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Measuring Infrastructure in BEA's National Economic Accounts

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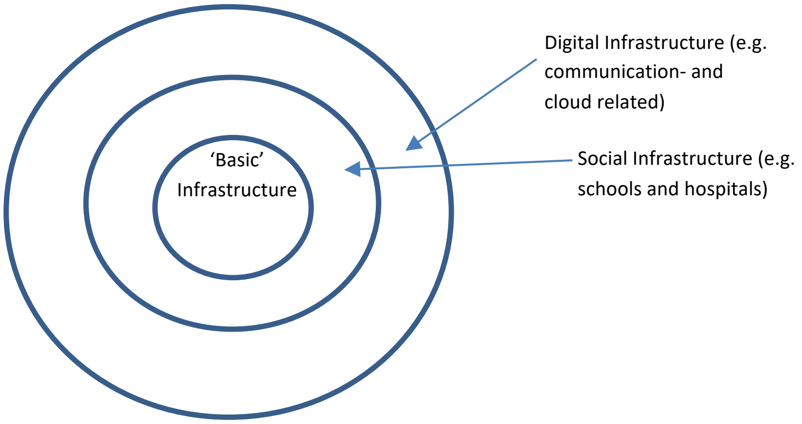
1. Introduction

Infrastructure has, once again, become a hot topic, with concerns that underinvestment in infrastructure may be restraining economic growth and improvements in living standards. For example, the widely cited Infrastructure Report Card from the American Society of Civil Engineers (2017) gives the U.S. a grade D+. Moreover, the nature of infrastructure is changing as networks, connectivity, alternative-energy infrastructure, and digital and intangible infrastructure have become increasingly important and the focus of policy debates. What do we know about the state of infrastructure in the United States at an aggregate level? Answering that question necessitates a return to the basics of economic measurement of infrastructure.

This paper's objective is to provide a broad overview of measures of infrastructure in the U.S. National Economic Accounts. The approach taken here is unabashedly descriptive and empirical rather than analytical or model based.[1]

Defining the economic boundaries of "infrastructure" is imprecise and somewhat subjective. We consider three different broad categories of infrastructure that can gauge different aspects of infrastructure from a national accounts standpoint. We begin with "basic" infrastructure (e.g. transportation and utilities), which would reflect 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.[2] The graphic 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.



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[1] The data developed and discussed in this paper will be available in downloadable spreadsheets to enhance opportunities for further research.

[2] As noted below, an interesting further extension would include a wide range of intangible infrastructure. 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 assets would require expanding the asset boundary in the Accounts. For one paper examining 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 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 focus on infrastructure by broad category, by detailed type, and by public or private ownership. We also will consider investment flows (gross and net), net capital stocks, and depreciation rates and service lives.

In addition to documenting trends, we are interested in developing metrics that speak to the question of the adequacy of infrastructure investment. While we do not develop a model that would allow us to gauge welfare gains from additional infrastructure investment and so cannot make qualitative statements about the adequacy of infrastructure in the United States, we do discuss a number of metrics that shed light on the question of adequacy.

This paper also reviews trends in price deflators and quality change as well as the methodology and estimates used for calculating depreciation rates for infrastructure. Our objective is both to highlight patterns and trends and to assess areas where updates to measurement methodology may be warranted. 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.[3] We have not worked out the best way to think about linkages between capital improvements, depreciation, maintenance expenditures, and service lives, but we do present some data for maintenance expenditures for highways that could be an important input into such analysis.

As interesting as national measures of infrastructure are, infrastructure is built in a particular place and has particular benefits for that place. In addition, stating the obvious, the geographic distribution of infrastructure carries considerable political salience. However, the National Accounts do not, in general, include information on regional breakdowns of infrastructure. To get some (limited) visibility into the geographic distribution of infrastructure, we present an experimental methodology and data on highway investment per capita by state.

The main findings of the paper fall into three categories: evidence on broad trends, adequacy of infrastructure, and observations on methodology. First, in terms of high-level trends, the share of gross investment devoted to basic infrastructure has fallen since the late 1950s, while the share of social and digital infrastructure have increased. For net capital stocks, the same pattern is evident for basic and social infrastructure. 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.

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

In terms of 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.

To help dig beneath these broad trends, we present two other types of data not typically available in the National Accounts. First, we develop (and present in the form of heat maps) experimental state-level data on gross real highway investment per capita. Second, we present data on maintenance expenditures for highways. With some additional work, it should be possible to develop maintenance expenditures for a wider set of infrastructure assets.

In terms of prices, the index for overall infrastructure has trended up more or less in line with the GDP deflator. Prices of infrastructure increased more rapidly than GDP prices in the first part of the sample (1947-87), but more slowly than GDP prices since 2000. Since 2010, overall infrastructure 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 actually have fallen since 2010, owing largely to declines in quality-adjusted prices for medical equipment.

The second category of conclusions pertain to metrics useful for assessing the adequacy of infrastructure. In terms of growth rates of real net capital stocks per capita, basic infrastructure has been soft for a long time, running below a 1 percent pace. The real net stock per capita of social infrastructure 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 quite volatile, though it has been much higher than that of other types of infrastructure.

In addition, the average age of the publicly-owned basic and social infrastructure stock in the U.S. has increased quite noticeably in recent decades. Moreover, average ages of stocks in the U.S. are often above those in Canada and have followed a different trend. While ages have increased in the U.S., the average age of comparable types of infrastructure in Canada has decreased during the past 10 years.

As noted, these metrics are not determinative about the adequacy of infrastructure. That being said, the weak growth in real net capital stocks per capita, the rising age of U.S. infrastructure, and the higher age of infrastructure relative to Canada all seem consistent with the narrative that the United States has underinvested in infrastructure. (Possible exceptions to this dark narrative about the adequacy of infrastructure are some categories of electric power structures and some categories of digital infrastructure.)

The final category of conclusions are observations about methodology. As we highlight below, depreciation 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; international comparisons raise the possibility that new research would generate different estimates. In addition, price deflators for some categories of infrastructure are based on cost indexes, which may not fully reflect quality improvements and productivity gains.

Finally, 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.
In terms of future research, we believe additional work on regional estimates of infrastructure and international comparisons would be extremely valuable. In addition, the observations about methodology made in the last paragraph highlight areas that could benefit from being revisited. Of course, we are not the first to make these observations, and the problems are challenging. Some creativity and novel data likely are the key to progress in these areas.

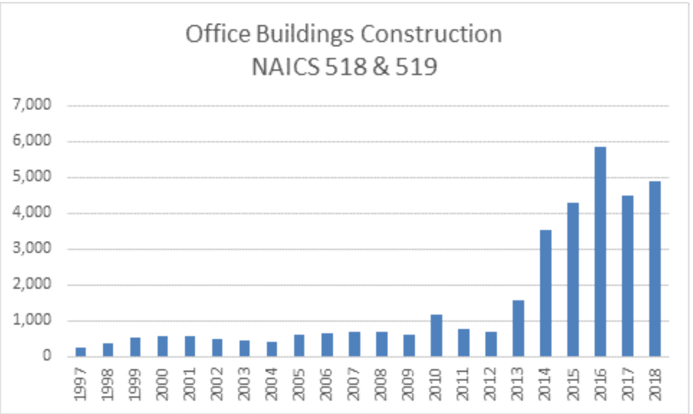
This paper is organized as follows. Section 2 describes our definitions of basic, social, and digital infrastructure, and Section 3 describes the methodologies and data used by the Bureau of Economic Analysis in its estimates of infrastructure investment, net capital stocks, depreciation rates, and prices. Section 4 turns to analysis of the data, highlighting trends over the past 20 years (and especially since the financial crisis) as well as providing some metrics useful for thinking about the adequacy of infrastructure in the United States. Section 5 concludes and offers our thoughts on directions for future research.

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 (HUD), defined infrastructure capital as the structures and equipment that comprise "the basic systems that bridge distance and bring productive inputs together." (Cisneros, 2010.) In this paper, our ‘basic’ measure of infrastructure is largely consistent with Cisneros’ concept as well as respected industry and academic experts who study this field.

We also categorize infrastructure by type of asset rather than by private industry or by government function; for example, we consider specific assets providing transportation rather than on the total capital stocks used in various industries providing transportation services. We believe this provides sharper focus for the analysis of whether existing levels of infrastructure assets are sufficient. In addition, this asset-type approach lines up more closely with estimates of depreciation rates and prices.

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. Next, we expanded our definition from core to include social infrastructure, including assets such as public safety facilities, schools, and hospitals. Our final expansion from basic infrastructure include assets that enable the storage and exchange of data through a centralized communication system; we refer to the collection of these assets as digital infrastructure. Digital infrastructure is particularly challenging to define, both because much represents new and evolving technologies and because, in some cases, the data are not sufficiently granular to separately identify assets of interest. Our definition includes pieces that are identifiable in the National Accounts and that we believe would unambiguously be considered infrastructure. In particular, we include private communication structures and selected assets used for broadcast, telecom, and cloud computing. In particular, we include computers, communications equipment, and software assets in the broadcast and telecommunications industry (BEA industry code 513) and in the data processing, internet publishing, and information services (BEA industry code 514). These assets 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. (We should be capturing the equipment in these data centers.) These structures likely fall within the “office” category of commercial construction, but are not currently broken out separately. As shown in the small chart below, “office” construction 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. 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.



One category 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 non-infrastructure components. If the asset boundary in the National Accounts were expanded, a wider set of intangibles could be included.[4]

To provide some quick intuition for the size of our defined categories, the small table below reports net capital stock shares for basic, social, and digital infrastructure out of total infrastructure for 1947, 1987, and 2017. These shares demonstrate the declining role of basic infrastructure and the greater role of social and digital infrastructure over the past 60 years. Table A1 in the Appendix provides full detail on these shares, and we discuss these developments further in Section 4. Table A2 provides detailed examples for the components of infrastructure.

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

Net Capital Stock Share of Infrastructure by Type (percent)			
	1947	**1987**	**2017**
Basic	80	65	61
Social	16	27	32
Digital	4	8	7
	100	100	100

3. Methodology and source data used for estimating investment, net stock and depreciation

In BEA's fixed assets accounts (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 the cumulative value of real fixed investment (i.e. capital formation) through that year, less the cumulative value of real depreciation through that year, less "other changes in the volume of assets" (mainly damages from major disasters). Real economic depreciation (consumption of fixed capital) is estimated as a fixed percentage of the net stock (geometric depreciation).[5]

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

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)

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 consumption of fixed capital (CFC)

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[5] Investment in the current year is depreciated using half the usual annual depreciation rates, under the assumption that investment occurs throughout the year. Price indexes used to deflate nominal investment reflect the average price of the asset over the period of investment whereas price indexes used to reflate quantities of net stock 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.

