather than just for routine maintenance, which counts as a current expense

rather than investment.) Moreover, as the population increases, demands on infrastructure would, all else equal, likely increase. Accordingly, we pivot to examine real net infrastructure investment per capita.

For total infrastructure, depreciation is sizable and, on a per capita basis, the gap between gross and net investment on a per capita basis in overall infrastructure has widened during the past 20 years, as reported in chart 15. This gap had been growing slowly in earlier decades, but more recently, the divergence opened up more noticeably. Thus, despite gradual increases in real budget resources being allocated to infrastructure (as measured by real gross investment in infrastructure), actual additions to the real capital stock per capita have been considerably weaker.

In terms of the components of total infrastructure, for basic infrastructure (chart 16), real net investment per capita has drifted downward since the financial crisis and stands at its lowest level since the series hit bottom in 1983. For social infrastructure (chart 17), real net investment per capita trended up from the mid-1980s through 2007, but then dropped back considerably after the financial crisis (though with a slight pickup in recent years). For digital infrastructure (chart 18), real net investment per capita trended up noticeably, on balance, since the 1950s, with a pickup in the second half of the 1990s (initial development of the internet), a drop back after 2000, and very rapid growth since then.

4.2 Real net capital stocks per capita

Overview

Another metric for assessing infrastructure is the growth rate of real net capital stocks per capita. Like net investment, this metric focuses on growth of infrastructure that is being used. This metric also can be linked to productivity outcomes. Such growth rates would feed directly into a growth accounting analysis that assessed contributions of infrastructure capital to productivity growth (perhaps adjusted by hours, rather than population, depending on the question being asked). And, of course, a simple one-sector Solow growth model would imply that capital per person should, at least in steady state, grow roughly in line with the growth rate of labor augmenting total factor productivity (TFP). (Multisector Solow models would have differential trends in capital stocks depending on trends in relative prices of different types of capital.) Thus, comparisons of the growth rates of real capital stocks per capita provide a very rough metric for thinking about whether infrastructure is growing rapidly or slowly relative to other economic trends, though such comparisons say nothing about the optimality of a particular growth rate of infrastructure.

Focusing on this metric, the growth rates of real net capital stocks by category are reported in Table A below over selected periods and in chart 19, with growth rates of TFP and real GDP per capita also shown in the table (from the BLS Multifactor Productivity Database[29]).

Table A. Real Net Capital Stock, by Type of Infrastructure
(annual percent change)

	1997–2007	2007–2017
Total	1.2	1.0
Basic	0.6	0.6
Social	2.2	1.2
Digital	3.7	4.5
Memo:		
TFP growth, private business	1.5	0.4
Real GDP per capita	2.1	0.7

The growth rate of basic infrastructure has been steady at a sluggish rate, below that of TFP from 1997–2007 and just barely above the very slow rate of TFP growth that has prevailed since 2007. The growth rate of social infrastructure stepped down considerably since the financial crisis, though with growth rates well above TFP in both periods. Digital infrastructure continues to grow rapidly, even faster in the last 10 years than in the prior 10 years. (In chart 19, note the separate scale on right for digital infrastructure.) We do not draw powerful inferences from these comparisons with TFP growth rates, but it does appear that capital stocks of basic infrastructure have grown slowly over the past 20 years relative to other trends in the economy.

All told, these metrics seem consistent with underinvestment in some key types of infrastructure. While we have not developed a model of optimal infrastructure, we note that Allen and Arkolakis (2019) compare the benefits of additional highway construction to the costs and find large but heterogeneous welfare gains from additional highway construction.

Details for basic, social, and digital

Among the components of basic infrastructure (chart 20), growth rates of the real net capital stock per capita have been quite weak in the past 10 years, except for the power category. Growth rates for water and sewer have been moving lower since 1970; over the last 10 years, they have dropped to about 0, after running at a bit less than 1 percent since the late 1990s. Transportation growth rates have also dropped to about 0, after running at less than 1 percent since the late 1980s; additionally, conservation and development stocks have been falling since about 2000. In these categories, gross investment just has not been enough to keep up with depreciation and population growth.

29. BLS, "Multifactor Productivity Trends 2018," March 20, 2019.

Power infrastructure is the only category that has seen stronger growth since the financial crisis. It is now rising at about a 1.5 percent pace, well above its rather sluggish rate of growth during the 1990s and mid-2000s. Within power infrastructure (chart 21), growth rates of real net capital stocks per capita for electric power have picked up in recent years, reaching 1 to 2 percent, comparable to rates in the 1980s. Recent growth rates come on the heels of a period of essentially no growth from 1990 to 2000. Growth rates prior to the 1980s were in general more rapid, in the 2 to 3 percent range. Growth rates for natural gas and petroleum follow a broadly similar pattern to those for electric power, although the growth rates for natural gas and petroleum are, with just a couple of exceptions, uniformly lower.

Within electric power (chart 22), growth rates of real net capital stocks per capita for wind and solar power structures have been striking (separate scale on the right for this category). (The nominal capital stock of this category was 8.3 percent of the nominal stock of electric power capital in 2017.) These growth rates have been quite volatile, reaching as high as 45 percent over a 3-year period in the late 2000s. Most recently, these rates have come down to about 5 percent. Elsewhere in electric power, electric power structures and electrical transmission equipment have remained quite sluggish in recent decades. Growth rates for turbines and steam engines (equipment used within electric power plants to generate electricity) have risen to about a 3 percent pace in recent years, though growth has been more volatile than those for power structures and transmission equipment.

Within transportation (chart 23), the growth rate of the net capital stock per capita for highways and streets has moved down to about zero percent years after rising at about a 1 percent pace from the late 1980s through the early 2000s.[30] Air transportation had been growing quite robustly from the late 1980s through the early 2000s, but its growth rate also has dropped back more recently to just above zero. Transit has been growing quite slowly since the time of the financial crisis. Real net capital stock per capita of the other category (including water, rail, and some other very small categories) has been falling over the entire period since 1950, dragged down by rail with only a small offset from growth in water transportation infrastructure. Overall, these patterns are consistent with narratives of aging transportation infrastructure that is not keeping up with demographic trends.

Growth rates of the real net stock per capita of social infrastructure are reported in chart 24. Education, the largest category, has been growing very slowly in recent years following a surge in the early 2000s. Perhaps this is not surprising, given actual and projected declines in the school-age population. Within education (chart 25), growth rates for all the major categories (state and local K-12, state and local higher education, and private K-12 and higher education institutions) have

30. For additional analysis of public spending on transportation and water infrastructure see CBO (2018). In addition, Barbara Fraumeni has done extensive work on highway infrastructure. See Fraumeni (1999 and 2007).

followed similar patterns, driven in part by the size of the school-age population. Growth rates for these categories currently range from less than 1 percent to about 1.5 percent.

Health has been growing about 2 percent a year since the mid-2000s, a rather slow pace relative to historical growth rates for this category of infrastructure (chart 24). Within health, growth rates of real net stocks of capital per capita have slowed for most major categories over the past 10 years (chart 26). Growth rates for private hospitals and state and local hospitals have slowed to below 1 percent, as has the growth rate of other health structures (doctors' offices and other nonhospital medical facilities). One exception to this pattern of relatively sluggish growth is in medical equipment (note the separate scale on the right-hand side of the chart). The growth rates for this category have dropped back following a very strong pace in the 2000s, but they remain around 5 percent. Nominal capital stock shares have moved quite noticeably within the health category, as shown in chart 27. The share of private hospitals has risen considerably since 1957, while the share of state and local hospitals has dropped back. The other big shift is for the share of medical equipment, which now accounts for about one-quarter of the stock of health infrastructure.

Public safety is a small share of social infrastructure, but perhaps one that looms large in the public's perception of state and local governments (the share of nominal capital stock within social infrastructure was 2 percent in 2017). The net capital stock for this category has fallen on a per capita basis since the mid-2000s (chart 24).

Turning to digital infrastructure, real net capital stocks per capita for most components of digital have grown very rapidly, as reported in chart 28. (Recall that our definition of digital infrastructure includes private, but not public, assets.) The one exception to rapid growth is private communications structures. After rising at 2 to 4 percent growth rates through the 1990s, growth rates have drifted down and have been near zero in recent years (see left scale of chart 28). (Again, recall that this category includes both newer cell towers as well as structures that once housed now-outdated telephone switching equipment.) Other categories within this graph capture infrastructure used for broadcast and telecom services and for cloud computing. Broadcast and telecommunications is identified by BEA's industry code 513. Isolating cloud computing in the accounts is difficult because of the lack of complete granularity for key categories, but we focus on the BEA industry of data processing, internet publishing, and information services (industry code 514). Hence, to capture digital infrastructure we focus on computers, communications equipment, and software assets in these two industry groups.[31] Computers and software have grown extremely rapidly in recent decades

31. As noted, we ideally would include the structures containing data centers as well as the equipment and software in the data centers. Data centers are likely classified as office structures; however, the data are not granular enough to isolate data centers. Office construction within industries acquiring digital infrastructure jumped after 2012 and has been robust recently, perhaps reflecting, in part, a surge in data center construction. These observations suggest that greater granularity to isolate data centers in the national accounts would be valuable.

(note the right-hand scale in chart 28) and each have been rising about 15 percent a year recently. Infrastructure for communications equipment within industry codes 513 and 514 also has increased quite rapidly in recent decades, increasing at a 10 to 12 percent pace in recent years.

Within digital infrastructure, shares of the nominal net capital stock have shifted notably during past decades, as reported in chart 29. In 1957, communications structures made up close to three-quarters of the category, with private communications equipment in 513 and 514 making up the rest. By 1987, the share of private communications equipment in 513 and 514 had grown to nearly half, with the share of communications structures dropping back to about half. And, by 2017, the explosion in computers and software in industry groups 513 and 514 is evident, with the share of equipment identified specifically as communications equipment in these industries dropping back.

4.3 New prototype measures of highway investment by state

BEA does not currently estimate fixed assets by state or region; however, for this paper, we have developed new prototype estimates of highway and street gross investment (nominal and real) for each state for 1992 through 2017. Highways are a natural place to start developing regional data given that it is the single largest category within infrastructure in the United States, and we believe this effort could be a first step in developing additional regional data on infrastructure.

State shares were derived from state and local outlays of highway capital published in *Government Finances Survey* by the Census Bureau for various years.[32] These shares were interpolated over missing years and then shares for each year-state pair were applied to current- dollar highway (regular and toll combined) gross investment to estimate investment for each state for each year. The price deflator for each state was set equal to the national deflator and chained-dollar real quantities were developed.

We summarize the estimates in state-by-state heat maps, with chart 30 reporting real investment per capita by state for 1992, 2002, 2012, and 2017, and chart 31 showing nominal investment as a share of nominal GDP by state for the same years. We draw the following conclusions from these data.

- The upper Midwest and North Central states (including Iowa, Minnesota, Nebraska, North Dakota, South Dakota, and Wyoming) consistently ranked in the highest quintile for real gross investment per capita for all time periods shown; the same is true for nominal investment as a share of GDP. Perhaps not surprisingly, Allen and Arkolakis (2019) find relatively low welfare benefits from additional highway construction in these states.

32. Due to measurement and timing issues, Census' highway capital outlays do not equal BEA's state and local highways investment. Highway capital outlays from Census were obtained for fiscal years 1993, 1996, 2002, 2009, 2013, and 2016.

- In contrast, many of the states in the western section of the United States—Arizona, California, Colorado, Oregon, and Utah—ranked in the lower quintiles for per capita investment in 2017, although this is a new development for some of these states (for example. Colorado and Utah). Allen and Arkolakis (2019) find large welfare benefits from additional highway construction in California. (They also find very large benefits for additional construction in the greater New York City area.)
- While nominal investment as a share of GDP peaked in the early 2000s for most states, this metric continued to increase from 1992 to 2017 in three states—North Dakota, Pennsylvania, and Vermont.
- For most states, the ranking of real investment per capita by state and nominal investment per GDP by state are very similar; however, this was not the case for New York in 2017. Real highway investment per capita for New York exceeded the national average in 2017 based on a small decrease in population for the state compared to its highway investment; in contrast, nominal investment in these assets as a share of GDP fell below the national average for the year.

4.4 Depreciation rates and service lives

Depreciation rates developed in Fraumeni (1997) largely were adopted by BEA at that time. Table 4 reports the depreciation rates and asset service lives from Fraumeni along with the latest updated estimates from BEA. Rates for infrastructure assets have been updated from Fraumeni only for two asset categories: highways and streets and solar and wind electric generation equipment (which was not included in the 1997 estimates). As can be seen scanning down the table, depreciation rates for basic and social infrastructure assets are quite low, accompanied by long service lives. Typical depreciation rates are in the neighborhood of 2 percent or so a year, with service lives ranging from 40 to 60 years.

As noted, Fraumeni's estimates drew heavily on the work of Hulten and Wykoff. Their work was done in the late 1970s and early 1980s, and these estimates largely are still in use today. Accordingly, the information underlying depreciation rates for most infrastructure assets dates back almost 40 years. While it is possible that infrastructure assets depreciate at similar rates today compared with 40 years ago, this time lapse also points to the desirability of revisiting estimates of depreciation rates.

Moreover, Hulten and Wykoff's estimates of depreciation rates for most infrastructure assets were based on a relatively thin information set. Hulten and Wykoff assigned assets to three categories depending on how much information they had about age-price profiles for each asset type. For Type A assets, Hulten and Wykoff had extensive data available for estimating geometric

depreciation rates. For Type B assets, Hulten and Wykoff had more limited data and so relied on a variety of other studies to estimate depreciation rates. For Type C assets, Hulten and Wykoff had no data available, and they obtained depreciation rates by using information from Type A or Type B assets for which they had more information.

Except for privately-owned hospitals, all infrastructure assets listed in table 4 are Type C assets. Accordingly, these estimates are pieced together based on a variety of estimates for other asset types. Put another way, depreciation rates for infrastructure assets reflect very little direct information about depreciation patterns for these asset types. On reflection, this observation is perhaps not so surprising given that publicly-owned infrastructure or privately-owned infrastructure-like assets trade infrequently, so obtaining prices/valuations of these assets as they age is extremely difficult. Moreover, many of these assets have unique characteristics thereby also making valuation over time difficult.

Cross-country comparisons of depreciation rates

We can gain further perspective on U.S. depreciation rates by comparing them to those in other countries for comparable assets. Table 5 compares U.S. depreciation rates for three types of infrastructure assets (hospitals, schools, and roads) to those for six other countries that also use geometric depreciation rates. These comparisons are based on a study (Eurostat, OECD 2016), and the choice of categories reflects the coverage in that study. For all three asset types, U.S. depreciation rates are at the lower end of the range. Indeed, other than Sweden (where rates match those in the United States), all other countries report higher depreciation rates. Depreciation rates in some countries are more than twice as high as those in the United States.

Specifically, for hospitals and schools, Canada, Japan, and Norway use rates that are more than twice as high as those in the United States. For roads, all other countries (except Sweden) have higher rates than the United States, with Canada's rate being nearly five times higher than the depreciation rate in the United States.

A more detailed comparison with Canada highlights other assets in which Canada uses higher depreciation rates for infrastructure assets. Table 6 reports depreciation rates and service lives for a range of infrastructure assets for the United States and Canada. For both privately-owned and publicly-owned assets, the Canadian rates are uniformly higher. Again, for the assets listed in the table, the Canadian rates are at least more than double those used by the United States.

As noted above, the long amount of time that has passed since U.S. estimates of depreciation rates for infrastructure assets were developed, the relatively thin information set on which these

estimates were based, and the differences between estimated rates in the United States and other countries all point to the desirability of revisiting estimates of depreciation rates for infrastructure assets in the United States.