Current-cost net stocks are estimated by reflating real net stocks (quantities) with corresponding end-of-year price indexes. For example, the current-dollar estimate of the net stock for 2010 is an estimate of the replacement cost or market value of the stock at the end of 2010. Similarly, current-cost depreciation or CFC is estimated by reflating real CFC with corresponding average year price indexes.

3.1 Data sources for investment

In BEA's fixed assets accounts, 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. 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.[6] Investment in state and local government structures is largely based on the five-year Census of Governments (COG) and the annual Surveys of State and Local Government Finances (GF), with the Census VIP data used for the months and years before the next round of GF data are available.[7]

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.

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

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

- Site preparation and outside construction of fixed structures or facilities

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, although BEA uses data from other government sources to estimate net purchases of used structures between private businesses and government agencies.

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 five-year Economic Census and the Annual Surveys of Manufacturers (ASM). 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 also 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 is based on industry shares of purchases fixed investment reported by the Census Bureau's Annual Capital Expenditures Survey (ACES) and the Information and Communication Technology Survey.

3.2 Capital improvements vs 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* (SNA)[8] defines "fixed assets" as produced assets that are used repeatedly or continuously in production processes for more than one year. Moreover, fixed investment (gross fixed capital formation in the SNA) may take the form of improvements to existing fixed assets that increase their productive capacity, extend their service lives, or both.

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[8] For more information on the 2008 System of National Accounts, see https://unstats.un.org/unsd/nationalaccount/sna2008.asp.

Distinguishing between capital improvements and maintenance and repairs can be particularly difficult in practice, and the SNA 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 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 or not 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 by 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 asset 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.

BEA's and the Census Bureau's definitions of fixed investment in new construction, improvements, and maintenance and repairs are generally consistent with the definitions prescribed in the 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 break out spending for new construction and for improvements, complicating efforts to separately track these expenditures. That being said, we develop estimates of maintenance and repair expenditures for highways, and these are discussed below.

3.3 Price measures

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 definitions of current-dollar investment, reflecting prices of new investment and improvements and excluding prices of maintenance and repair and land.

Given the heterogenous nature of many of the infrastructure-related structures (e.g. bridges, tunnels, power plants, hospitals, etc.), constructing accurate, constant-quality price indexes for these types of assets presents challenges. Where possible, BEA uses producer price indexes (PPI) published by the Bureau of Labor Statistics (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.[9] 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 building
- 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 BLS employment cost index for the construction industry, of Bureau of Reclamation construction cost trends for bridges and for power plants, of PPI for material and supply inputs to construction industries, and of PPI for communications equipment.
- 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 of Turner Construction Co. building-cost index.

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[9] 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 non-infrastructure parts of the National Economic Accounts. Of particular note 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 Federal Reserve Board (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.

3.4 Depreciation Rates and Service Lives for U.S. Infrastructure

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.[10]

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 two-years old reflects depreciation. At the same time, 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 particular vehicle more or less attractive to buyers.)

For the National Economic Accounts, 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, obsolescence, accidental damage, and aging."[11] Assets withdrawn from service (retirements) also count within BEA's definition of depreciation. This definition

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[10] See Fraumeni (1997) and Diewert (2005) for an introduction to and discussion of the issues.

[11] Katz and Herman (1997).

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 National Economic Accounts 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.[12]

4. Data trends and analysis

In this section, we highlight broad trends in the data and discuss underlying details and methodological questions that are of particular interest for infrastructure assets. As noted, our contribution here is intentionally descriptive and not analytical. 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 also can be scaled, perhaps by GDP or by population. These different metrics are useful for answering different questions. We are particularly interested in three broad questions and these guide our choice of metrics to present in the paper.

- The first question is the adequacy of infrastructure and so we are particularly interested in trends in the past 20 years (especially since the financial crisis) and how these trends compare with longer-term averages. For much of this analysis, we will scale measures by population. The question of adequacy also directed us toward measures of the growth rate of the real stock per capita.

- Second, we want to highlight areas in which infrastructure measures could benefit from additional research and so devote attention to measures of and methodologies for prices and depreciation as well as the average age of different types of infrastructure.

- Finally, we believe that a rich area for future work is the interplay between stocks of infrastructure and maintenance and repair expenditures. We made less progress on this area than we hoped but present some preliminary results that we hope will spur further thinking in this area.

4.1 Overview of Long-Term Trends

To provide the broadest possible overview, we begin by focusing on the mix of types of infrastructure within total infrastructure, specifically, nominal gross investment as a share

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[12] BEA deviates from geometric depreciation for assets for which empirical studies have provided evidence of non-geometric depreciation.

of total gross investment in infrastructure. Figure 1 in appendix B reports these shares for 1957, 1987, and 2017. As shown in the figure, gross investment has shifted away from basic since 1957 towards social and more recently, towards digital. Despite this shift in investment shares, 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 (see Figure 2). 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.

In terms of the mix of public and private ownership of infrastructure, the nominal net capital stocks share of publicly owned infrastructure has risen modestly since 1957 as reported in Figure 3.[13]

4.2 Metrics for Assessing the Adequacy of Infrastructure Investment

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 maintenance and repair, spending must be for significant improvements rather than just for routine maintenance which counts as a current expense rather than investment. See below for some preliminary data on maintenance expenditures.) Not only is depreciation sizable for these assets, but 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 Figure 4. This gap had been growing slowly in earlier decades, but more recently, the divergence has opened up more noticeably. Thus, despite gradual increases in real budget resources being allocated to infrastructure on a per capita basis (as measured by real gross investment in infrastructure), actual additions to the real capital stock per capita have been considerably weaker. This relationship between gross and net investment matches that for private business capital, where the shift toward shorter-lived, often high-tech assets has boosted depreciation. The same set of forces likely are at work for digital infrastructure and for social infrastructure (reflecting the growing importance of shorter-lived medical equipment that is counted as a part of social infrastructure for health care).

Compared with historical levels, real net investment per capita has been weak and has not been rising, with the exception of digital infrastructure; figures 5 through 7 report these metrics for basic, social, and digital infrastructure. For basic infrastructure, 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, 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). Digital

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[13] In contrast, gross investment shares have moved in the opposite direction, with the share of private gross investment rising modestly. This difference in share trends between investment and capital stocks arises because of the increase in the investment share of digital infrastructure (all private according to our definition). That investment has pushed up the private share of investment but because that capital depreciates so rapidly it has had a less noticeable effect on capital stock shares.

infrastructure real net investment per capital trended up steadily since the 1950s, with a more rapid rate of increase since about 2000 and a marked uptick possibly connected to Y2K related investment.

Growth in real net capital stock per capita. Another metric for assessing infrastructure (and the one we will focus on below for assessing trends in finer detail) is growth rates of real net capital stock per capita. Like net investment, this metric focuses on growth of infrastructure that is being used in inflation and quality adjusted dollars rather than on budget resources devoted to infrastructure investment.

Growth in real net capital stocks per capita also is the metric that could most easily 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 investment is fast or slow relative to other economic trends, though such comparisons say nothing about the optimality of a particular growth rate of infrastructure.

Looking at real net capital stocks per capita, the growth rates by category of infrastructure are reported in the small table below and in Figure 8, with growth rates of TFP and real GDP per capita also shown (from the BLS Multifactor Productivity database[14]).

Real Net Capital Stock, by type of infrastructure
(annual percent change)

	1997-2007	**2007-2017**
Total	1.2	1.0
Basic	.6	.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

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[14] BLS, Multifactor Productivity Trends, 2018, March 20, 2019.

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 last 10 year than in prior 10. (Note the separate scale on right for digital infrastructure in Figure 8.) 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.

Age of the infrastructure 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 current-cost average age of infrastructure as reported in Figures 9 to 11 on a current-cost basis.[15] Figures 9 and 10 highlight categories of basic infrastructure, with notable increases for highways and streets, power, and conservation and development. Figure 11 reports social infrastructure ages, showing the rise in average ages of health care and educational infrastructure.[16] For comparison, the black dashed line in those figures 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 is difficult without a model of optimal age, but the changes certainly are consistent with public narratives of aging infrastructure and inadequate investment.

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. Figures 12 to 14 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 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 must be interpreted cautiously because data limitations make only a partial comparison to Canada feasible. The relevant Canadian data were available only starting in 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 Figures 9 to 11. Ages tend to be lower on an historical cost basis because older assets still in service

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[15] 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 figures, 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.

[16] Digital infrastructure has a short average age (in the neighborhood of 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).

are aggregated up using long-ago purchase prices which are lower than current prices for many assets.

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.

4.3 Interesting Details about Infrastructure Capital Stocks

Within basic infrastructure (as reported in Figure 15), growth rates of the real net capital stock per capita have been quite weak in the past 10 years, with the exception of 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. And, conservation and development stocks have been falling since about 2000.

Power infrastructure is the only category that has seen stronger growth since the financial crisis. It is now rising at about a 1-1/2 percent pace, well above its rather sluggish rate of growth during the 1990s and mid 2000s. Within power (Figure 16**),** 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 & petroleum follow a broadly similar pattern to those for electric power, although the growth rates are, with just a couple of exceptions, uniformly lower.

Within electric power (Figure 17), 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 (see Figure 18), 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.[17] Air transportation had been growing quire 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.

Growth rates of the real net stock per capita of social infrastructure are reported in Figure 19. Education, the largest category, has been growing very slowly in recent years following a surge in the early 2000s. Perhaps not surprising given actual and projected declines in the school-age population. Within education (figure 20), growth rates for all of the major categories (state and local K-12, state and local higher education, and private) have 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 1-1/2 percent.

Health has been growing about 2 percent a year since the mid 2000s, a relatively slow pace relative to historical growth rates for this category of infrastructure. Within health, growth rates of real net stocks of capital per capita have slowed for most major categories over the past 10 years (figure 21). Growth rates for private hospitals and state and local hospitals has slowed to below 1 percent, as has the growth rate of other health structures (doctors' offices and other non-hospital medical facilities). One exception to this pattern of relatively sluggish growth is in medical equipment (note the separate scale on right). 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 Figure 22. The share of private hospitals has risen considerably 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 (share of nominal capital stock with social was 2 percent in 2017). The net capital stock for this category has fallen on a per capita basis since the mid-2000s.