4.5 Age of the infrastructure capital stock

Another way to assess trends in infrastructure is by reviewing the age of the infrastructure stock. Government infrastructure has aged very dramatically in recent decades, based on the average age of infrastructure as reported in charts 32 to 34 on a current-cost basis.[33] Charts 32 and 33 highlight categories of basic infrastructure, with notable increases for highways and streets, power, and conservation and development. Chart 34 reports social infrastructure ages, showing the rise in average ages of health care and educational infrastructure.[34] For comparison, the black dashed line in those charts plots the average age of private nonresidential structures. These assets have seen a gradual increase in age since about 1990, but to a lesser extent than the stock of government infrastructure.

Interpreting the increase in age for basic and social infrastructure is difficult without a model of optimal age, but the changes certainly are consistent with public narratives of aging infrastructure and investment not keeping up with growing needs as the population grows. To shed further light on these issues, we turn to a metric introduced by Statistics Canada in 2017, a new measure referred to as "remaining useful life ratios." The remaining useful life of a given asset is the difference between the average age and the expected service life. The remaining useful life ratio is simply the remaining useful life divided by the expected service life. The resultant ratio indicates the percentage of the asset class that remains. The closer to zero, the older the asset is relative to its expected service life.[35] We present this new metric for U.S. data as another tool for assessing the overall state of infrastructure. Chart 35 presents remaining useful life ratios beginning with 1950 for basic infrastructure owned by state and local governments. The long-term trend shows that the remaining useful service lives for these asset types have all decreased.

Moreover, while average ages of U.S. infrastructure generally have moved higher in recent decades, average ages of Canadian infrastructure have tended to move lower in the past 10 years. Charts 36 to 38 present comparisons for selected categories for which comparable categories and data were available on an historical-cost basis. As shown for highways and communications structures, the

33. Current-cost age is calculated by tracking for each dollar of each type of capital the amount remaining in the stock each year. With these charts, an average age for each type of capital can be calculated for each year. These ages are then combined for each year to get an overall average age using the current cost for each type of capital in that year.

34. Private digital infrastructure has a short average age (about two years recently for our definition). The average age moved lower from 1990 to 2000, moved back up by 2010, and has been mixed since then (with the age of computers rising and the age of software edging down).

35. For information on Statistics Canada's remaining useful life ratios, see https://www150.statcan.gc.ca/n1/pub/13- 604-m/13-604-m2017085-eng.htm.

average age of Canadian infrastructure has moved lower while the average age of U.S. infrastructure in these categories has moved higher. In contrast, the average age of electric power structures is lower in the United States than in Canada and has moved lower since the mid-2000s.

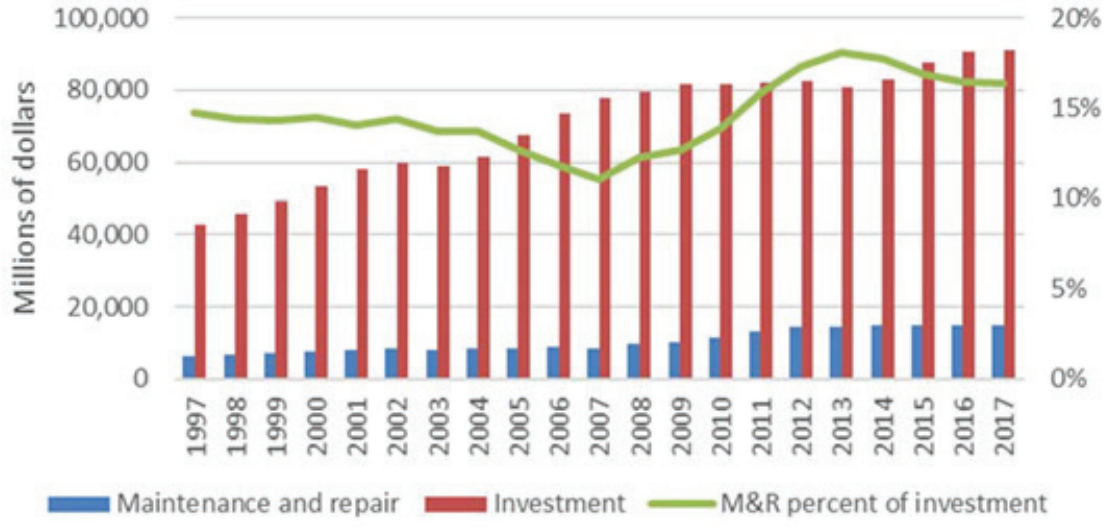
These graphs of average ages must be interpreted cautiously because data limitations make only a partial comparison to Canada feasible. The relevant Canadian data are available only since 2009 and only for select categories for which clean comparisons were possible. In addition, the Canadian data on average age are presented on a historical cost basis, rather than the current-cost basis typically used for U.S. data and that were reported in charts 32 to 34. Ages tend to be lower on an historical cost basis because older assets still in service are aggregated up using long-ago purchase prices which are lower than current prices for many assets.

4.6 Estimates of maintenance and repair

Trends in expenditures for maintenance and repair of infrastructure, while not part of infrastructure investment, may add useful detail to our portrait of infrastructure spending. Although estimates unique to specific infrastructure asset types generally are not available, estimates for state and local expenditures on maintenance and repair on highways and streets can be estimated from BEA's detailed benchmark supply-use tables. Chart C below compares experimental estimates of maintenance and repair expenditures to total gross fixed investment for state and local highways and streets. The green line in the chart is the ratio. This ratio declined from about 13 percent in 1997 to a little less than 10 percent in 2007; since then it has risen to a bit above 15 percent. In future work, we plan to explore the possibility of developing additional estimates of maintenance and repair for other types of infrastructure assets.

Chart C. State and Local Highways and Streets

Maintenance and Repair (M&R) Versus Investment



Estimates of maintenance and repair expenditures could be especially useful for developing richer models of depreciation. For example, Diewert (2005) develops a model in which maintenance expenditures can sustain the service flow from an asset. In his model, retirement decisions become endogenous (rather than a physical feature of an asset) and depend on how long an owner is willing to continue paying maintenance expenditures. Interestingly, Diewert's model still yields a geometric pattern of depreciation though what lies behind that pattern would be more nuanced than in the standard application of geometric depreciation rates.

4.7 Prices

In this section, and in table 7 and charts 39 and 40, we highlight price trends for major categories of infrastructure. Additional charts show trends in some of the more interesting subcategories of infrastructure.

Overall, prices for infrastructure assets have trended more or less in line with GDP prices (chart 39) although infrastructure prices have risen somewhat faster. For the full period analyzed, 1947–2017, infrastructure prices increased 3.6 percent at an average annual rate while GDP prices increased 3.1 percent. Prices of infrastructure increased noticeably more rapidly than GDP prices in the first part of the sample (1947–87), but about in line with GDP prices in the latter part of the sample. However, since 2010 overall infrastructure prices have changed little, a pace substantially below that for GDP prices.

The softness in infrastructure prices since the financial crisis reflects a stepdown in rates of increase for basic and social infrastructure. Within social infrastructure, prices for health care have fallen since 2010, owing to quality adjusted price declines for medical equipment.

Table 7 and chart 40 disaggregate prices of total infrastructure into its basic, social, and digital components. Basic infrastructure accounts for most of total infrastructure, and its prices track overall infrastructure prices reasonably closely, especially in the first half of the period analyzed. In the latter part of the sample (especially since about 2000), prices of basic infrastructure have risen more rapidly than the overall price index. Because basic infrastructure consists mostly of structures, these price trends largely track trends in prices for construction.

- Within basic infrastructure, transportation accounts for the largest share and these prices grow steadily over all four periods analyzed (chart 41). Within transportation, highways and streets are by far the largest component and these prices become volatile and show notable increases beginning in 1970 and continuing into the early 1980s, with an average annual price increase of about 10 percent from 1970 to 1982 (chart 43). Prices are generally more stable from the early

1980s until the latter half of the 2000s, where they begin to increase notably again. Swings in overall construction costs and the price of petroleum byproducts, which are inputs to the construction of highways and streets, could explain some of the variation in prices over time.

These relatively rapid price increases for highways and streets generally line up with those estimated by Brooks and Liscow (2019) for the cost per mile of interstate highway construction. They report that the cost per mile in real terms in 1990 was about three times higher than it was in the 1960s (from about $8 million per mile during most of the 1960s to $25 million per mile in 1990). Although Brooks and Liscow report moving averages over spans of years, if their time periods are converted to span, for example, 1968 to 1990, their implied annual rate of increase is 5.3 percent. Over the same period, the price index in the national accounts for highways and streets exhibits an annual rate increase of 6 percent.

- The second largest component within basic infrastructure is power, which primarily consists of private electric power plants and machinery (chart 42). Prices for electric power infrastructure are relatively flat from 1947 until the early 1970s but since then have grown quite a bit more rapidly.

  - Within the power category, prices for electric power plants show relatively stable increases throughout, although we do observe a slowdown in price increases during the last few years.

    Electric power machinery consists of turbines used to generate electricity as well as the equipment used for transmission and distribution. We observe relatively rapid increases in prices for this machinery from the early 1970s through the early 1990s. We also see an interesting trend in prices tied to increasing shares of imported machinery. In 1992, nearly 90 percent of this machinery was produced domestically, but by 2007 that had dropped to 60 percent, where it remains today. Over this period, prices for imported electric power machinery are consistently lower than the prices of competing domestic machinery, resulting in relatively modest price increases over this period.

Trends in prices for social infrastructure—mostly education and health care—are broadly consistent with trends in prices for all infrastructure prices (charts 40 and 44). Prices for health care infrastructure show a notable slowdown in the latter half of the period falling from 4.6 percent average annual growth for the period 1947–1987 to 1.3 percent for the period 1987–2017; prices decline from 2010–2017 (chart 45). This slowdown and later downturn largely reflect declines in BEAs estimates of quality-adjusted prices for components of electro-medical equipment, including magnetic resonance imaging equipment, ultrasound scanning devices, and CT-scan machinery.[36]

36. For more information, see Chute, McCulla, and Smith (2018).

Trends in prices for digital infrastructure—which consist of communications structures, equipment, and software, and computers—are roughly consistent with trends in prices for all infrastructure until about the early 1990s, when prices for digital infrastructure began to fall markedly while prices for all infrastructure prices continued to increase (chart 46). In the 1947–1987 period, annual growth for digital infrastructure prices was 4.2 percent, primarily reflecting communications structures and equipment prices. From 1987 through 2017, prices declined at an annual rate of 1.3 percent. During this period, prices of all asset types of digital infrastructure experienced slowdowns, with communications equipment (–5.4 percent) and computers (–10.4 percent) exhibiting the largest declines.

5. Conclusion

This paper provides a broad overview of data on U.S. infrastructure from the NEAs. We begin by offering a definition of infrastructure, starting with traditional "basic" infrastructure and then extending that to social and digital infrastructure. With that definition in hand, we review the methodology underlying infrastructure data in the national accounts, provide an overview of available data, and assess the degree to which infrastructure investment has kept up with depreciation and a growing population. This paper also presents new prototype data on investment in highways and streets by state and on maintenance and repair expenditures for highways. In terms of our analysis of trends, different stories and conclusions are appropriate for different categories of infrastructure. For important types of basic infrastructure, the trends in real net investment per capita and growth rates of real net stocks are consistent with narratives of infrastructure investment that has not kept up, or only barely kept up, with depreciation and population growth. Social and digital infrastructure generally look better on these metrics, with variation across categories.

Our state-level data highlight considerable variation in highway spending per capita (or as a share of GDP) across states. In addition, state-by-state rankings have tended to be relatively stable since 1992.

Another view of how well infrastructure investment is keeping up is to consider the average age of infrastructure. Our estimates highlight that for many important assets, the average age has risen in recent decades and the remaining service life of these assets has fallen. These statistics are consistent with widespread narratives about aging and sometimes decrepit infrastructure in the United States.

Our review of trends in prices of infrastructure highlights rapid increases in prices for some types of infrastructure for some periods (such as highways).

In terms of measurement methodology, we highlight that depreciation rates used in the accounts are based on estimates developed roughly 40 years ago and that these estimates are, for many categories, well below those used in some other countries. In addition, price indexes for infrastructure warrant additional attention given that some are based on input cost indexes rather than actual asset prices. Finally, for digital infrastructure, data classifications are sometimes not granular enough to identify relevant assets. Some additional work here also likely would pay dividends.

All the data reported in this paper are downloadable in a spreadsheet, and we hope that the review in this paper and the availability of the data will spur further research on infrastructure.

References

Allen, Treb and Costas Arkolakis. 2019. "The Welfare Effects of Transportation Infrastructure Improvements," National Bureau of Economic Research Working Paper Series no. 25487 (Cambridge, MA: NBER January).

Aschauer, David. 1989. "Is Public Expenditure Productive?" *Journal of Monetary Economics* 23, no. 2 (March):177–200.

Baldwin, John, Huju Liu, and Marc Tanguay. 2015. "An Update on Depreciation Rates for the Canadian Productivity Accounts," Statistics Canada, January.

Brooks, Leah and Zachary Liscow. 2019. "Infrastructure Costs," paper presented at the Summer Institute, July.

Bureau of Economic Analysis. 2003. *Methodology, Fixed Assets and Consumer Durable Goods in the United States, 1925-1997*, (Washington, D.C.: U.S. Government Printing Office, September)

Bureau of Economic Analysis. 2019. *NIPA Handbook of Concepts and Methods*, (Washington, D.C.: BEA December).

Bureau of Labor Statistics. *Multifactor Productivity Trends 2018*, Economic News Release, March 20, 2019.

Chute, Jason W., Stephanie H. McCulla, and Shelly Smith. "Preview of the 2018 Comprehensive Update of the National Income and Product Accounts: Changes in Methods, Definitions, and Presentations," *Survey of Current Business* 98 (April 2018).

Cisneros, Henry. 2010. "America's Essential Infrastructure: A Key to Competitiveness," in *The Handbook of Infrastructure Investing*, ed. by Michael Underhill, (Hoboken, NJ: Wiley & Sons).

Congressional Budget Office. 2018. "Public Spending on Transportation and Water Infrastructure, 1956 to 2017," Report, (Washington, D.C.: CBO October).

Corrado, Carol, Jonathan Haskel, and Cecilia Jona-Lasinio. 2017. "Public Intangibles: The Public Sector and Economic Growth in the SNA," *Review of Income and Wealth* 63, supp. 2, (December): S355–S380.

Diewert, Erwin. 2004. "Measuring Capital," University of British Columbia, Department of Economics, Discussion Paper No.: 04-10, (Vancouver, British Columbia: UBC April). www.econ.ubc.ca

Diewert, Erwin. 2005. "Issues in the Measurement of Capital Services, Depreciation, Asset Price Changes, and Interest Rates," in *Measuring Capital in the New Economy*, ed. by Carol Corrado, John Haltiwanger, and Daniel Sichel, (Boston, MA: NBER and Chicago, IL: University of Chicago Press, August).

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, and World Bank. *System of National Accounts 2008* (New York: 2009).

Eurostat/OECD. 2015. *Eurostat-OECD Compilation Guide on Land Estimation*, (especially Chapter 6.5, "The Importance of Service Lives and Depreciation.")

Fair, Ray. 2019. "U.S. Infrastructure: 1929–2017," mimeo, Yale University.

Fernald, John. (1999), "Roads to Prosperity? Assessing the Link between Public Capital and Productivity," *American Economic Review* 89 no. 3 (March):619–638.

Fraumeni, Barbara. 1997. "The Measurement of Depreciation in the U.S. National Income and Product Accounts," *Survey of Current Business* 77, (July):7–23.

Fraumeni, Barbara. 1999. "Productive Highway Capital Stock Measures," Federal Highway Administration, Department of Transportation report under subcontract to Battelle Memorial Institute, Contract DTFH61-97-C-00010.

Fraumeni, Barbara. 2007. "Productivity Highway Capital Stocks and the Contribution of Highways to Growth in GDP: Volume 1," Federal Highway Administration Department of Transportation report under subcontract to Battelle Memorial Institute, Subcontract No. 208937 to Work Order Bat-03-21.

Giandrea, Michael D., Robert Kornfeld, Peter B. Meyer, and Susan G. Powers. 2018. "Incorporating Canadian Capital Asset Depreciation Rates into U.S. Capital and Multifactor Productivity Measures," Fifth World KLEMS Conference, Cambridge, MA.

Hulten, Charles R. and Frank C. Wykoff. 1981a. "The Estimation of Economic Depreciation Using Vintage Asset Prices." *Journal of Econometrics* 15 (April): 367–396.

Hulten, Charles R., and Frank C. Wykoff. 1981b. "The Measurement of Economic Depreciation." in *Depreciation, Inflation, and the Taxation of Income from Capital*, ed. Charles R. Hulten. (Washington, DC: The Urban Institute Press): 81–125.

Hulten, Charles R., and Frank C. Wykoff. 1996. "Issues in the Measurement of Economic Depreciation: Introductory Remarks." *Economic Inquiry* 24 (January):10–23.

Katz, Arnold J. and Shelby W. Herman. 1997. "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929–95." *Survey of Current Business* 77 (May): 69–92.

Lally, Paul R. 2009. "BEA Briefing: How BEA Accounts for Investment in Private Structures," *Survey of Current Business* 89 (February):11.

Munnell, Alicia H. 1992. "Policy Watch: Infrastructure Investment and Economic Growth." *Journal of Economic Perspectives* 6, no. 4 (Fall): 189–198.

Statistics Canada (Baldwin, John, Huju Liu and Marc Tanguay). 2015. "An Update on Depreciation Rates for the Canadian Productivity Accounts," *The Canadian Productivity Review*, Catalogue no. 15-206-X, January 26, 2015. http://www.statcan.gc.ca/pub/15-206-x/15-206- x2015039-eng.htm

Appendix

Table 1. Real Net Stocks and Nominal Net Stock Shares of Infrastructure

	Real net stocks (millions of 2012 dollars)			Nominal net stock shares (percent)		
	1957	1987	2017	1957	1987	2017
Total	3,603,208	8,456,642	15,359,512	100.0	100.0	100.0
Basic	2,785,755	5,876,110	9,208,860	77.0	65.4	60.9
Water	130,776	316,322	576,355	3.8	3.7	4.0
Sewer	160,315	473,080	759,160	4.5	5.5	5.2
Conservation and development	196,343	352,276	433,687	5.2	4.2	2.8
Power	780,243	1,821,224	2,937,757	23.3	21.6	19.1
Electric	521,995	1,377,501	2,349,967	16.3	17.5	15.5
Wind and solar structures	0	0	205,699	0.0	0.0	1.3
Other structures	428,040	1,079,038	1,500,997	11.1	12.5	10.3
Equipment	65,784	238,263	514,875	4.2	4.1	3.1
Turbines/steam engines	28,171	60,200	128,396	1.1	0.8	0.7
Petroleum	84,184	103,073	162,524	2.3	1.0	1.0
Natural gas	174,064	340,650	425,266	4.7	3.2	2.7
Transportation	1,518,077	2,913,208	4,501,901	40.2	30.4	29.8
Highways and streets	900,093	2,178,097	3,311,203	19.5	20.9	21.8
Air transportation	31,182	121,449	327,523	0.7	1.2	2.2
Rail transportation	504,227	399,894	369,996	17.5	5.9	2.5
Transit	54,001	135,363	366,522	1.8	1.5	2.5
Water transportation	16,065	51,983	89,113	0.4	0.5	0.6
Other transportation	12,509	26,421	12,787	0.3	0.3	0.1
Social	728,874	2,211,426	4,786,118	18.0	26.7	32.0
Public Safety	29,608	140,062	254,038	0.8	1.9	1.9
Education	532,071	1,323,417	2,774,969	12.0	14.1	18.9
Health care	167,194	747,947	1,757,111	5.1	10.8	11.2
Structures	163,227	685,446	1,265,156	4.8	9.2	8.5
Equipment	3,967	62,501	491,956	0.3	1.6	2.7
Digital	88,579	369,106	1,364,534	5.0	7.9	7.1
Structures	84,682	327,975	639,499	3.5	4.0	3.9
Equipment and software in NAICS 513 and 514	3,897	41,131	725,035	1.5	3.9	3.1

Table 2. Infrastructure Component Examples

Basic	
Water	Plant, wells, water transmission pipelines, tunnels and water lines, pump stations, reservoirs, tanks, and towers.
Sewer	Solid waste disposals (incinerator or burial), sewage treatment plants, sewage disposal plants, wastewater disposal plants, recycling facilities, sanitary sewers, sewage pipeline, interceptors and lift/pump stations, water collection systems (nonpotable water), and storm drains.
Conservation and development	Dam/levees—includes non-power dams, dikes, levees, locks and lock gates; breakwater/jetty—includes breakwaters, bulkheads, tide-gates, jetties, erosion control, retaining walls, and sea walls; dredging.
Power	
Electric	
Structures	Power plants (nuclear, oil, gas, coal, wood), nuclear reactors, hydroelectric plants, dry-waste generation, thermal energy facilities, electric distribution systems, electrical substations, switch houses, transformers, and transmission lines.
Equipment	Power, distribution, and specialty transformers; electricity and signal testing instruments.
Gas	Buildings and structures for the distribution, transmission, gathering, and storage of natural gas.
Transportation	
Highways and streets	Pavement, lighting, retaining walls, tunnels, bridges and overhead crossings (vehicular or pedestrian), toll/weigh stations, maintenance buildings, and rest facilities.
Air transportation	Passenger terminals, runways, as well as pavement and lighting, hangars, air freight terminals, space facilities, air traffic towers, aircraft storage, and maintenance buildings.
Water transportation	Includes docks, piers, wharves, and marinas, boatels, and maritime freight terminals.
Rail transportation	
Transit	Maintenance facilities, passenger/freight terminals for buses & trucks.
Social	
Public safety	Detention centers, jails, penitentiaries, prisons, police stations, sheriffs' offices, fire stations, rescue squads, and dispatch and emergency centers.
Education	In addition to all types of schools, includes zoos, arboreta, botanical gardens, planetariums, observatories, galleries, museums, libraries, and archives.
Health care	
Structures	Hospitals, mental hospitals, medical buildings, and infirmaries.
Equipment	Electromedical machinery and medical instruments.
Digital	
Structures	Telephone, television, and radio, distribution and maintenance buildings and structures. Includes fiber optic cable.
Equipment	Internet switches, routers and hubs; cloud computing hardware and software.

Table 3. Private and Public Ownership Shares of Nominal Net Stocks

	Private (percent)			Federal government (percent)			State and local government (percent)		
	1957	1987	2017	1957	1987	2017	1957	1987	2017
Total	51.9	44.9	40.5	6.4	5.2	3.5	41.7	49.8	56.0
Basic	54.3	40.4	33.8	6.9	5.4	3.7	38.8	54.1	62.4
Water	9.7	12.2	9.2	0.0	0.0	0.0	90.3	87.8	90.8
Sewer	8.3	8.5	6.6	0.0	0.0	0.0	91.7	91.5	93.4
Conservation and development	4.4	6.9	7.4	85.2	71.3	61.9	10.3	21.8	30.7
Power	92.5	86.5	87.5	0.2	0.2	0.6	7.3	13.3	11.9
Electric	89.7	83.8	85.3	0.2	0.2	0.8	10.1	16.0	13.9
Petroleum/natural gas	99.0	97.6	96.7	0.0	0.0	0.0	1.0	2.4	3.3
Transportation	48.1	21.6	9.8	2.0	1.7	1.4	49.9	76.7	88.8
Highways and streets	0.0	0.0	0.0	3.0	1.6	1.1	97.0	98.4	98.9
Air transportation	20.9	19.8	11.9	0.0	0.0	0.0	79.1	80.2	88.1
Rail transportation	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Transit	87.7	20.4	2.8	0.0	0.0	0.0	12.3	79.6	97.2
Water transportation	9.3	7.0	6.4	0.0	0.0	0.0	90.7	93.0	93.6
Social	27.8	39.6	40.1	6.3	6.4	3.7	65.8	54.0	56.2
Public Safety	23.4	9.2	8.0	18.7	36.7	24.2	57.8	54.1	67.7
Education	17.5	15.7	18.1	4.2	3.2	1.5	78.2	81.0	80.4
Health care	52.7	76.0	82.8	9.3	5.2	3.7	38.0	18.7	13.4
Digital	100.0	100.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4. BEA Depreciation Rates and Service Lives

	Depreciation rates		Service lives	
	Fraumeni (1997)	BEA (current)	Fraumeni (1997)	BEA (current)
Government (federal, state, and local)				
Buildings				
Industrial	.0285	.0285	32	32
Educational	.0182	.0182	50	50
Hospital	.0182	.0182	50	50
Other	.0182	.0182	50	50
Non-buildings				
Highways and streets	**.0152**	**.0202**	**60**	**45**
Conservation and development	.0152	.0152	60	60
Sewer systems	.0152	.0152	60	60
Water systems	.0152	.0152	60	60
Other	.0152	.0152	60	60
Private structures				
Educational	.0188	.0188	48	48
Hospitals (B)	.0188	.0188	48	48
Railroad replacement track	.0249	.0249	38	38
Railroad other structures	.0176	.0176	54	54
Communications	.0237	.0237	40	40
Electric light and power	.0237	.0211	45	45
Gas	.0237	.0237	40	40
Petroleum pipelines	.0237	.0237	40	40
Wind & solar		**.0303**		**30**
Local transit	.0237	.0237	38	38

Source: Fraumeni (1997) and BEA current estimates: https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf

Table 5. Official Depreciation Rates for Selected Assets (for countries using geometric depreciation rates)

	Hospitals	Schools	Roads
USA	0.0188	0.0182	0.0202
Austria	0.0210	0.0200	0.0300
Canada	0.0610	0.0550	0.1060
Iceland	0.0250	0.0250	0.0300
Japan	0.0590	0.0590	0.0330
Norway	0.0400	0.0400	0.0330
Sweden	0.0188	0.0182	0.0202

Source: Eurostat/OECD, 2016, p. 12.

Table 6. U.S./Canada Comparisons of Depreciation Rates and Service Lives for Selected Infrastructure Assets

	Depreciation rates (percent)		Service lives (years)	
	USA	Canada[a]	USA	Canada[a]
Private structures				
Educational	.0188	.055[b]	48	40[b]
Hospitals	.0188	.061[b]	48	36[b]
Railroad replacement track	.0249	.053[b]	38	27[b]
Railroad other structures	.0176	.056[b]	54	37[b]
Communications	.0237	.128[b]	40	20[b]
Electric light and power	.0211	.058[b]	45	38[b]
Gas	.0237	.066[b]	40	34[b]
Petroleum pipelines	.0237	.078[b]	40	29[b]
Water supply	.0225	.057	40	39[b]
Sewer and waste disposal	.0225	.078[b]	40	29[b]
Wind and solar	.0303	.065	30	34
Local transit	.0237	.075[b]	38	29[b]
Government (federal, state, and local)				
Buildings				
Industrial	.0285	.072[b]	32	25[b]
Educational	.0182	.055[b]	50	40[b]
Hospital	.0182	.061[b]	50	36[b]
Other	.0182		50	
Non-buildings				
Highways and streets	.0202	.106[b]	45	29[b]
Conservation and development	.0152	.076[b]	60	29[b]
Water systems	.0152	.057	60	39[b]
Sewer systems	.0152	.078[b]	60	29[b]
Other	.0152		60	

a The charts for Canada reported for government infrastructure are for the corresponding category of private buildings and nonbuildings. Estimates for Canada are from Giandrea, Kornfeld, Meyer and Powers (2018) unless noted otherwise.

b Estimates from Statistics Canada (2015).

Source: For Canada, Giandrea, Kornfeld, Meyer, and Powers (2018), table 1 and Statistics Canada (2015), Appendix C. For U.S., Fraumeni (1997) and BEA, "BEA Depreciation Estimates," available at https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf

Table 7. Infrastructure Price Indexes, Average Annual Growth Rates
(Percent)

	1947–2017	1947–1987	1987–2017	2000–2017	2000–2010	2010–2017
Gross Domestic Product	**3.1**	**3.9**	**2.1**	**1.8**	**2.1**	**1.4**
Infrastructure	**3.6**	**4.8**	**2.1**	**1.2**	**2.2**	**0.0**
Basic	**4.0**	**4.6**	**3.1**	**3.4**	**4.6**	**1.9**
Water	4.1	4.8	3.1	3.4	4.3	2.3
Sewer	4.1	5.0	3.1	3.4	4.3	2.3
Conservation and development	3.7	4.4	2.9	3.0	3.9	1.9
Power	3.8	4.8	2.6	2.5	3.3	1.6
Electric power	3.7	4.7	2.5	2.3	3.0	1.5
Petroleum/natural gas	4.1	4.6	3.6	4.0	5.4	2.3
Transportation	4.1	4.5	3.5	4.1	5.6	2.1
Highways and streets	4.0	4.2	3.7	4.3	6.1	2.1
Air transportation	4.0	4.2	3.6	3.8	4.8	2.6
Water transportation	4.0	4.2	3.7	3.9	5.3	2.3
Rail transportation	3.8	5.0	2.4	2.0	2.4	1.4
Transit	…	…	2.8	3.4	4.5	2.0
Social	**3.7**	**4.8**	**2.2**	**1.9**	**3.2**	**0.2**
Public safety	3.9	4.5	3.1	3.0	3.0	3.1
Education	4.1	4.7	3.4	3.6	4.9	2.0
Health care	3.2	4.6	1.3	0.1	1.0	–1.1
Digital	**1.8**	**4.2**	**–1.2**	**–3.7**	**–3.9**	**–3.5**
Communications structures	3.1	3.4	2.6	2.9	4.3	1.1
Communications equipment*	–1.1	2.3	–5.3	–7.6	–8.3	–6.8
Communications software*	…	…	–2.0	–1.6	–2.3	–0.7
Computers*	…	…	–10.4	–6.3	–10.2	–1.1

* Includes Communications equipment, software and computers used in the provision of digital services.