Turning to digital infrastructure, real net capital stocks per capita for most components of digital have grown very rapidly as reported in Figure 23. (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. 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

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[17] 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).

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.[18] Computers and software have grown extremely rapidly in recent decades (note right scale in figure 23) and have been rising about 15 percent a year recently. Infrastructure for communications equipment within 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 over past decades as reported in Figure 24. In 1957, communications structures made up close to ¾ 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 decreasing.

4.4 Prices

In this section, and in Table A3 and Figures 25 and 26, we highlight price trends for major categories of infrastructure. Additional graphs in the appendix show trends in some of the more interesting subcategories of infrastructure.

Overall, prices for infrastructure assets have tended to rise more or less in line with GDP prices, as shown in Figure 25. For the full period analyzed, 1947-2018, infrastructure prices increased 3.6 percent at an average annual rate while GDP prices increased 3.1 percent. Prices of infrastructure increased more rapidly than GDP prices in the first part of the sample (1947-87), but more slowly than GDP prices since 2000. Since 2010, overall infrastructure 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, price for health care actually have fallen since 2010, owing to quality adjusted price declines for medical equipment.

Table A3 and Figure 26 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. From 1987 forward, including after the financial crisis, prices for

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[18] 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 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 date centers in the National Accounts would be valuable.

basic infrastructure rose more rapidly than the overall price index. Because basic infrastructure consists mostly of structures, these price trends parallel trends in prices for construction rather than prices for the high-technology equipment found in health care and the digital economy.

- Within basic infrastructure, transportation accounts for the largest share and these prices grow steadily over all four periods analyzed (see also the figures in the appendix). 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 1980's, with an average annual price increase of about 10 percent. Prices are generally more stable from early 1980's until the latter half of the 2000's, where they begin to increase notably again. [19] Swings in overall construction costs and the price of petroleum by-products, which are inputs to the construction of highways and streets, could explain some of the variation in prices over time

- The second largest component within basic infrastructure is power, which primarily consists of private electric power plants and machinery. Prices for electric power infrastructure show two notable trends. First, prices are relatively flat from 1947 until the early 1970s when oil prices jump significantly. The jump in oil prices results in increased input costs for producing these assets as well as increased demand for electricity, which also drives up prices for plants and machinery. Second, like overall infrastructure, prices show more notable increases through the 2000's, roughly consistent with overall real estate price trends.

    - Within Power, prices for electric power plants show relatively stable increases throughout, although we do observe a slowdown in price increases in the latter time periods. We also observe slightly larger increases—an average annual growth rate of 4.5 percent—over the span 2000-2010 that are consistent with overall real estate trends noted previously.

    - Prices for electric power machinery consists of turbines used to generate electricity as well as the equipment used for transmission and distribution. We observe increases in prices for this machinery in the 1970's about in line with those for other categories of electric power. 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 price of competing domestic machinery, resulting in relatively modest price increases over this period.

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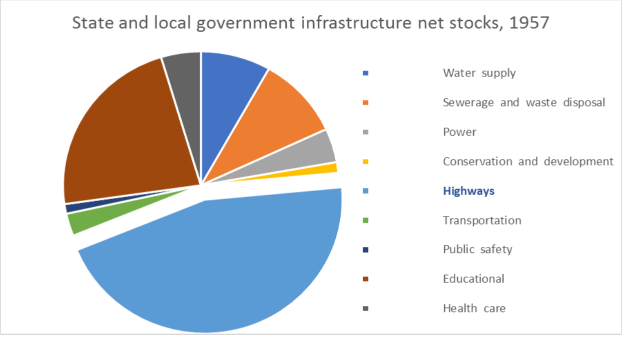
[19] These rapid increases in prices of highways line up with Brooks and Liscow (2019) who find that costs per mile of highway construction have risen very rapidly since the 1970s. They provide evidence that the increase does not reflect geography, but rather reflects greater "citizen voice" in infrastructure decisions.

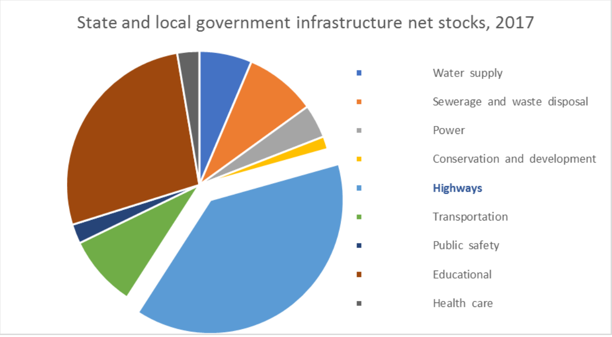
Trends in prices for social infrastructure—mostly education and health care are broadly consistent with trends in prices for all infrastructure prices. Prices for health care infrastructure show a notable slowdown in the latter half of the period falling from 4.6 percent average annual growth for the period 1947-1987 to 1.3 percent for the period 1987-2018; prices actually decline from 2010-2018. This slowdown and later downturn are 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.[20]

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 begin to fall markedly while prices for all infrastructure prices continue to increase. 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 2018, prices declined -1.3 percent annually. 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.

4.5 Experimental statistics of highways by state

As shown in the pie charts below, state and local highways and streets is the dominant asset of U.S. public infrastructure, although its share has declined over time. (Note that BEA's figures for highways and streets include all spending regardless of funding source.) In addition, for the United States as a whole, chained-dollar real investment per capita peaked in 2001 at $391 and has been on a downward trajectory with per capita in 2017 coming in at $260.


State and local government infrastructure net stocks, 1957


State and local government infrastructure net stocks, 2017

BEA does not currently estimate fixed assets by state or region; however, for this paper, we have developed some experimental estimates of highway and street gross real investment for each

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[20] For more information, see Chute, McCulla, and Smith (2018).

state for 1992 through 2017. We believe this 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 U.S. Census Bureau for various years.[21] 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 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.

Appendix Figure 33 shows heatmaps of real investment per capita by state for 1992, 2002, 2012, and 2017. By looking at per capita spending for investment by state for highways and streets for the 1992-2017 period, a few conclusions can be drawn:

- The upper Midwest (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. Interestingly, Allen and Arkolakis (2019) find relatively low welfare benefits from additional highway construction in these states.

- In contrast, many of the states in the western section of the U.S.—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 (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.)

4.6 Depreciation Rates and Service Lives for Infrastructure

Depreciation rates developed in Fraumeni (1997) largely were adopted by BEA at that time. Appendix Table A4 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 assets: 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 draw 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

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[21] 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.

today as 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 A4 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 A5 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 Eurostat/OECD study from 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 for Sweden (where rates match those in the U.S.), all other countries report higher depreciation rates. Depreciation rates in some countries are more than twice as high as those in the United States.

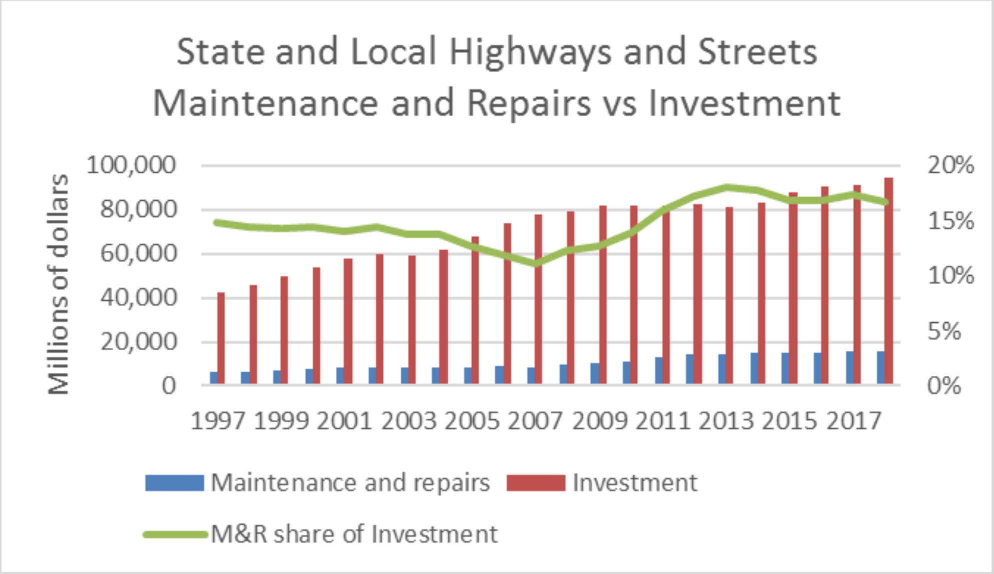
Specifically, for hospitals and schools, Canada, Japan, and Norway use rates that are more than twice as high as those in the United States. For roads, all other countries (except for Sweden) have higher rates than the United States, with Canada's rate being nearly five times higher than the depreciation 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 A6 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 more than double those used of 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 U.S. and other countries all point to the desirability of revisiting estimates of depreciation rates for infrastructure assets in the United States.

4.7 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 are generally 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. The chart 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.



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.

5. Conclusion

Infrastructure is (or will be) a hot topic. This paper assesses and provides a broad overview of U.S. infrastructure from the perspective of the National Economic Accounts. Our intention is to provide some metrics useful for the debate about the adequacy of U.S. infrastructure. Our approach is intentionally descriptive, rather than analytical.

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, assess recent trends in quantities and prices, and highlight aspects of infrastructure measurement methodology that could benefit from additional research.

Our main findings fall into three broad categories: evidence on broad trends, adequacy of infrastructure, and observations on methodology. In terms of broad trends, we report that the investment share of basic infrastructure has fallen, while shares of social and digital infrastructure have increased. In terms of gross resources devoted to infrastructure, gross real investment per capita has gently drifted up, but net real investment per capita has barely risen as depreciation has absorbed a bigger share over time. Weakness in basic and social infrastructure during the past decade has been offset by strength in digital.

To help dig beneath these broad trends, we present two other types of data not typically available in the National Accounts. First, we develop (and present in the form of heat maps) experimental state-level data on gross real highway investment per capita. Second, we present data on maintenance expenditures for highways. With some additional work, it should be possible to develop maintenance expenditures for a wider set of infrastructure assets.

Regarding adequacy, we look at growth rates of real net capital stocks of infrastructure and the average age of the infrastructure stocks. With a few exceptions, the data are consistent with the popular narrative of underinvestment in infrastructure.

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. Finally, for digital infrastructure, data classifications are sometimes not granular enough to identify relevant assets. Some additional work here also likely would pay dividends.