Chart 1. Real Infrastructure Investment

[Millions of chained (2012) dollars]

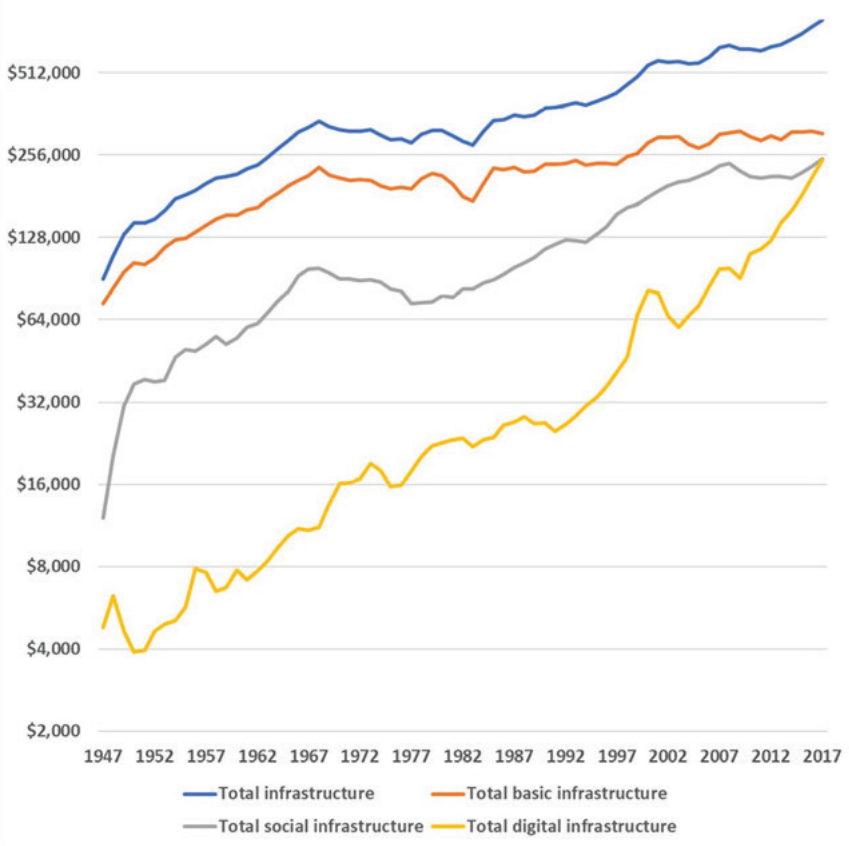


Chart 2. Infrastructure Shares by Type: Investment

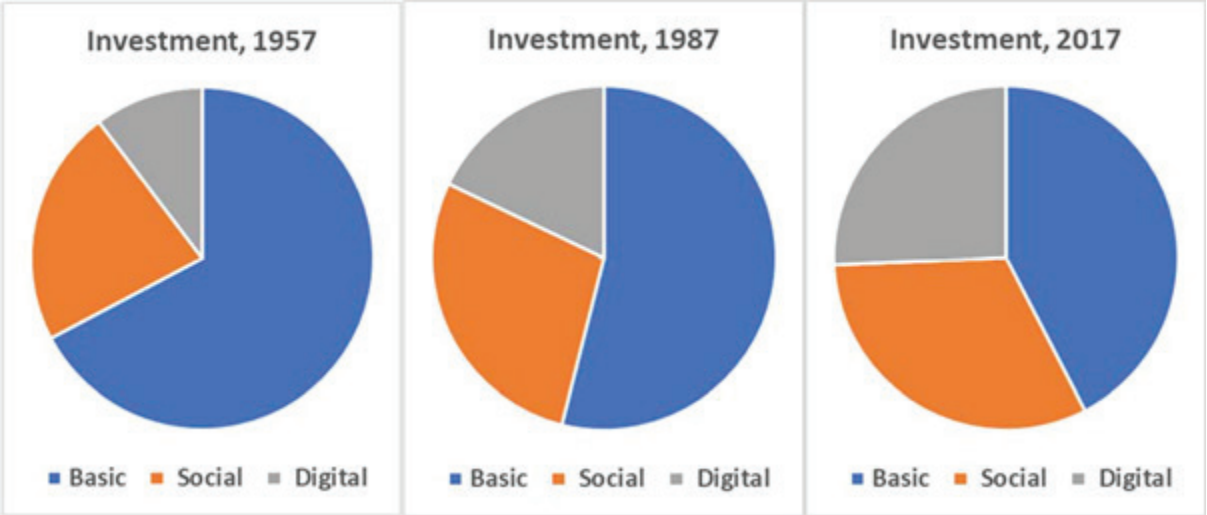


Chart 3. Infrastructure Shares by Type: Net Stocks

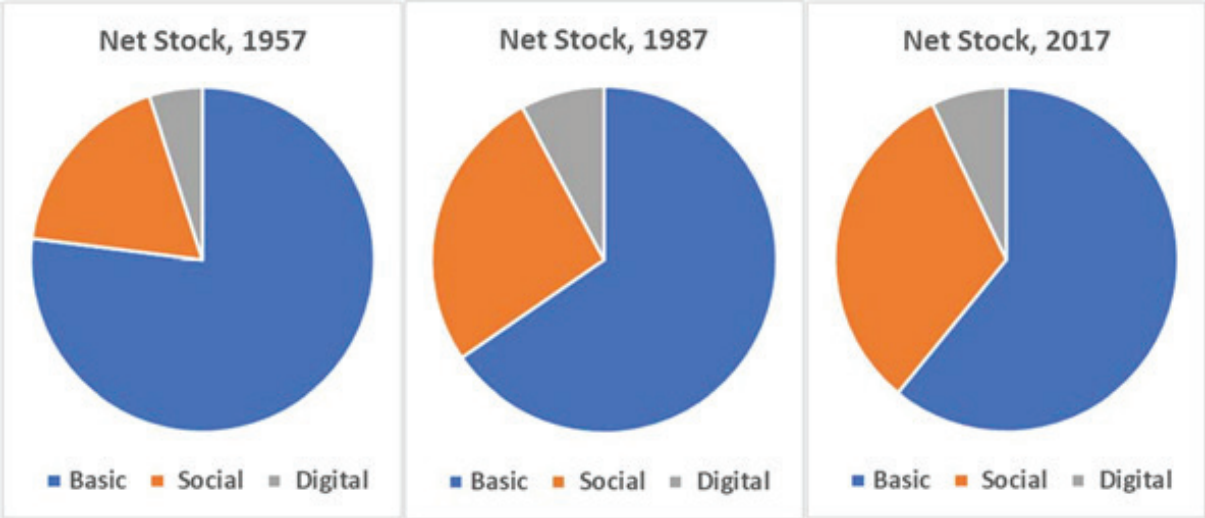


Chart 4. Real Basic Infrastructure Investment

[Millions of chained (2012) dollars]

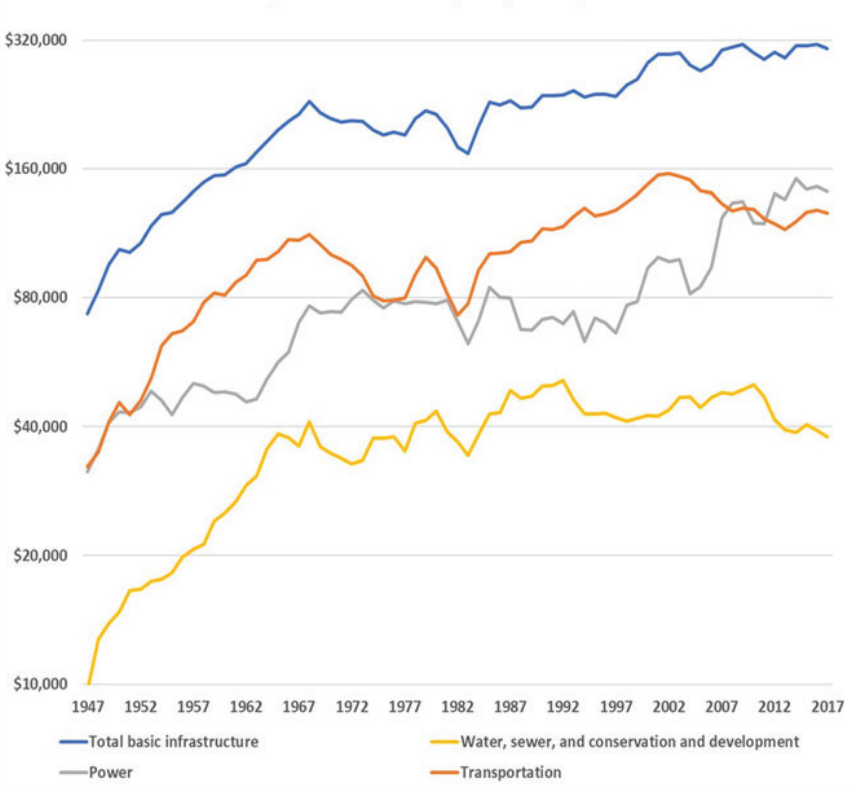


Chart 5. Real Basic Infrastructure Investment: Transportation

[Millions of chained (2012) dollars]

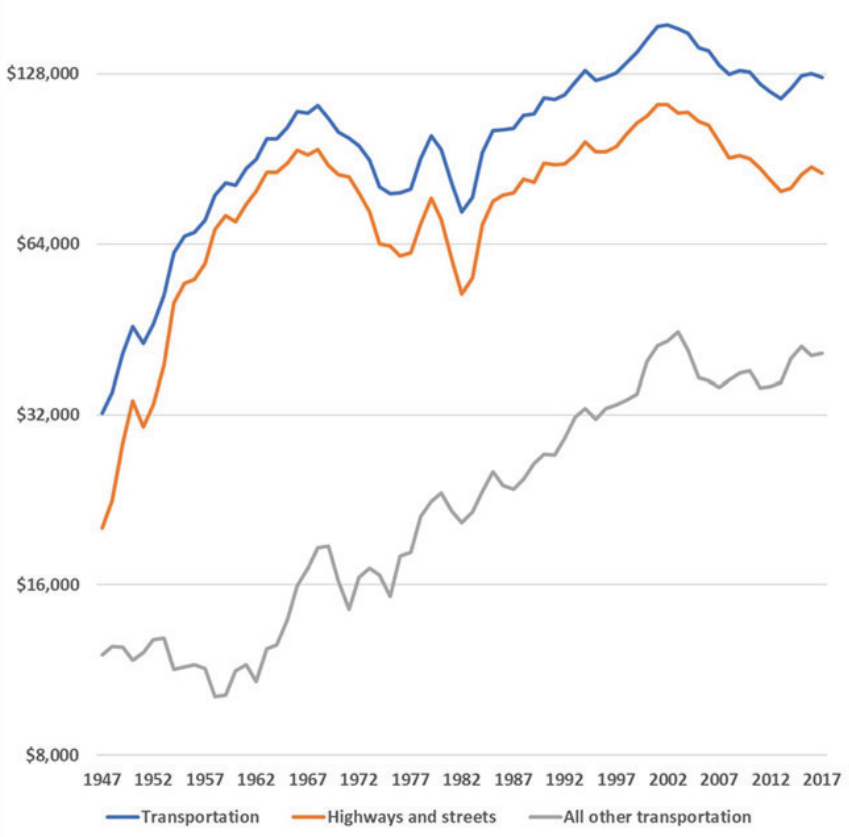


Chart 6. Real Basic Infrastructure Investment: All Other Transportation

[Millions of chained (2012) dollars]

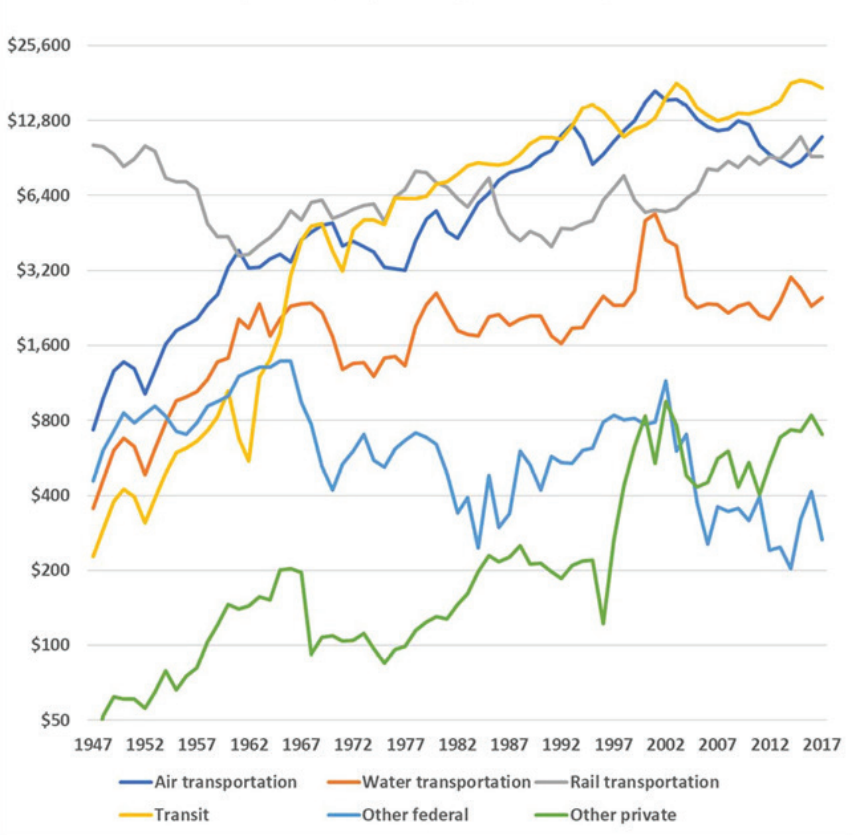


Chart 7. Real Basic Infrastructure Investment: Electric Power

[Millions of chained (2012) dollars]

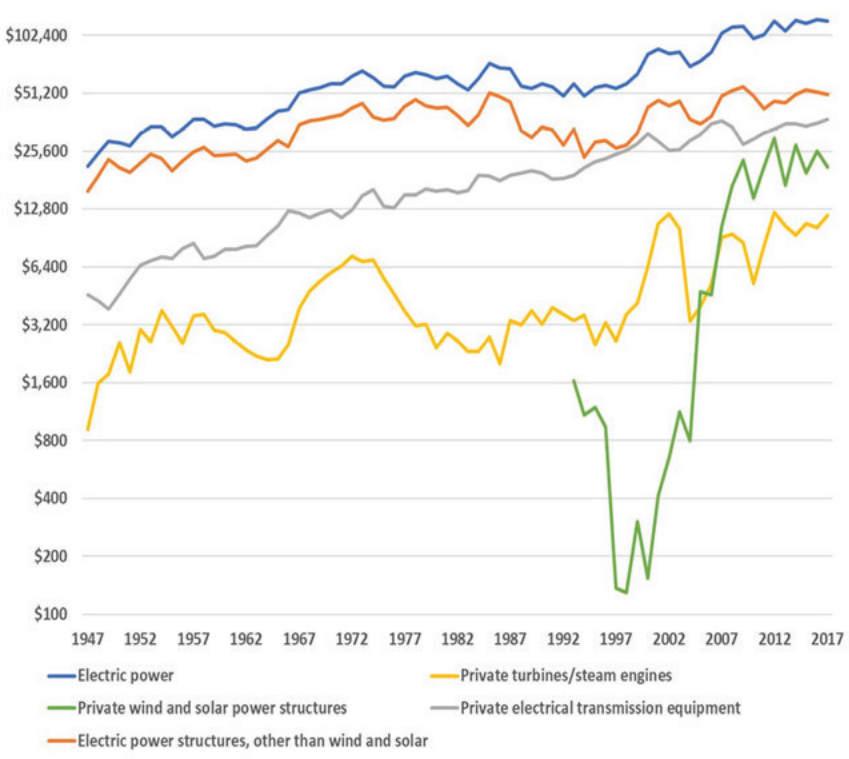


Chart 8. Real Basic Infrastructure Investment: Petroleum and Natural Gas

[Millions of chained (2012) dollars]

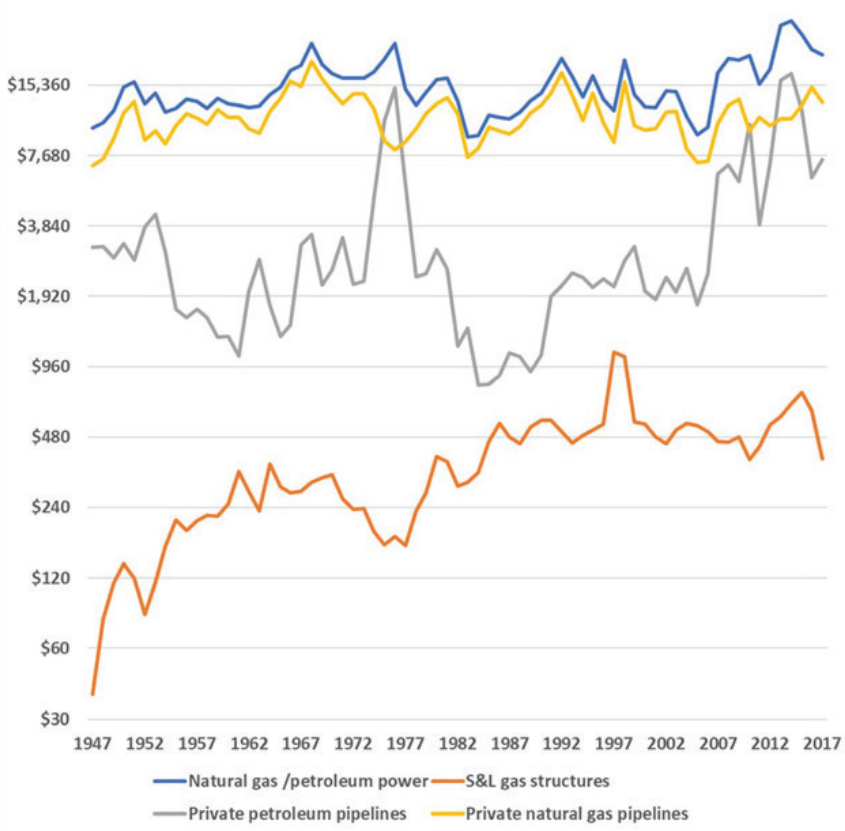


Chart 9. Real Basic Infrastructure Investment: Water Supply, Sewer and Waste, Conservation and Development

[Millions of chained (2012) dollars]

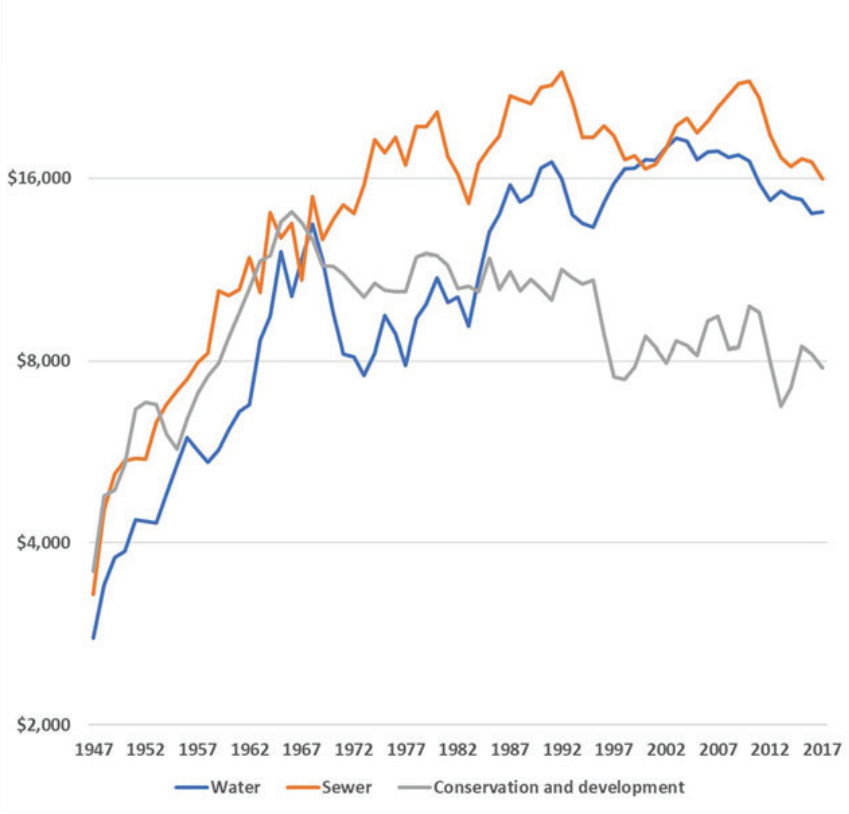


Chart 10. Real Social Infrastructure Investment

[Millions of chained (2012) dollars]

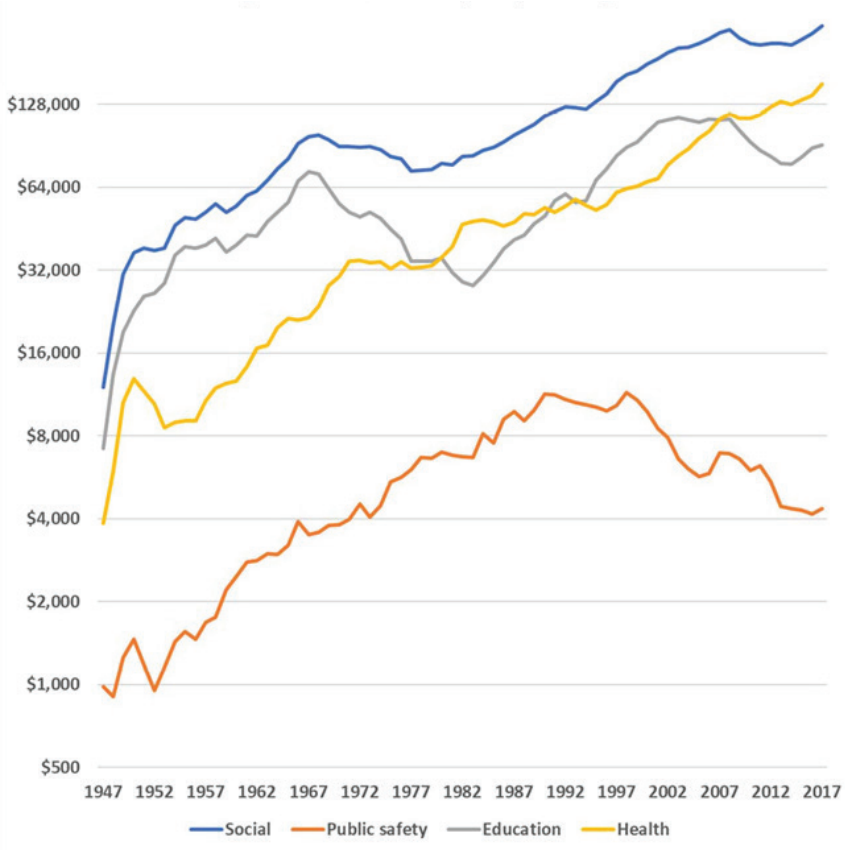


Chart 11. Real Social Infrastructure Investment: Health

[Millions of chained (2012) dollars]

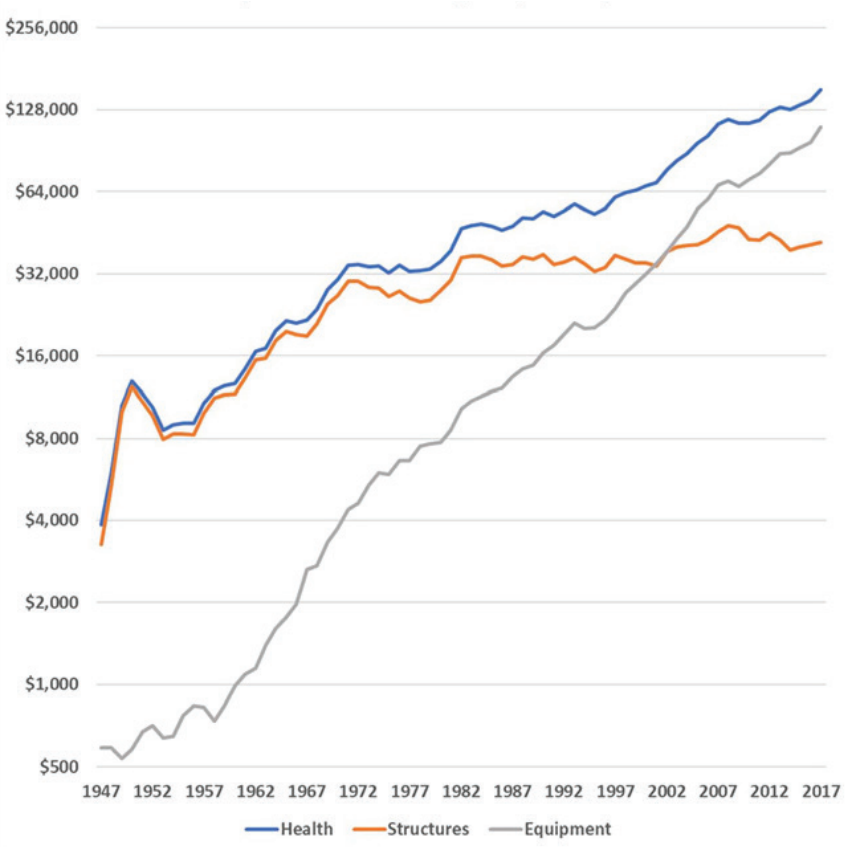


Chart 12. Real Social Infrastructure Investment: Education

[Millions of chained (2012) dollars]

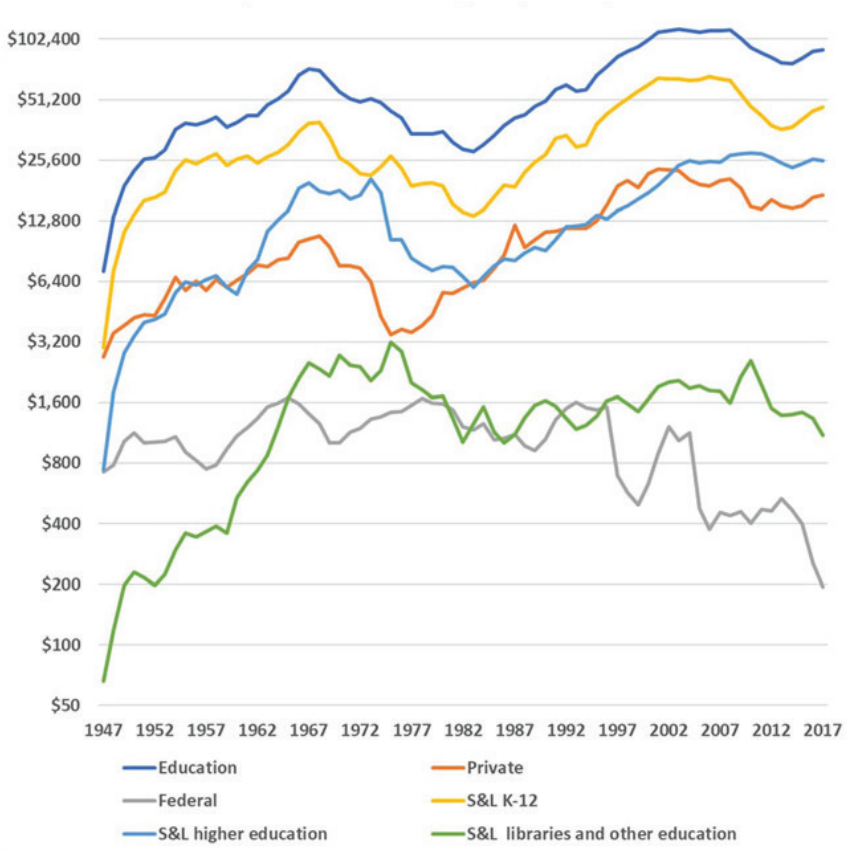


Chart 13. Real Social Infrastructure Investment: Public Safety

[Millions of chained (2012) dollars]

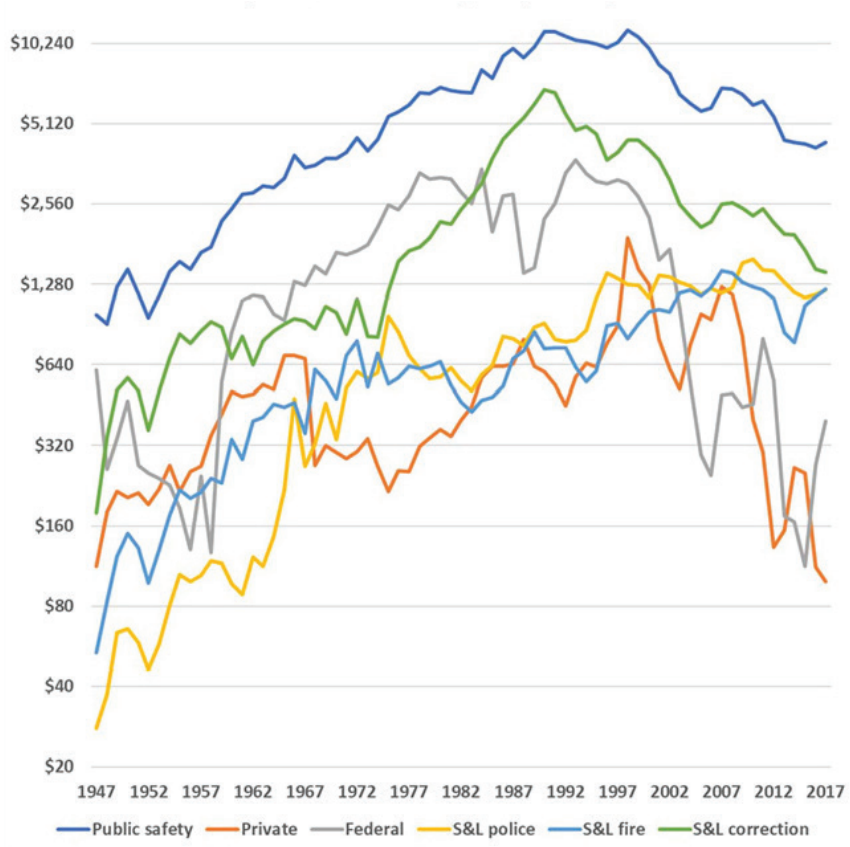


Chart 14. Real Digital Infrastructure Investment

[Millions of chained (2012) dollars]

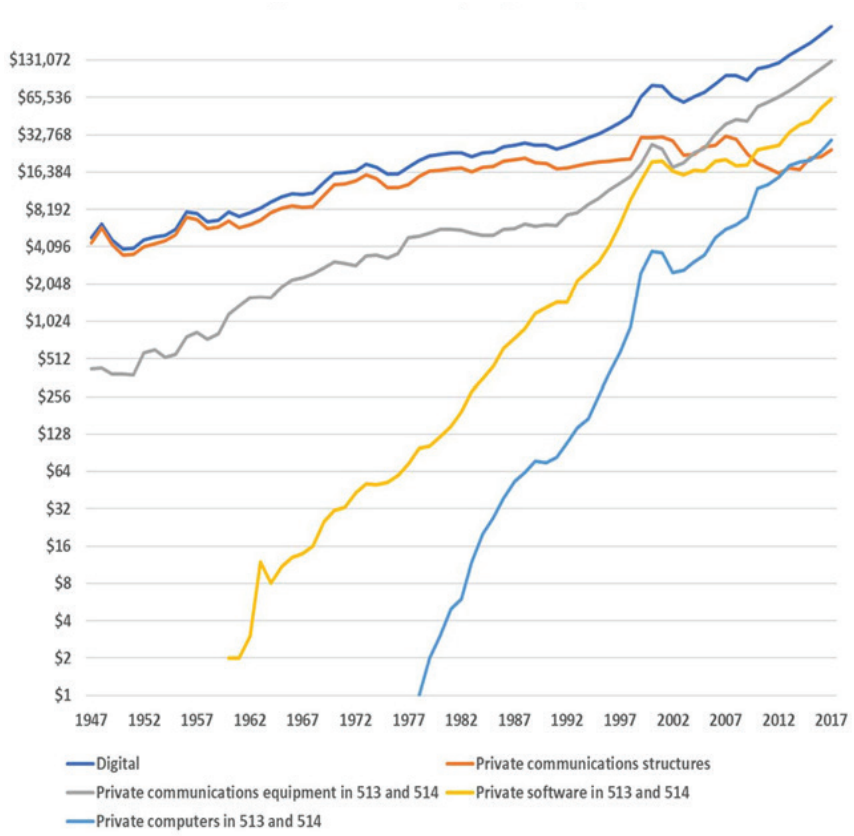


Chart 15. Real Total Infrastructure Investment per Capita Gross and Net, Ratio Scale

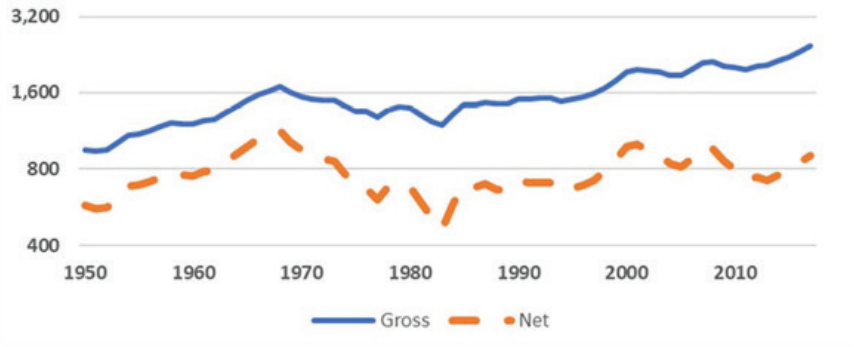


Chart 16. Real Basic Infrastructure Investment per Capita Gross and Net, Ratio Scale