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Appendix A.—Tables

Table A1.--Components (and net stock shares) of Infrastructure

	1947	1987	2017
Basic	**80%**	**65%**	**61%**
Water	4%	4%	4%
Sewer	4%	6%	5%
Conservation and development	7%	4%	3%
Power	17%	21%	19%
Electric	11%	18%	15%
Structures	9%	13%	12%
Equipment	2%	5%	4%
Gas	6%	4%	4%
Transportation	49%	31%	30%
Highways and streets	23%	21%	22%
Air transportation	1%	1%	2%
Water transportation	0%	1%	1%
Rail transportation	22%	6%	2%
Transit	2%	2%	2%
Social	**16%**	**27%**	**32%**
Public safety	1%	2%	2%
Education	11%	14%	19%
Health care	4%	11%	11%
Structures	4%	9%	9%
Equipment	0%	2%	3%
Digital	**4%**	**8%**	**7%**
Structures	3%	4%	4%
Equipment	1%	4%	3%

Table A2.--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, waste water 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 busses & trucks.
Social	
Public safety	Detention centers, jails, penitentiaries, prisons, police stations, sheriffs' offices, fire stations, rescue squads, 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 A3. -- Infrastructure Price Indexes

Average Annual Growth Rates

	1947-2018	1947-1987	1987-2018	2000-2018	2000-2010	2010-2018
GDP	**3.1%**	**3.9%**	**2.2%**	**1.9%**	2.1%	1.7%
Infrastructure	**3.6%**	**4.8%**	**2.2%**	**1.3%**	2.2%	0.1%
Basic	**4.0%**	**4.6%**	**3.2%**	**3.6%**	4.6%	2.3%
Water	4.0%	4.8%	3.0%	3.2%	4.3%	1.9%
Sewer	4.2%	5.0%	3.3%	3.7%	4.3%	2.9%
Conservation and development	3.8%	4.4%	3.1%	3.4%	3.9%	2.7%
Power	3.9%	4.8%	2.7%	2.7%	3.3%	2.0%
Transportation	4.1%	4.5%	3.7%	4.3%	5.6%	2.7%
Social	**3.7%**	**4.8%**	**2.2%**	**1.9%**	3.2%	0.4%
Public safety	3.9%	4.5%	3.2%	3.3%	3.0%	3.6%
Education	4.2%	4.7%	3.6%	3.9%	4.9%	2.5%
Health care	3.2%	4.6%	1.3%	0.0%	1.0%	-1.2%
Digital	**1.7%**	**4.2%**	**-1.3%**	**-3.8%**	-3.9%	-3.7%
Communications structures	3.1%	3.4%	2.7%	3.0%	4.3%	1.4%
Communications equipment*	-1.2%	2.3%	-5.4%	-7.9%	-8.3%	-7.4%
Communications software*	...	...	-2.0%	-1.6%	-2.3%	-0.7%
Computers*	...	...	-10.4%	-6.3%	-10.2%	-1.0%

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

Table A4. -- BEA Depreciation Rates and Service Lives

	Depreciation rates		Service lives	
	Fraumeni (1997)	BEA (current)	Fraumeni (1997)	BEA (current)
Government (federal, state, & 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 & streets	**.0152**	**.0202**	**60**	**45**
Conservation & 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, available at https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf.

Table A5.--Cross-Country Comparisons of Depreciation Rates for in National Accounts for Selected Infrastructure Assets (for countries using geometric depreciation rates)

	Hospitals	Schools	Roads
USA	.0188	.0182	.0202
Austria	.021	.020	.030
Canada	.061	.055	.106
Iceland	.025	.025	.030
Japan	.059	.059	.033
Norway	.040	.040	.033
Sweden	.0188	.0182	.0202

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

Table A6.--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 & 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 & solar	.0303	.065	30	34
Local transit	.0237	.075[b]	38	29[b]
Government (federal, state, & 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 & streets	.0202	.106[b]	45	29[b]
Conservation & 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	

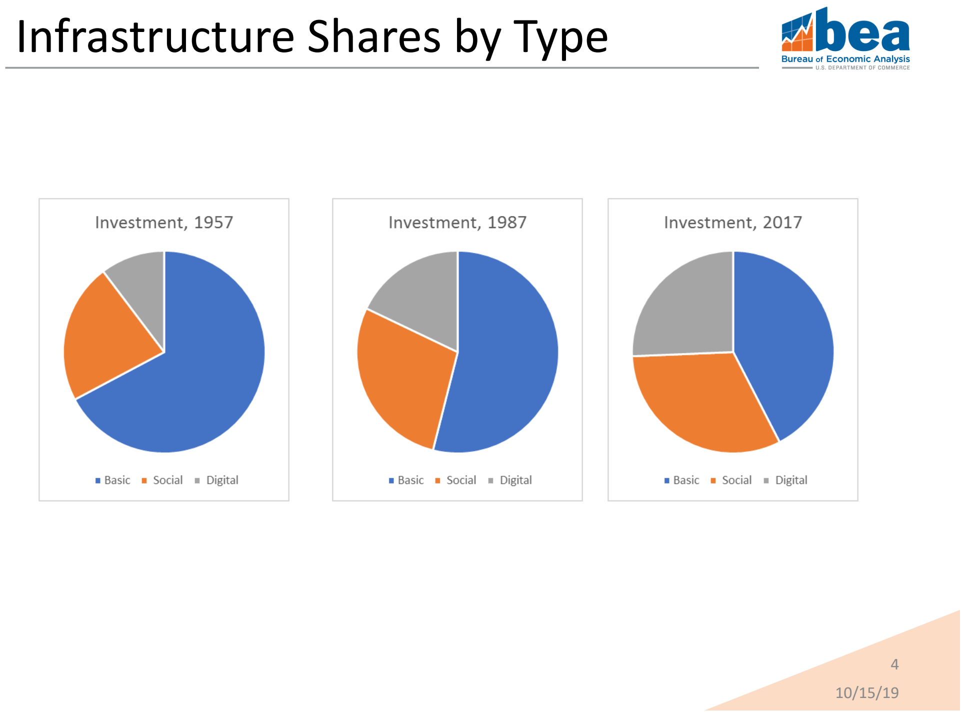
[a] The figures for Canada reported for government infrastructure are for the corresponding category of private buildings and nonbuildings. Estimates for Canada are from Giandrea, Kornfeld, Meyer and Powers (2018) unless noted otherwise.

[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 Bureau of Economic Analysis, "BEA Depreciation Estimates," available at https://apps.bea.gov/national/pdf/BEA_depreciation_rates.pdf

Appendix B.—Graphs

Figure 1

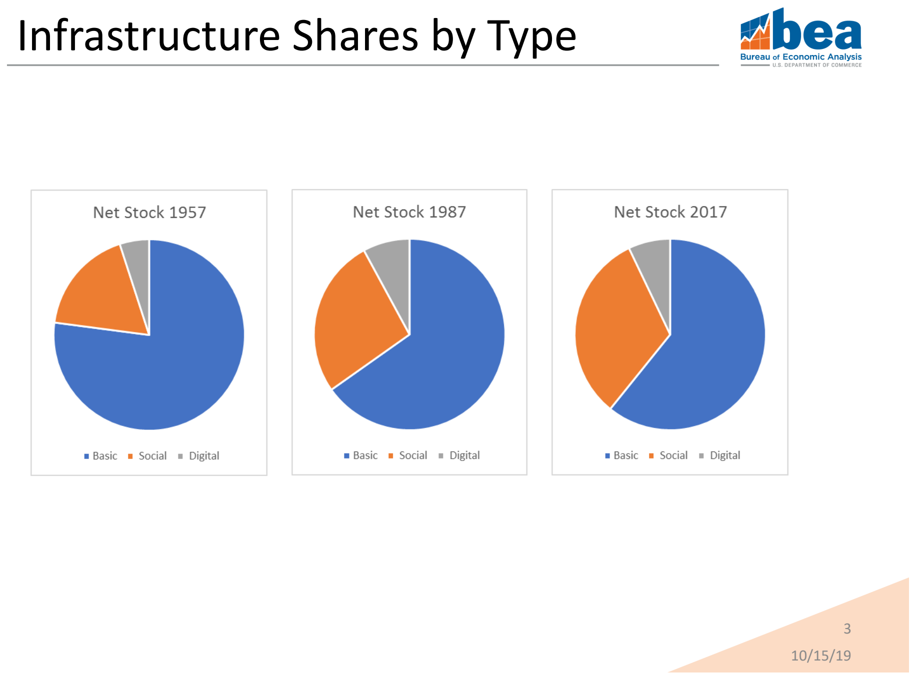


Infrastructure Shares by Type

4

10/15/19

Figure 2

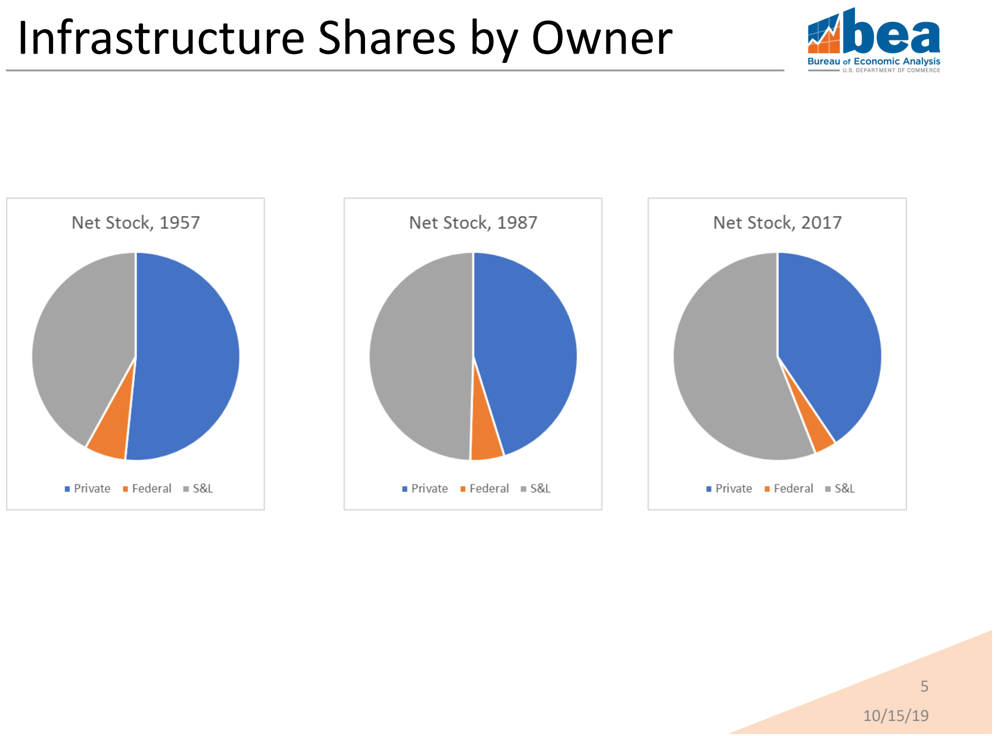


Infrastructure Shares by Type

3

10/15/19

Figure 3



Infrastructure Shares by Owner

5
10/15/19

Figure 4

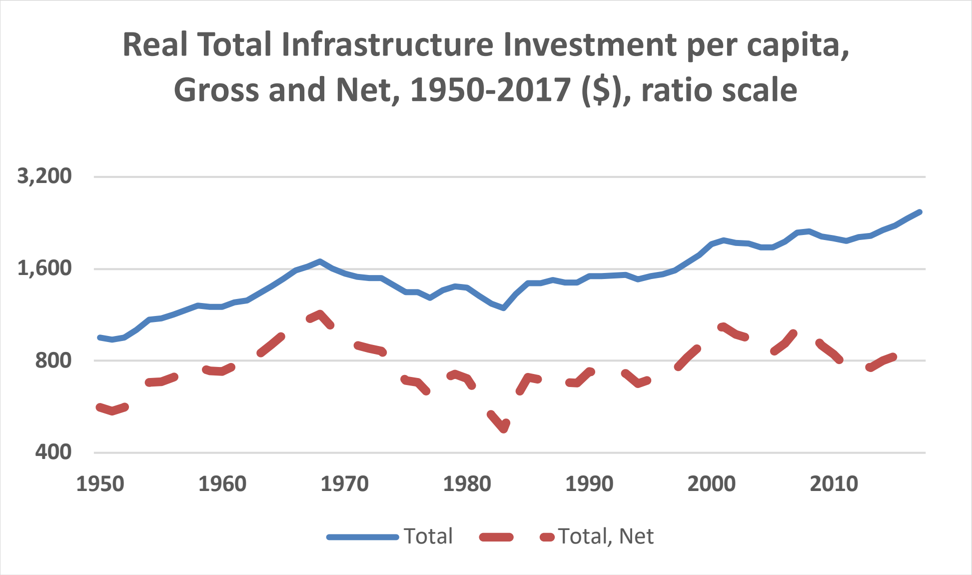


Figure 5

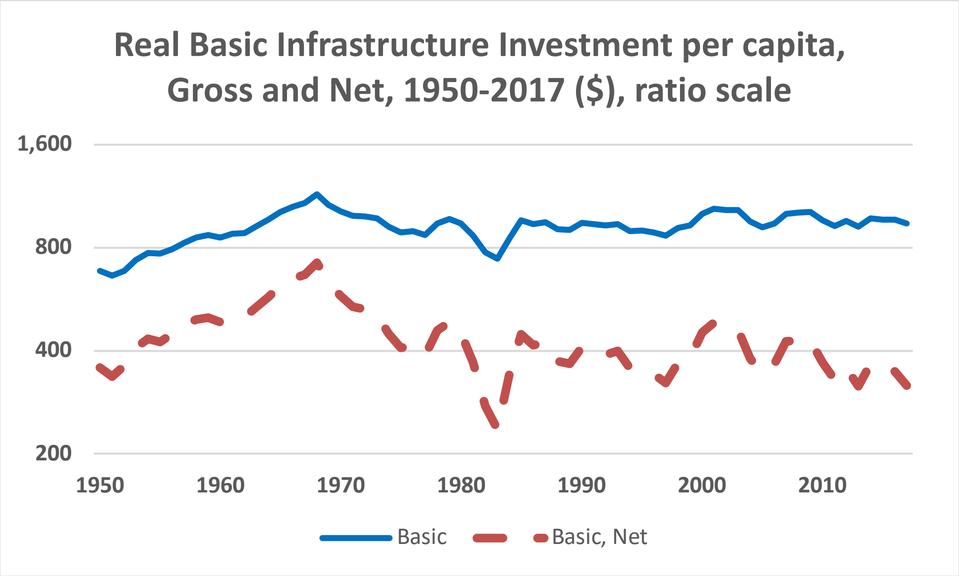


Figure 6

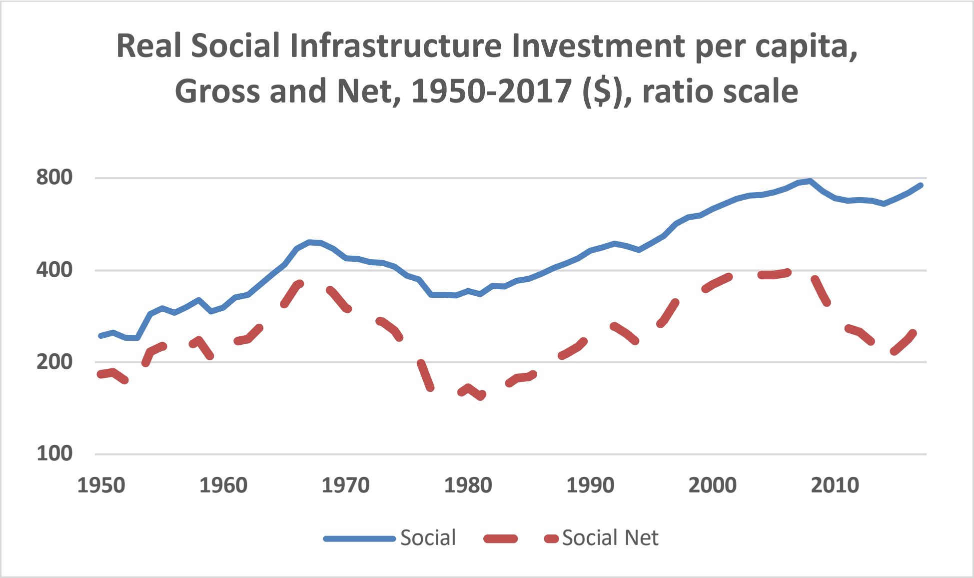


Figure 7

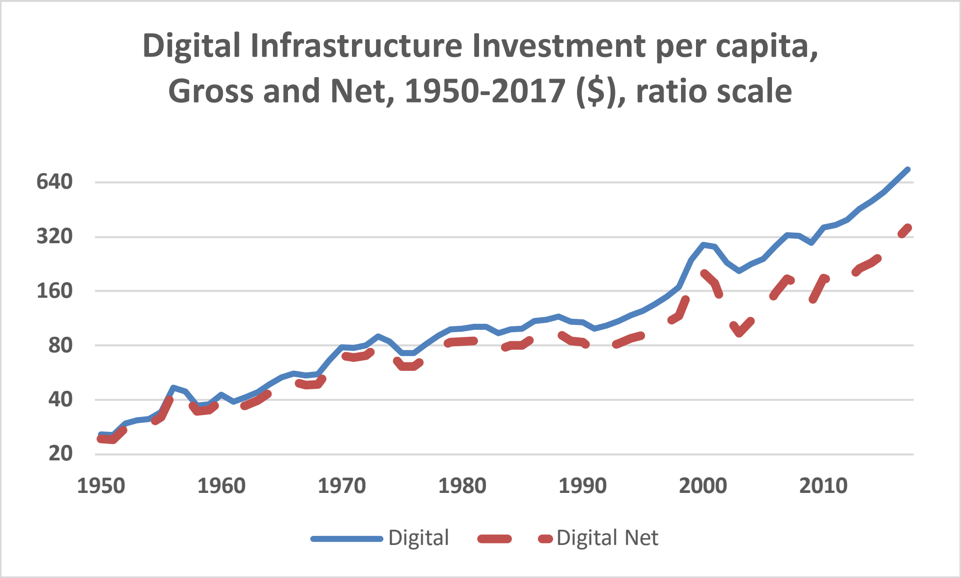


Figure 8

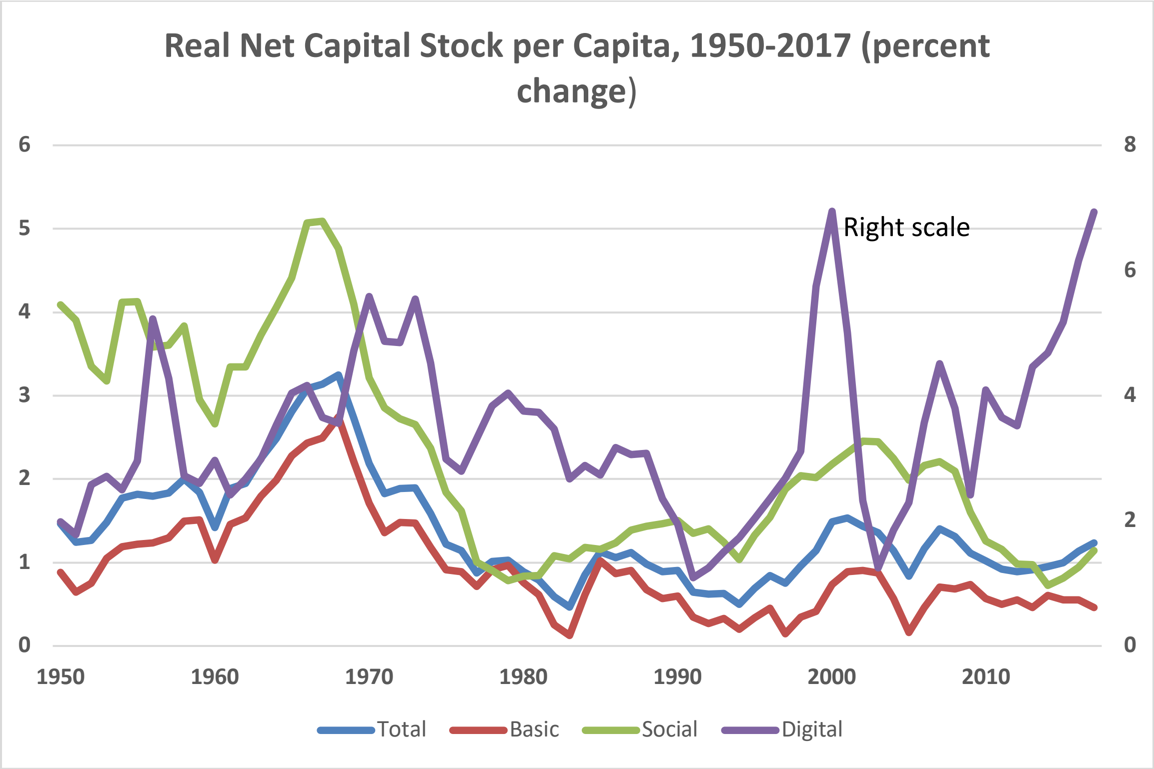

Real Net Capital Stock per Capita, 1950-2017 (percent change)
6
5
4
3
2
1
0
8
6
4
2
0
1950
1960
1970
1980
1990
2000
2010
Right scale
Total
Basic
Social
Digital