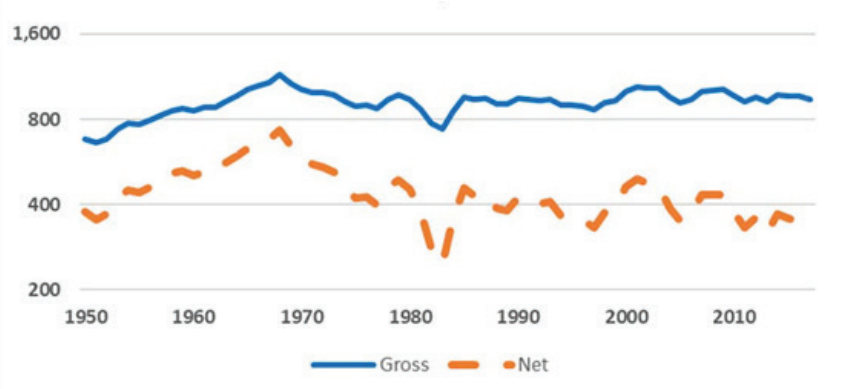


Chart 17. Real Social Infrastructure Investment per Capita Gross and Net, Ratio Scale

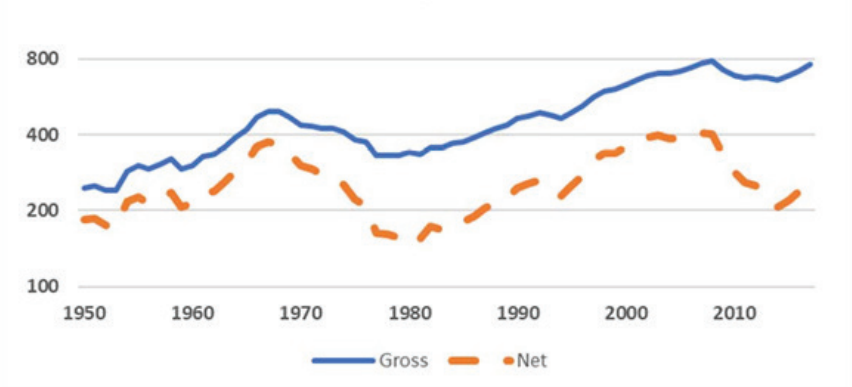


Chart 18. Real Digital Infrastructure Investment per Capita Gross and Net, Ratio Scale

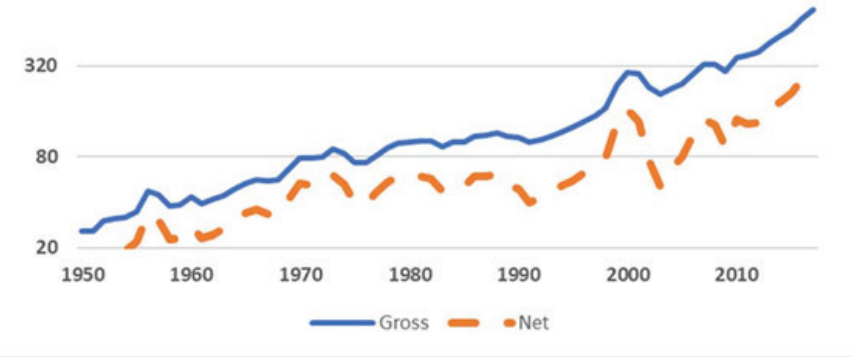


Chart 19. Real Net Capital Stock per Capita

(percent change)

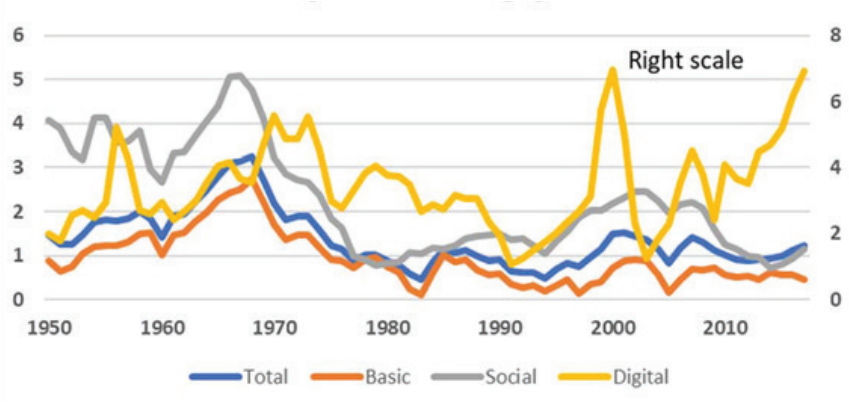


Chart 20. Real Net Capital Stock per Capita for Components of Basic

(3-year average annual growth rate)

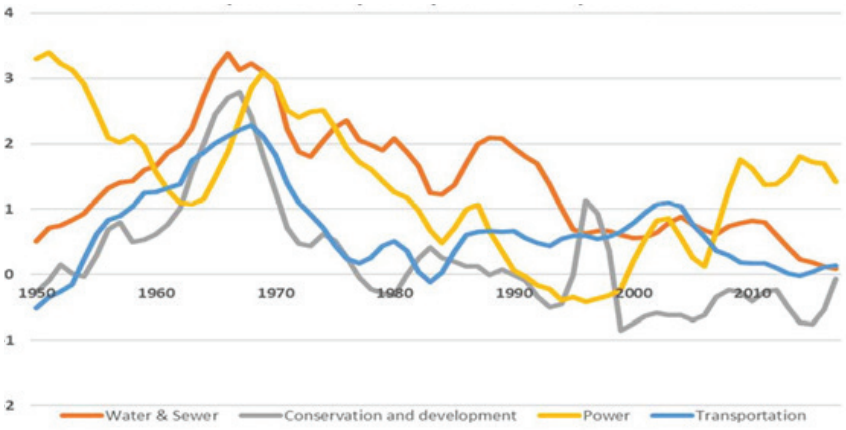


Chart 21. Real Net Capital Stock per Capita for Components of Power

(3-year average annual growth rate)

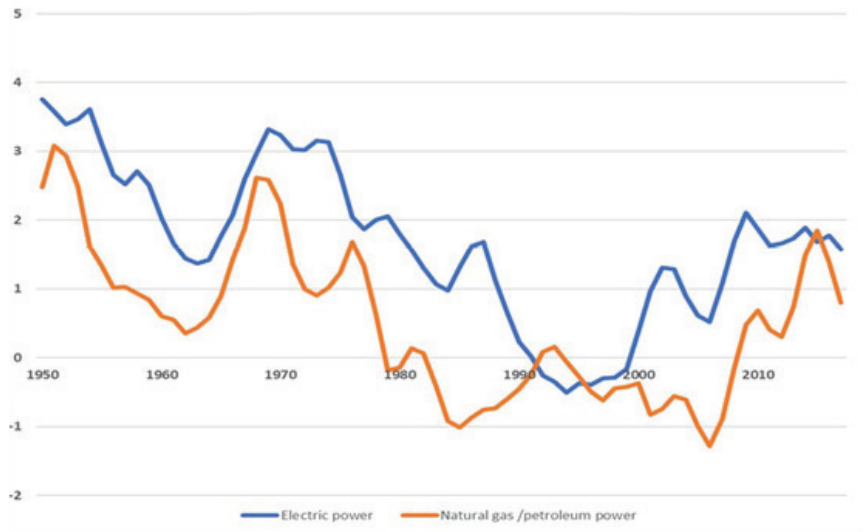


Chart 22. Real Net Capital Stock per Capita for Components of Electric Power

(3-year average annual growth rate)

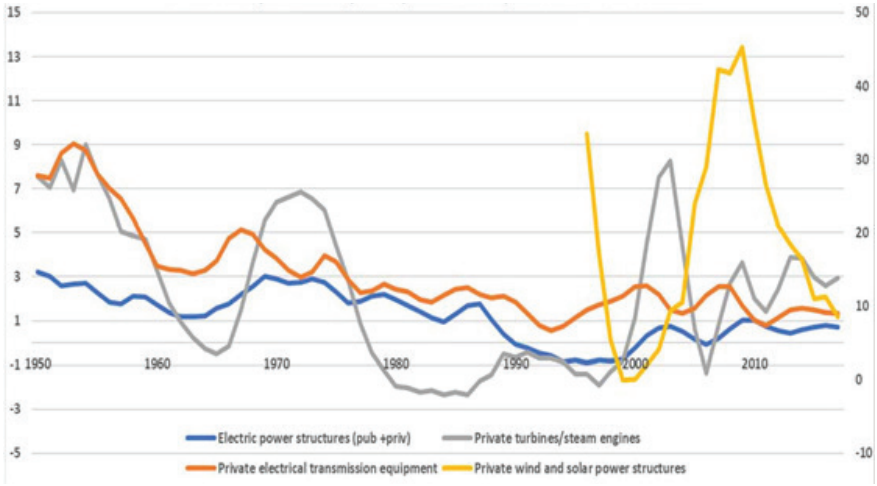


Chart 23. Real Net Capital Stock per Capita for Components of Transportation

(3-year average annual growth rate)

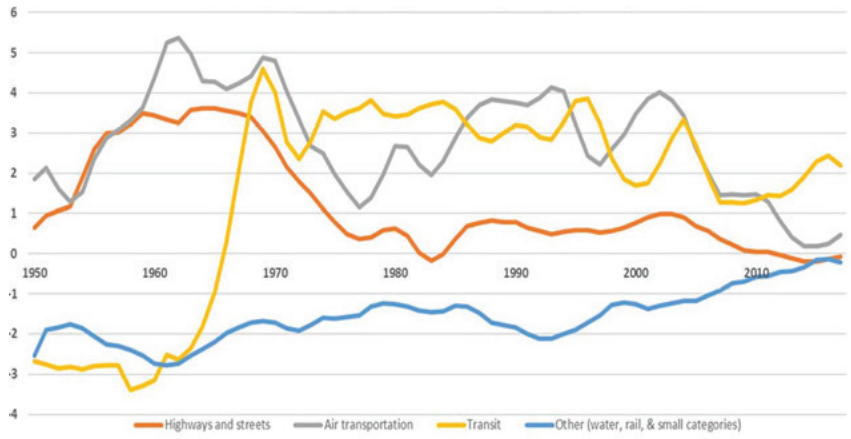


Chart 24. Real Net Capital Stock per Capita for Components of Social

(3-year average annual growth rate)

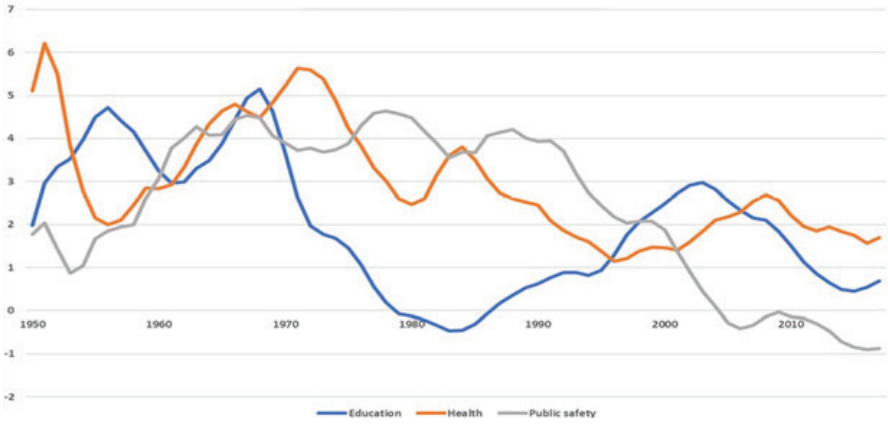


Chart 25. Real Net Capital Stock per Capita for Selected Components of Education

(3-year average annual growth rate)

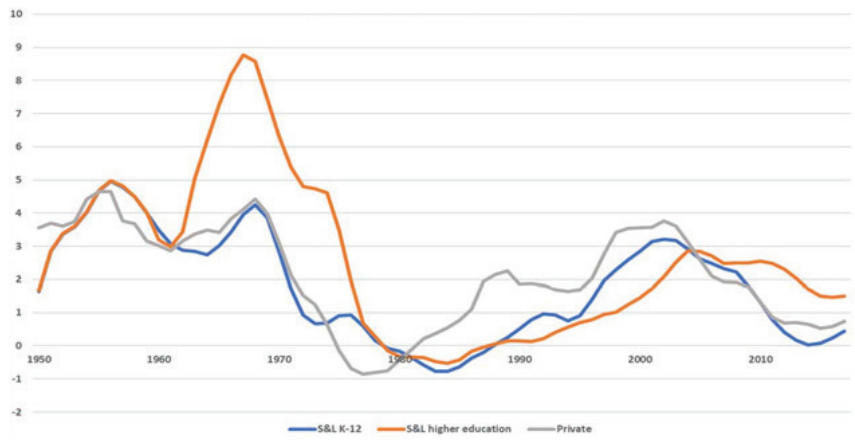


Chart 26. Real Net Capital Stock per Capita for Selected Components of Health

(3-year average annual growth rate)

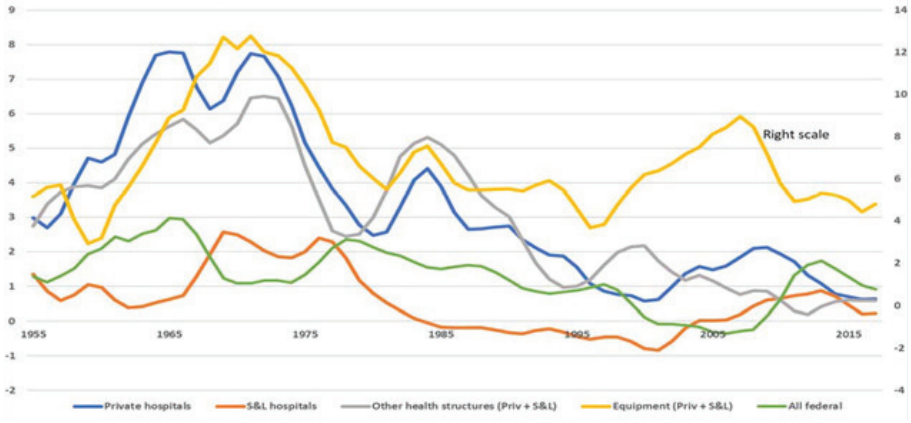
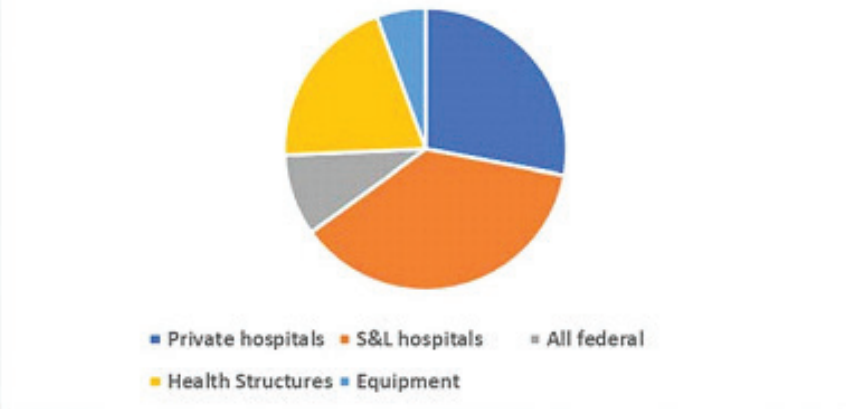


Chart 27.