Figure 9

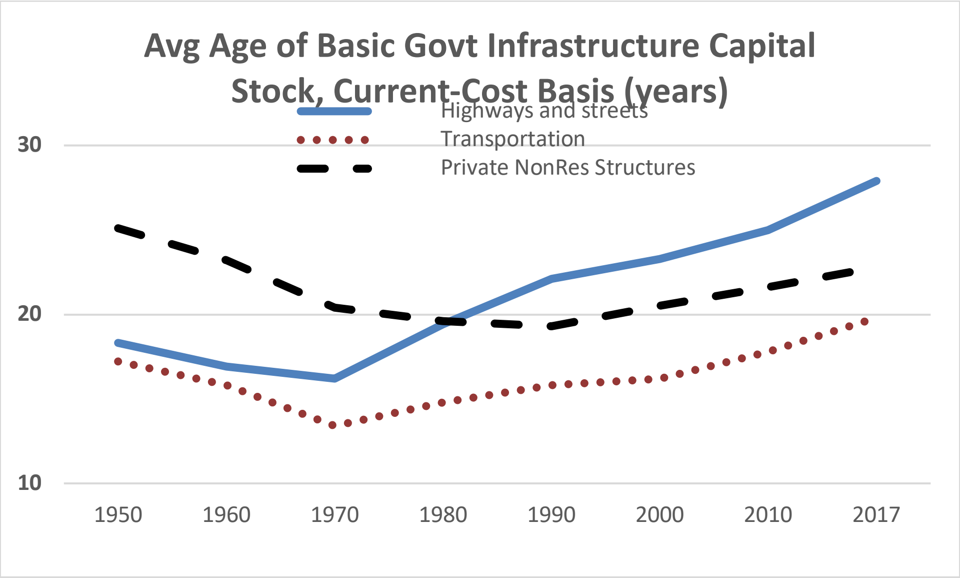


Figure 10

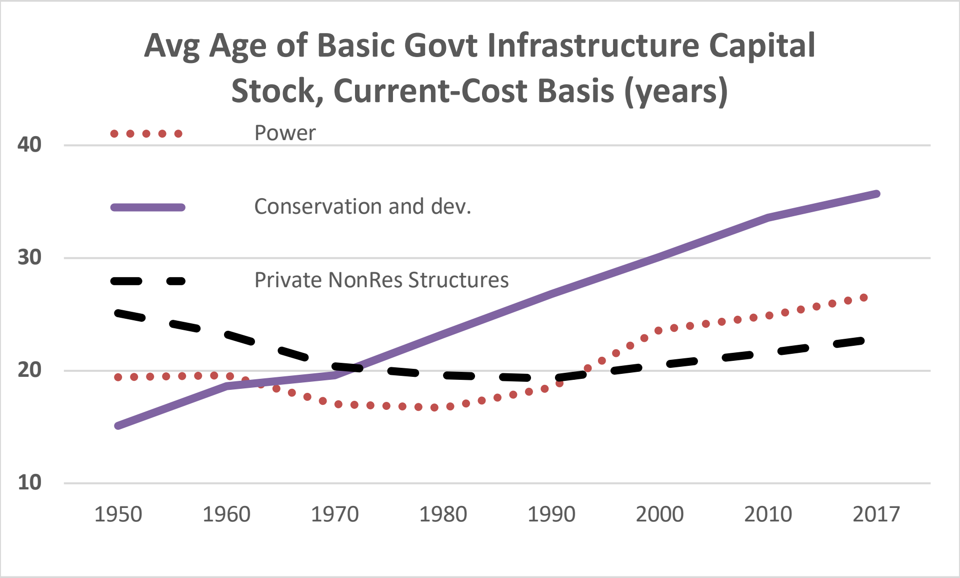


Figure 11

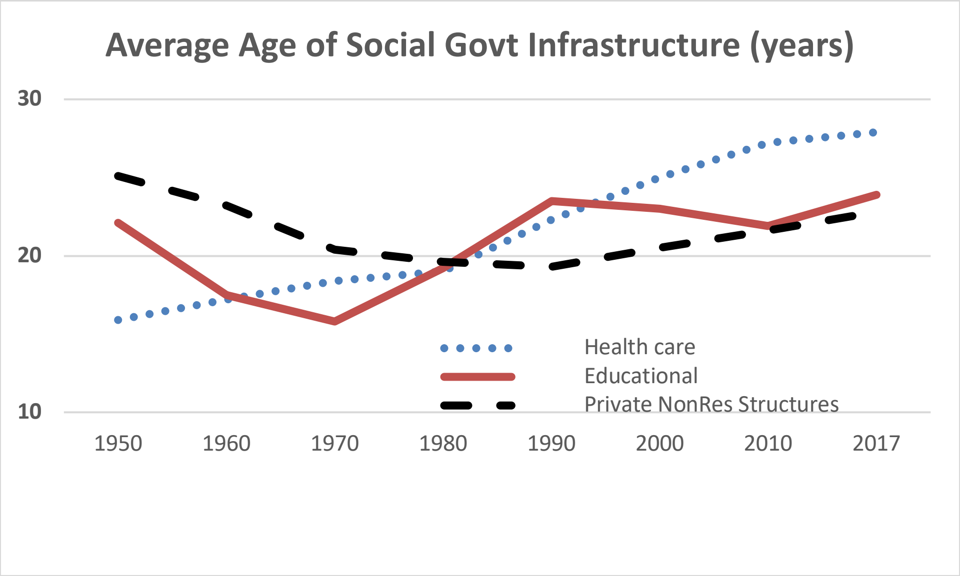
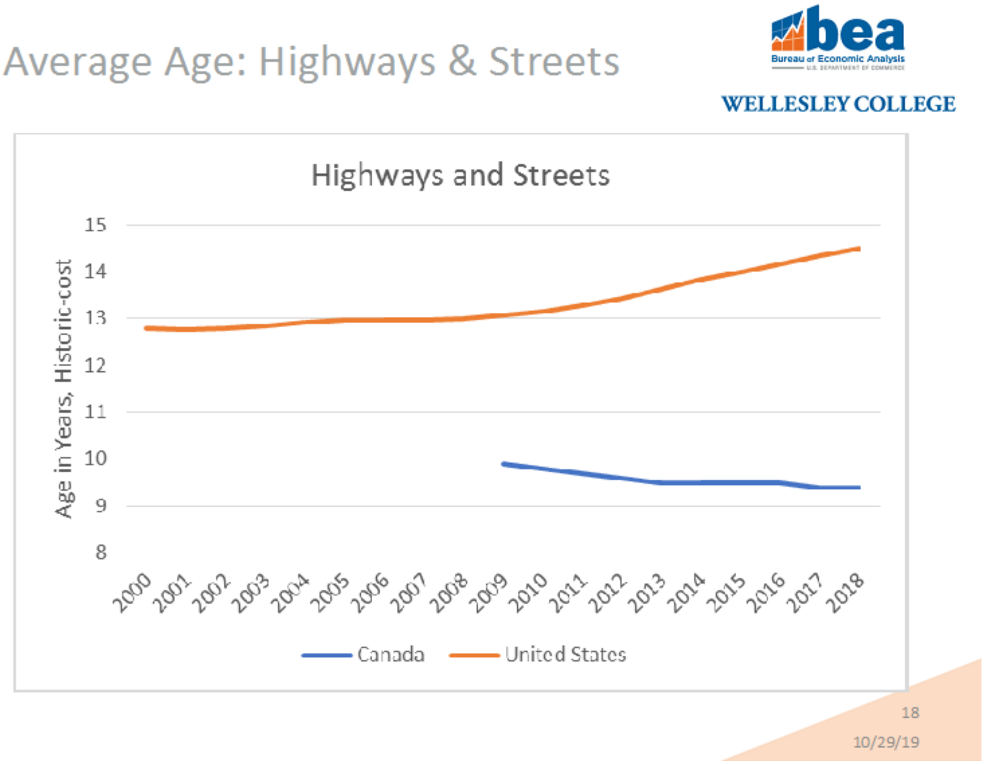