Nominal Net Capital Stock Shares, 1957



Nominal Net Capital Stock Shares, 1987

Nominal Net Capital Stock Shares, 2017

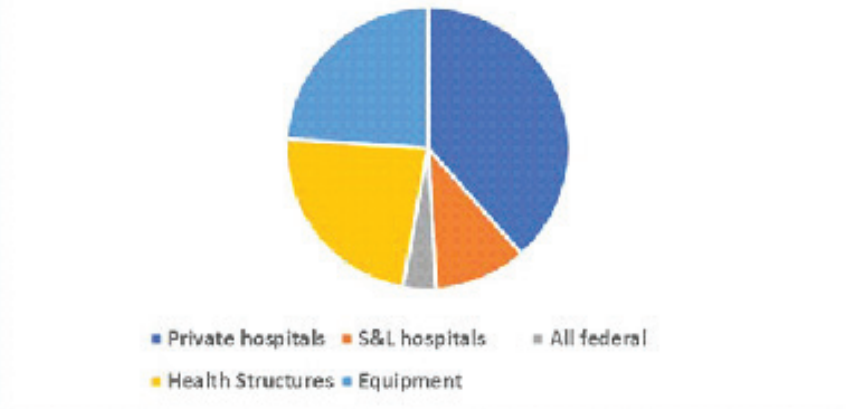


Chart 28. Real Net Capital Stock per Capita for Components of Digital

(3-year average annual growth rate)

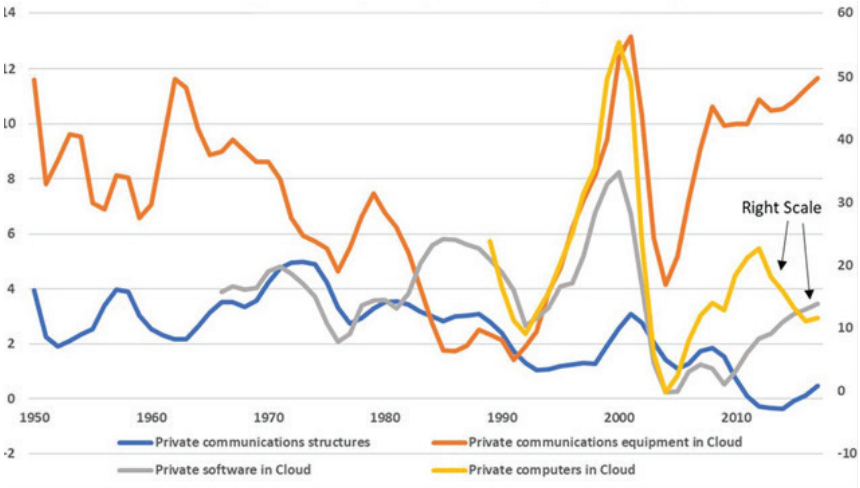
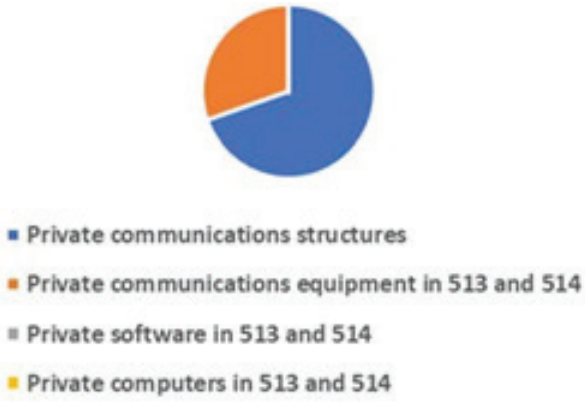
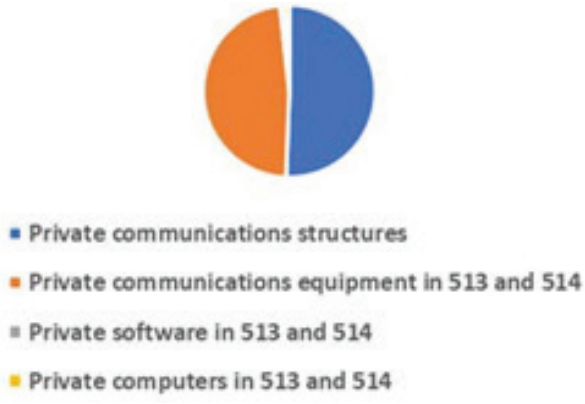


Chart 29.

Nominal Net Capital Stock Shares, Digital, 1957



Nominal Net Capital Stock Shares, Digital, 1987



Nominal Net Capital Stock Shares, Digital, 2017

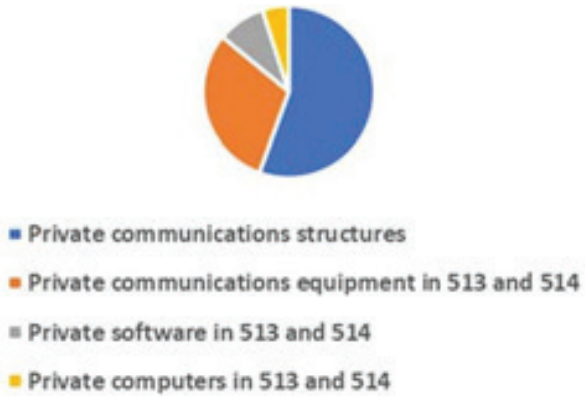
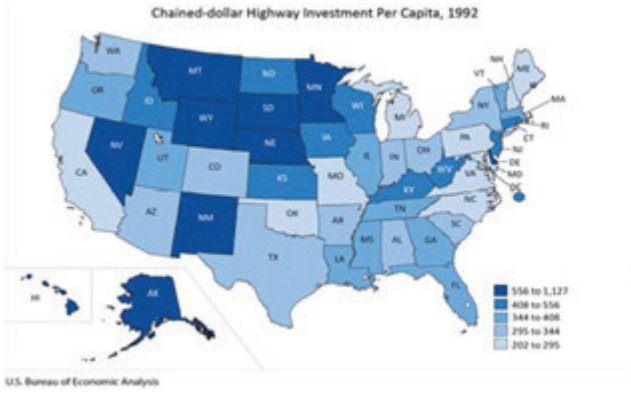
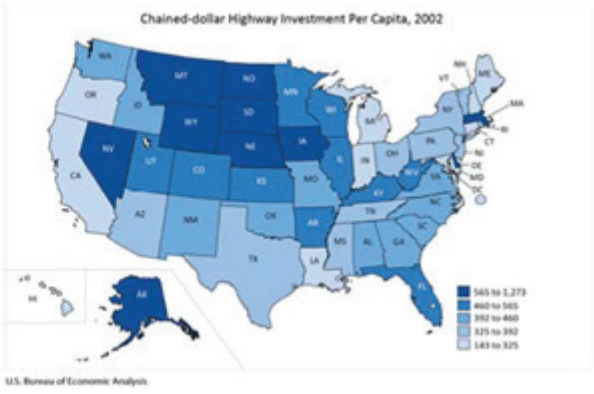
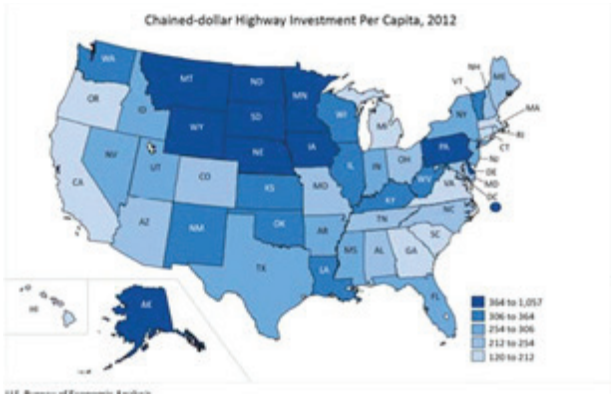


Chart 30. Gross Highway Real (chained) Investment per Capita by State: 1992, 2002, 2012, 2017







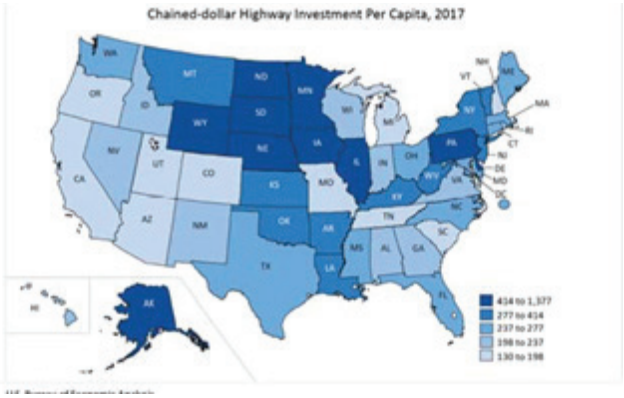
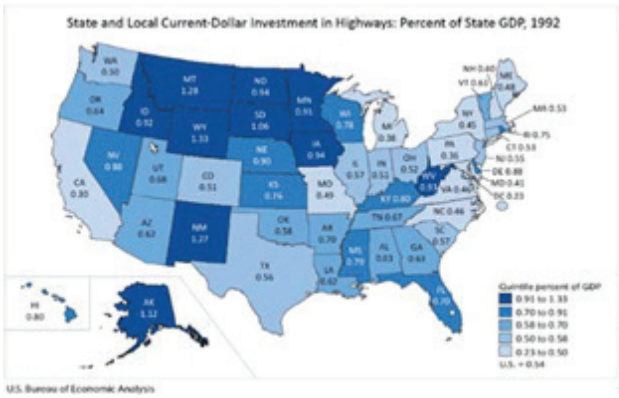
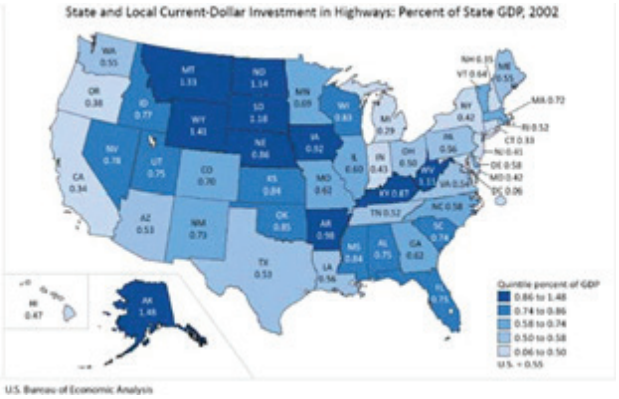
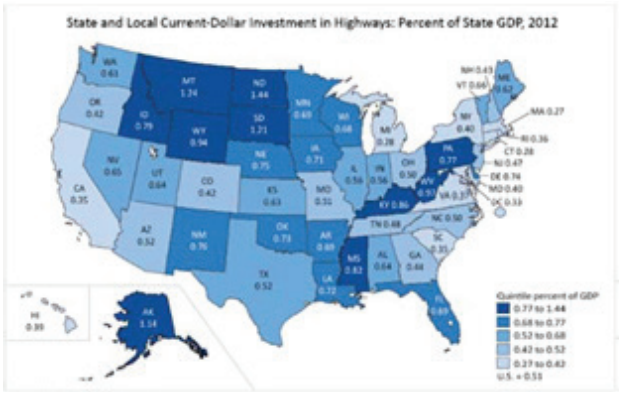


Chart 31. Gross Highway Investment as a Share of GDP by State: 1992, 2002, 2012, 2017







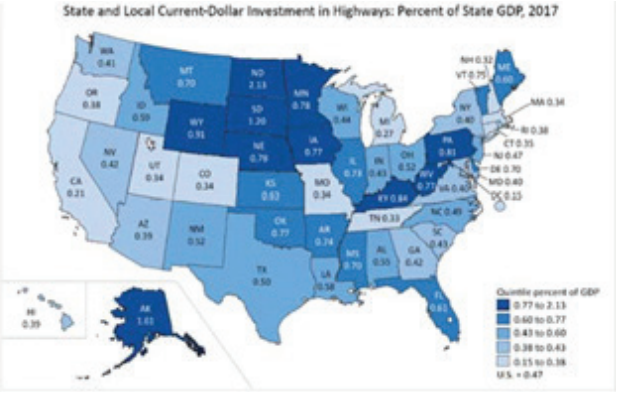


Chart 32. Average Age of Basic Government Infrastructure, Current-Cost Basis in Years

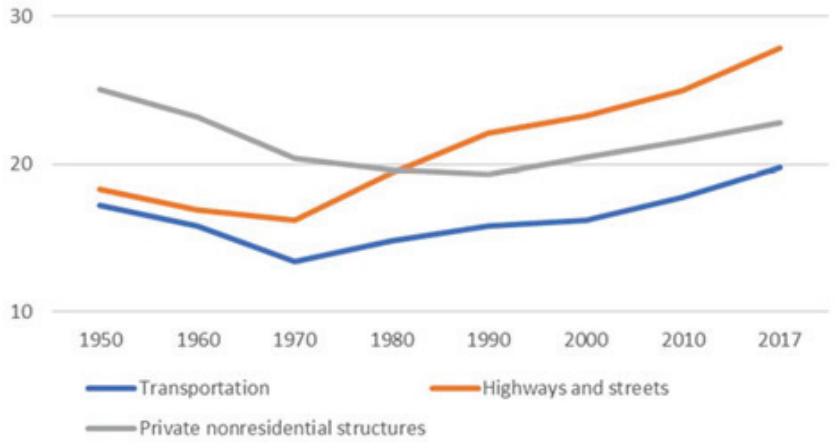


Chart 33. Average Age of Basic Government Infrastructure, Current-Cost Basis in Years

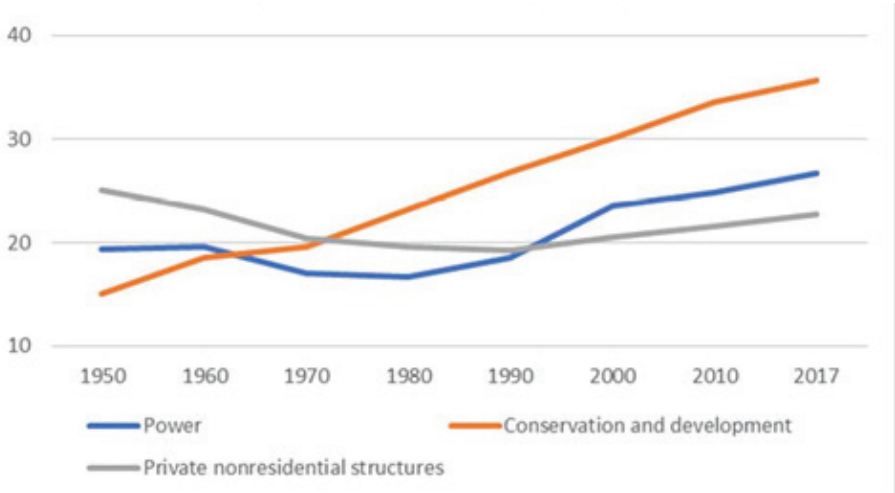


Chart 34. Average Age of Social Government Infrastructure, Current-Cost Basis in Years

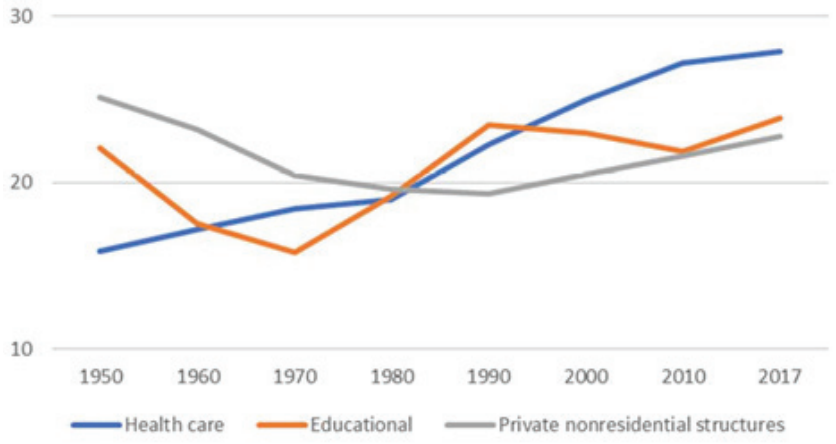


Chart 35. Remaining Useful Life to Total Service Life: State and Local Government Infrastructure