Figure 12

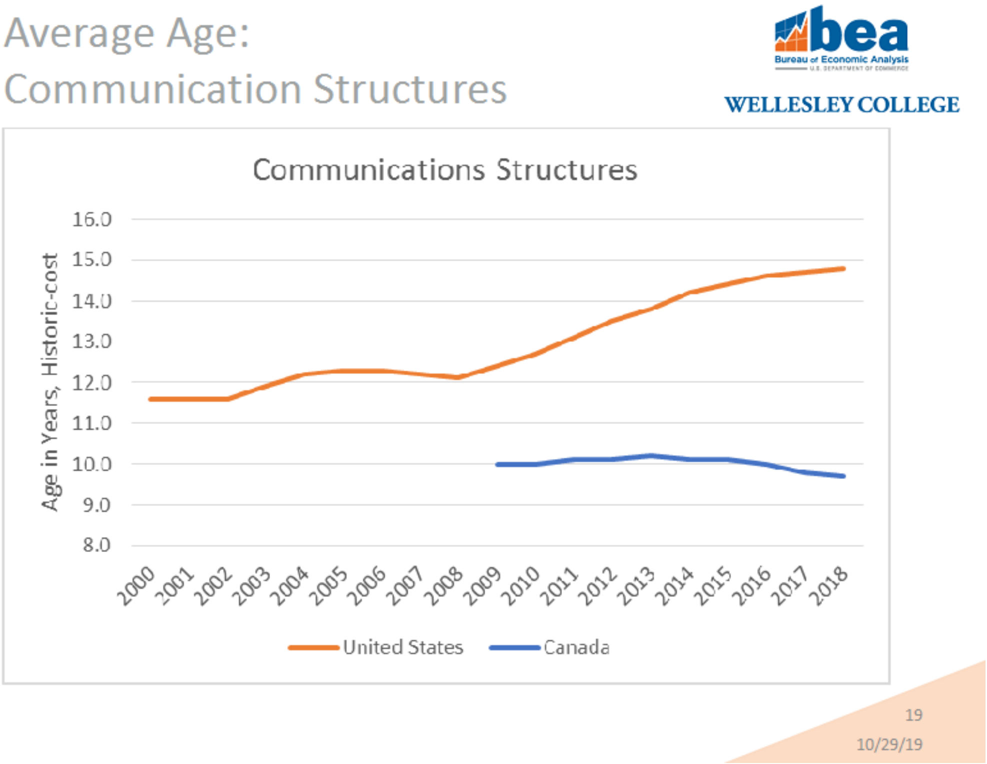

Average Age: Highways & Streets

WELLESLEY COLLEGE

18

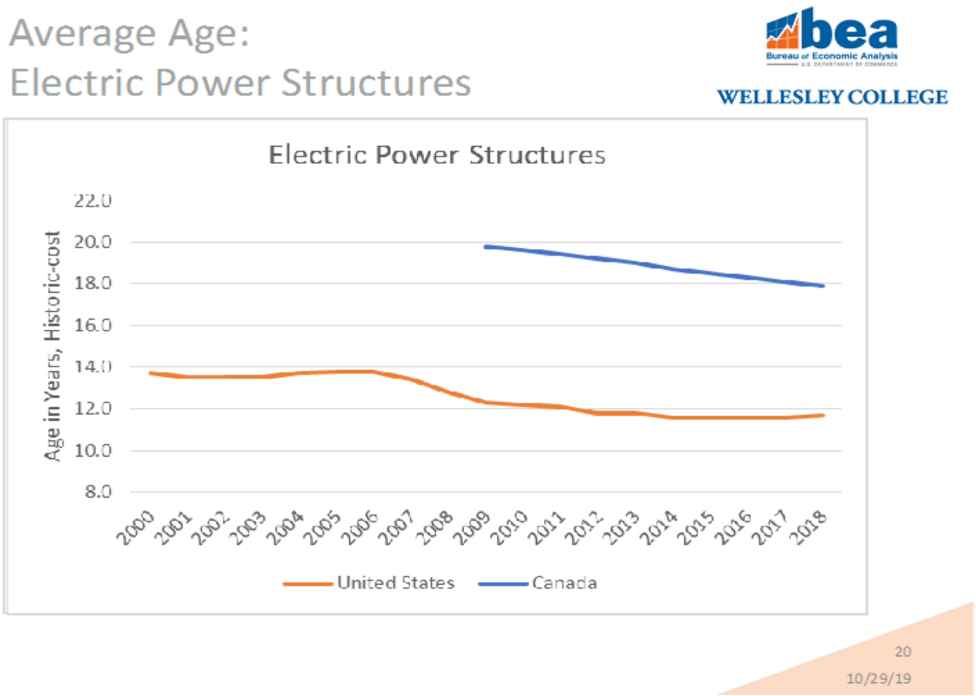
10/29/19

Figure 13



Average Age:
Communication Structures

Figure 14



Average Age:
Electric Power Structures

Figure 15

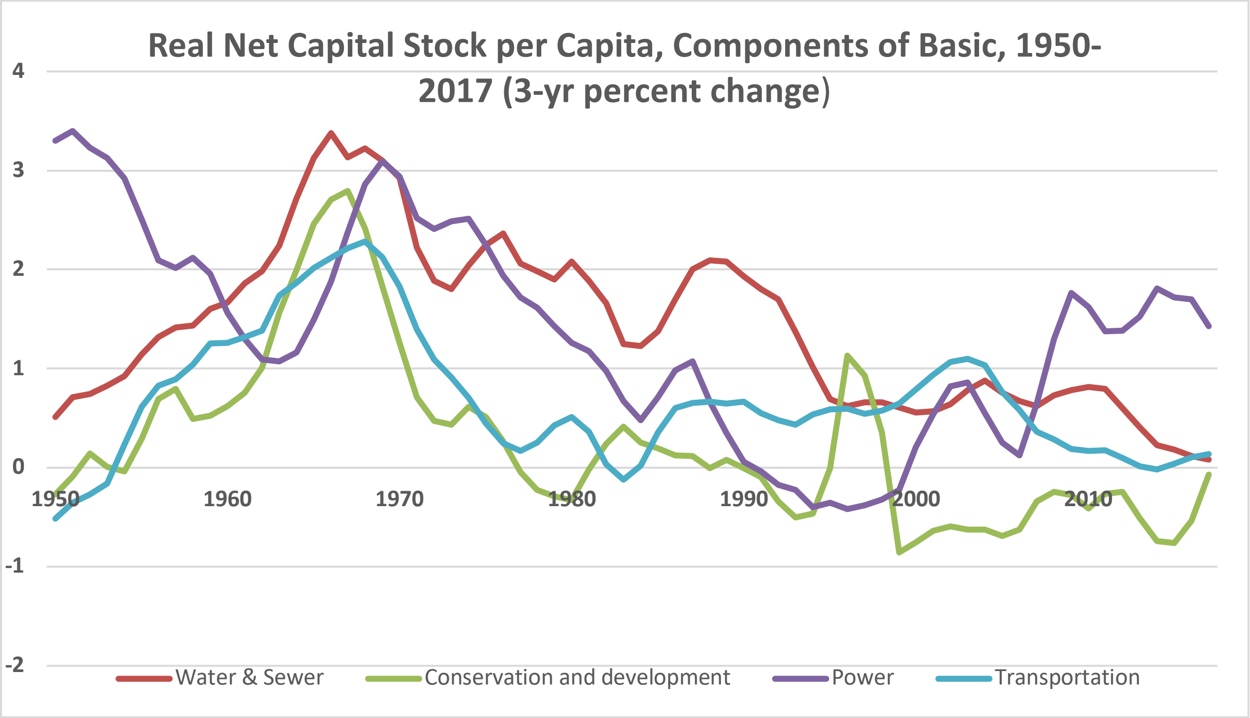

Real Net Capital Stock per Capita, Components of Basic, 1950-2017 (3-yr percent change)
4
3
2
1
0
-1
-2
1950
1960
1970
1980
1990
2000
2010
Water & Sewer
Conservation and development
Power
Transportation