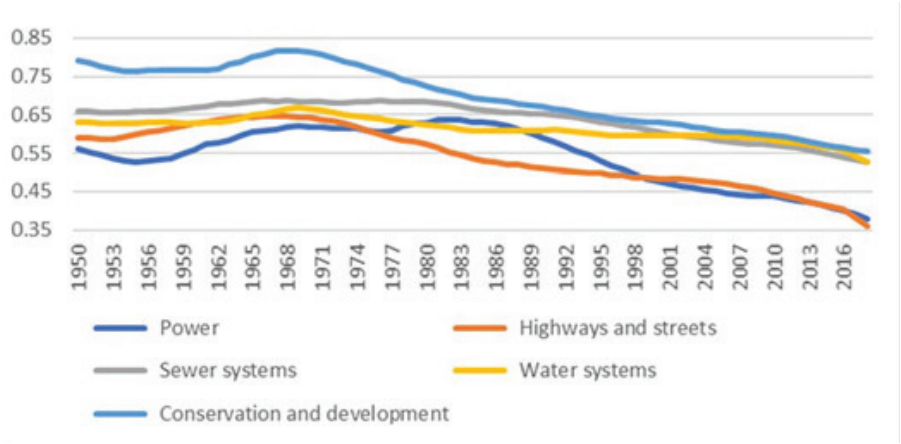


Chart 36. Average Age: Highways and Streets

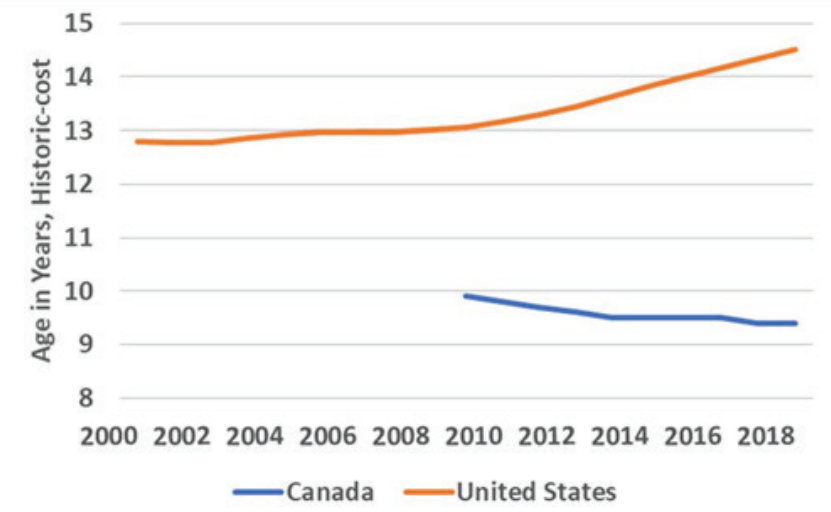


Chart 37. Average Age: Communications Structures

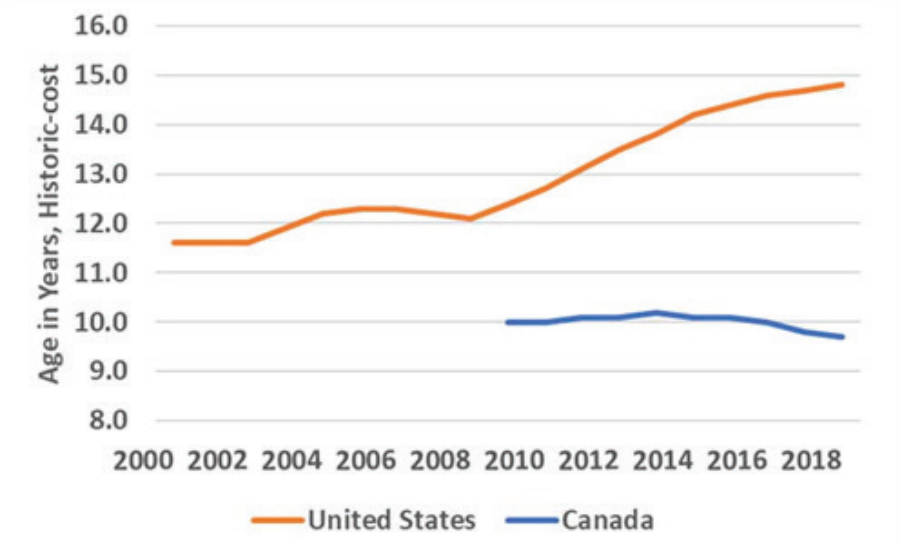


Chart 38. Average Age: Electric Power Structures

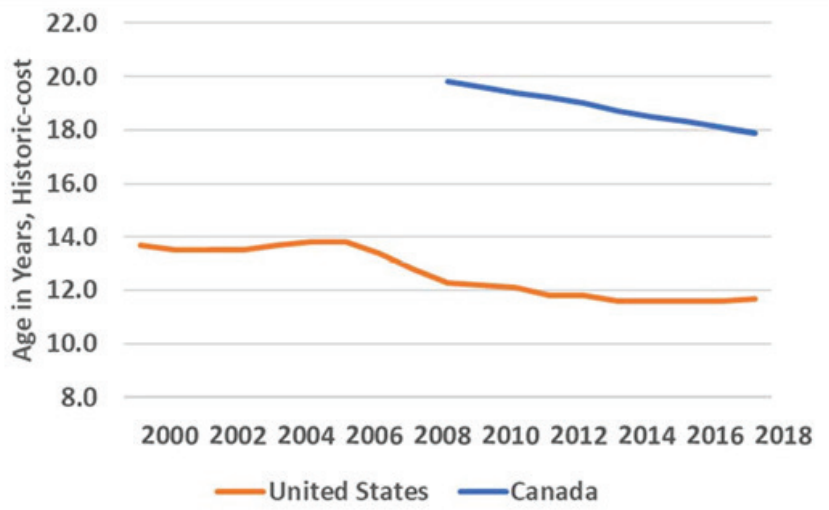


Chart 39. GDP and Infrastructure

(Price Indexes, 2012 = 100.0)

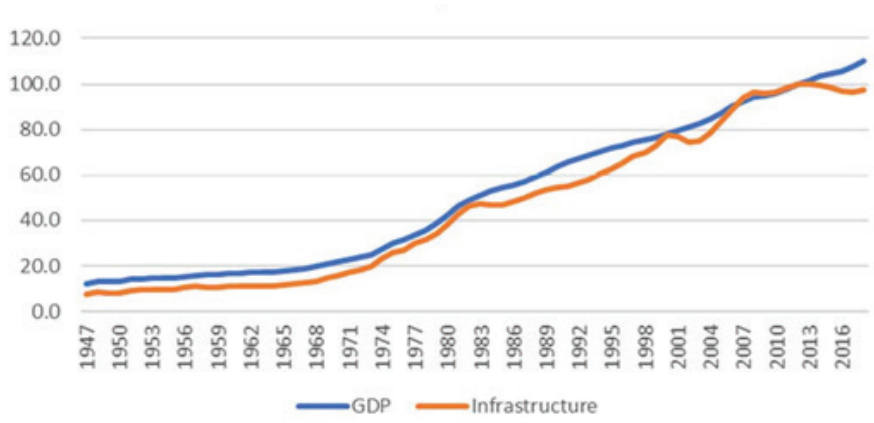


Chart 40. Total Infrastructure, by Type

(Price Indexes, 2012 = 100.0)

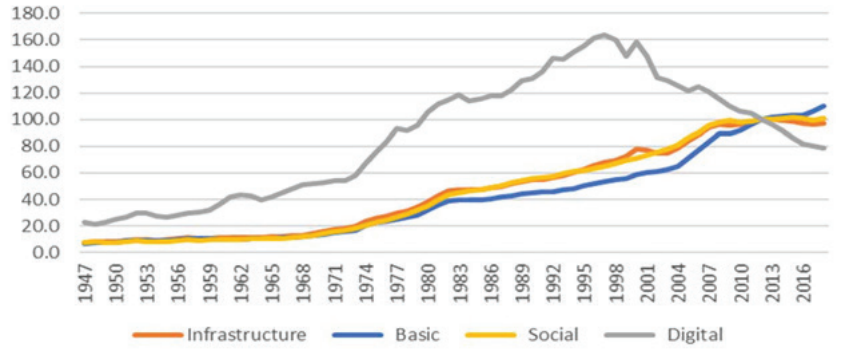


Chart 41. Basic Infrastructure

(Price Indexes, 2012 = 100.0)

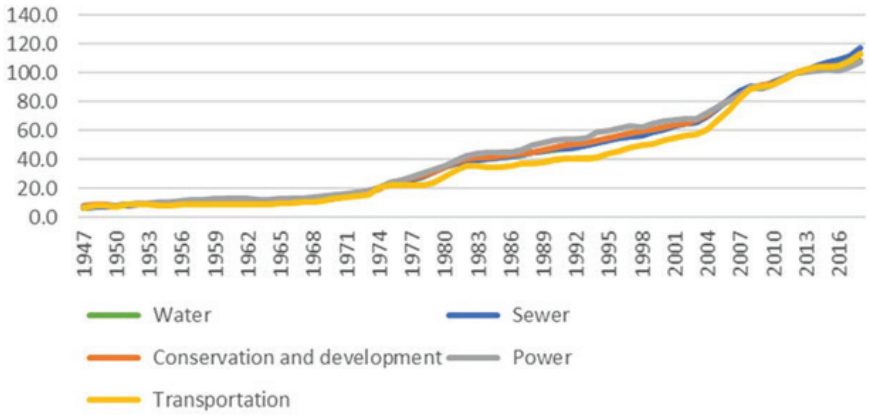


Chart 42. Electric Power Plants and Machinery

(Price Indexes, 2012 = 100.0)

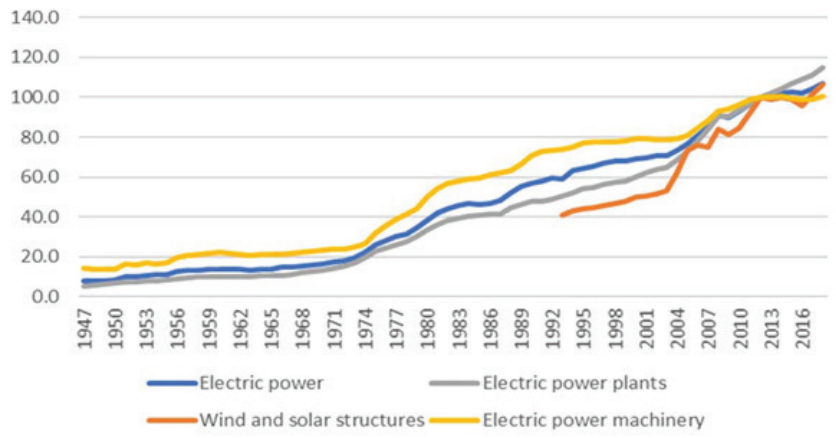


Chart 43. Transportation Infrastructure

(Price Indexes, 2012 = 100.0)

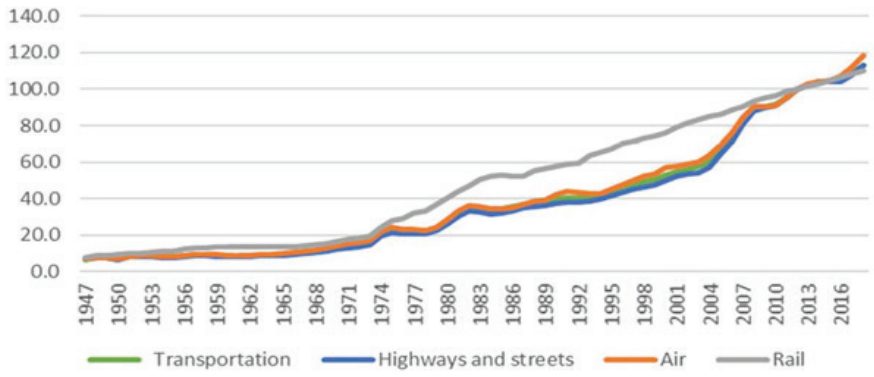


Chart 44. Social Infrastructure

(Price Indexes, 2012 = 100.0)

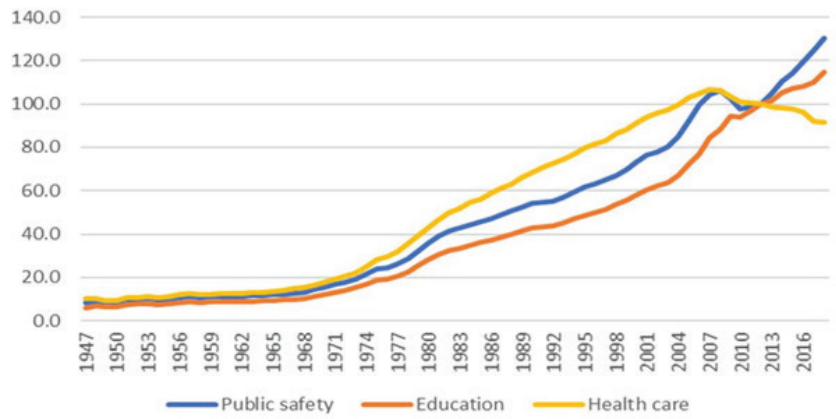


Chart 45. Health Care Infrastructure

(Price Indexes, 2012 = 100.0)

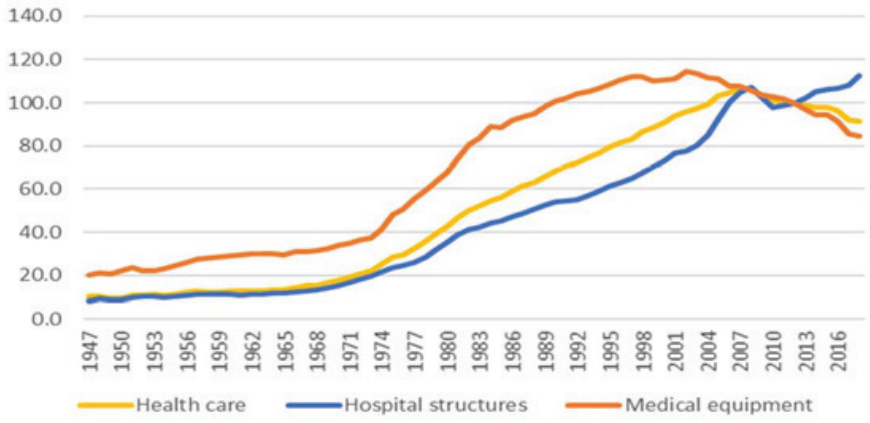
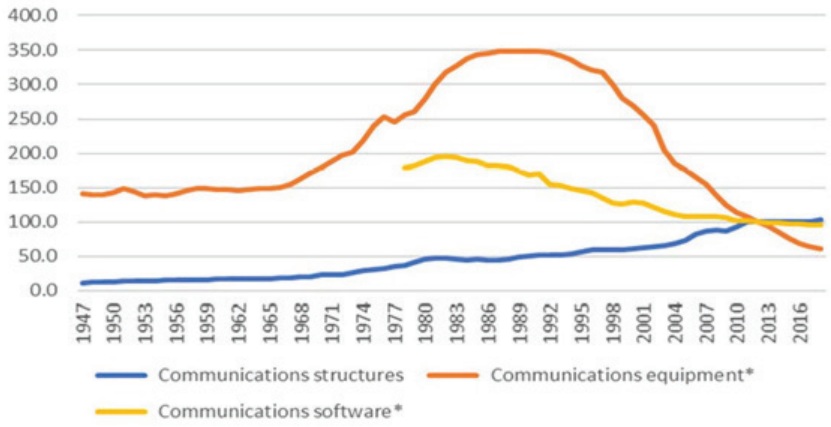


Chart 46. Digital Infrastructure

(Price Indexes, 2012 = 100.0)



* Includes Communications equipment, software and computers used in the provision of digital services.