Figure 16

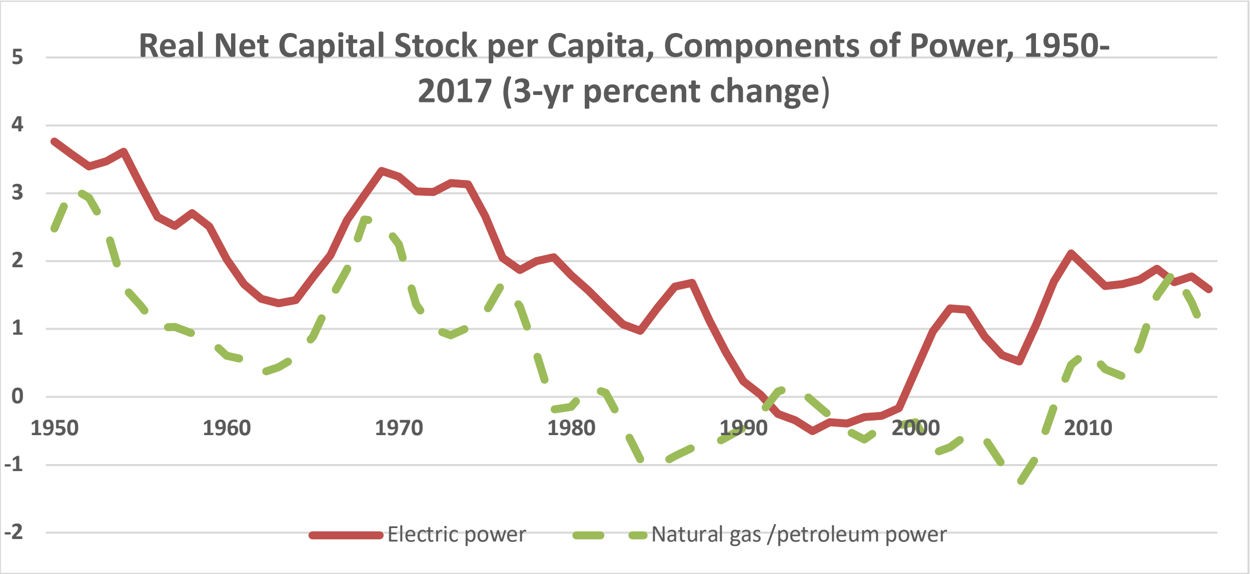


Figure 17

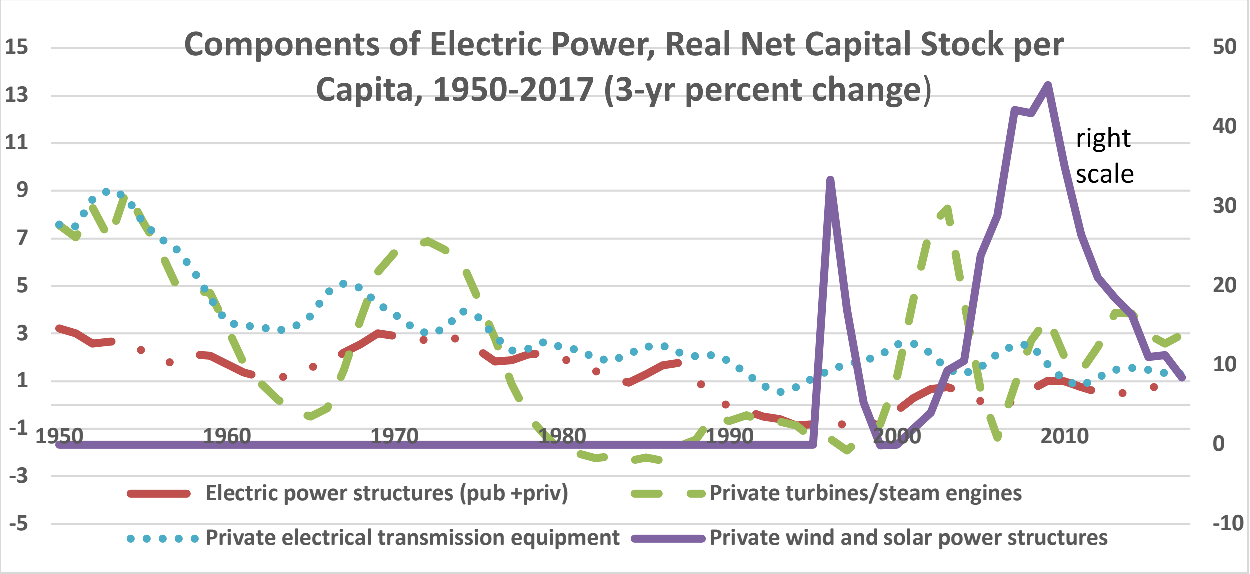


Figure 18

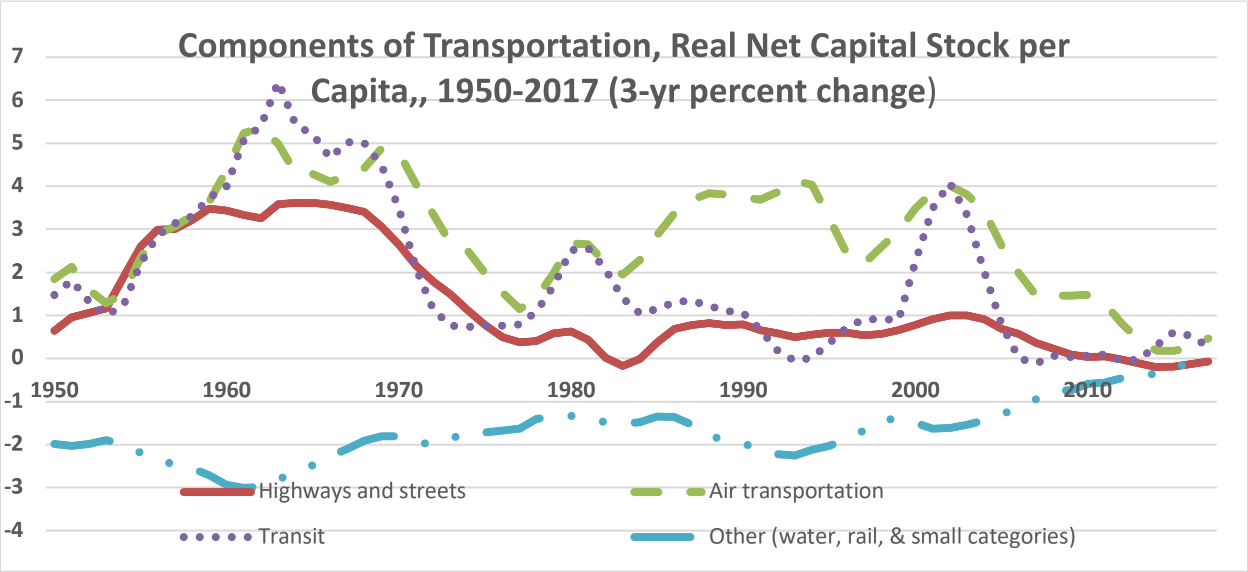


Figure 19

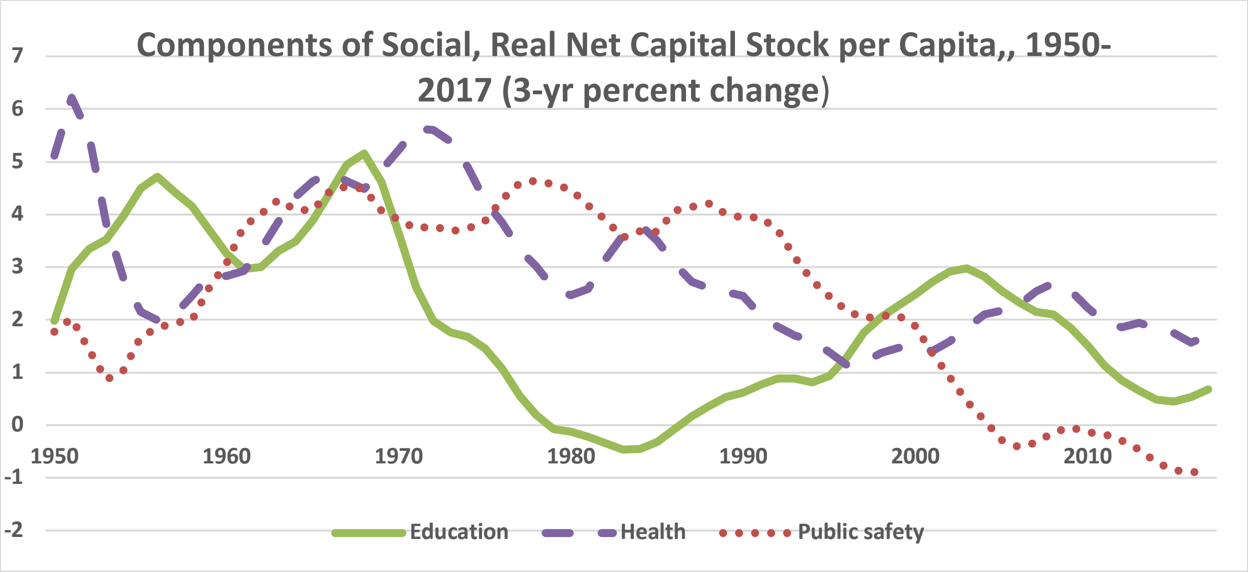


Figure 20

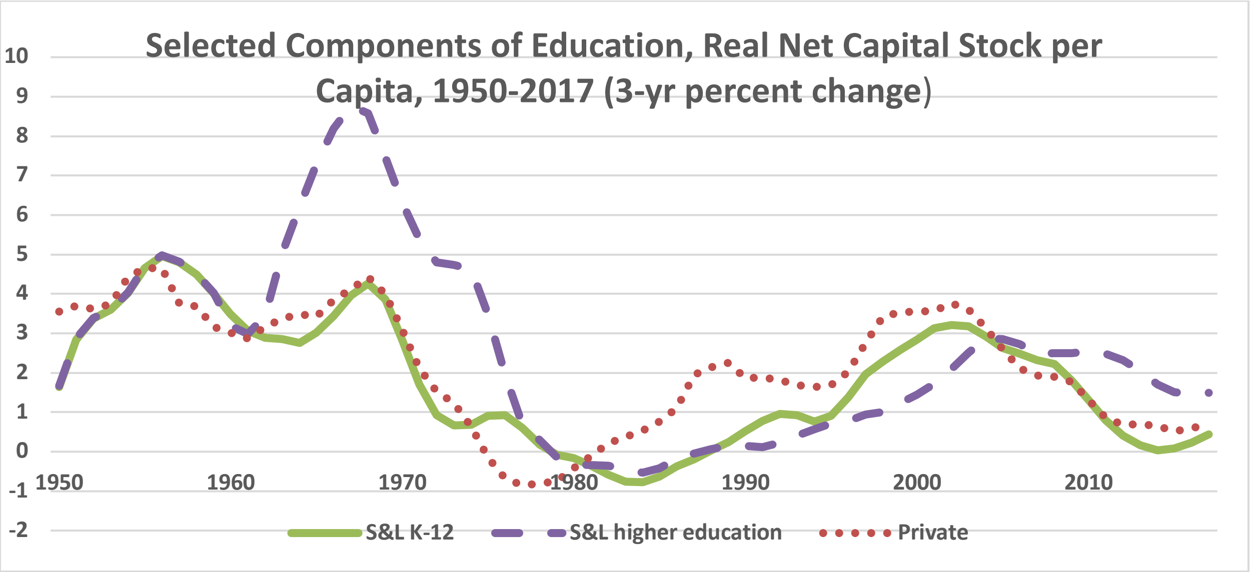


Figure 21

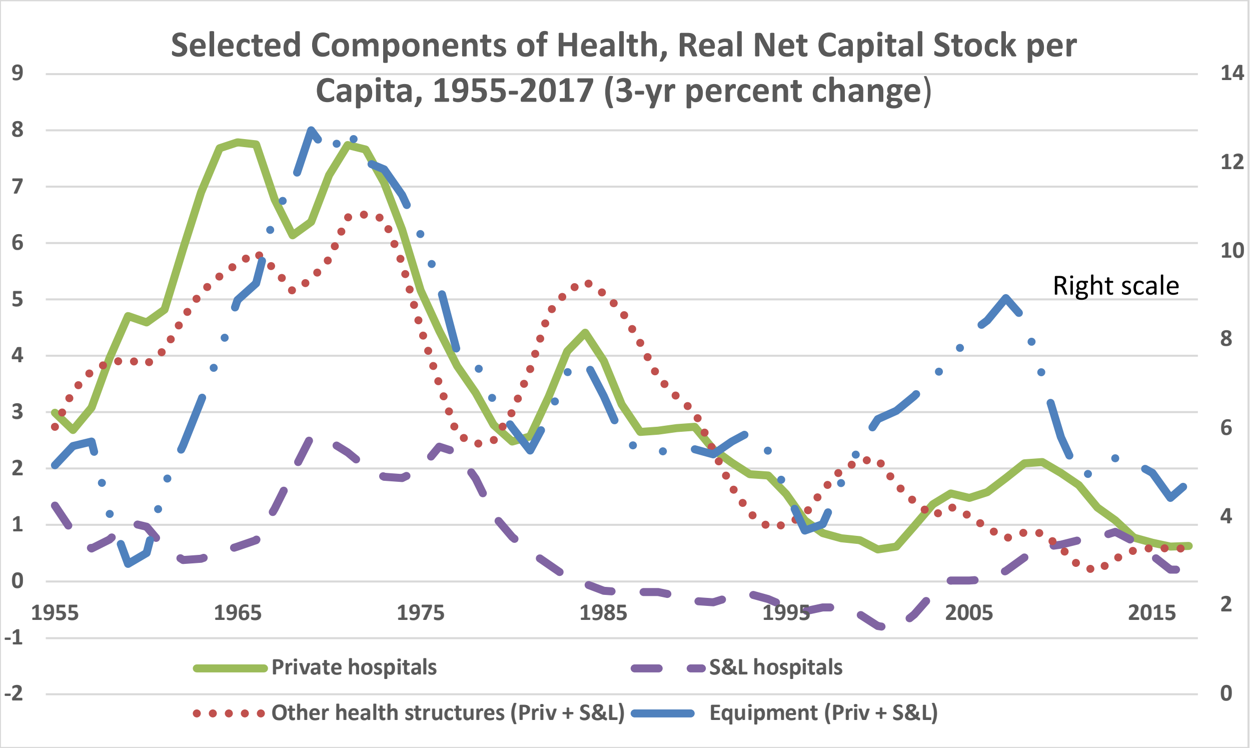


Figure 22

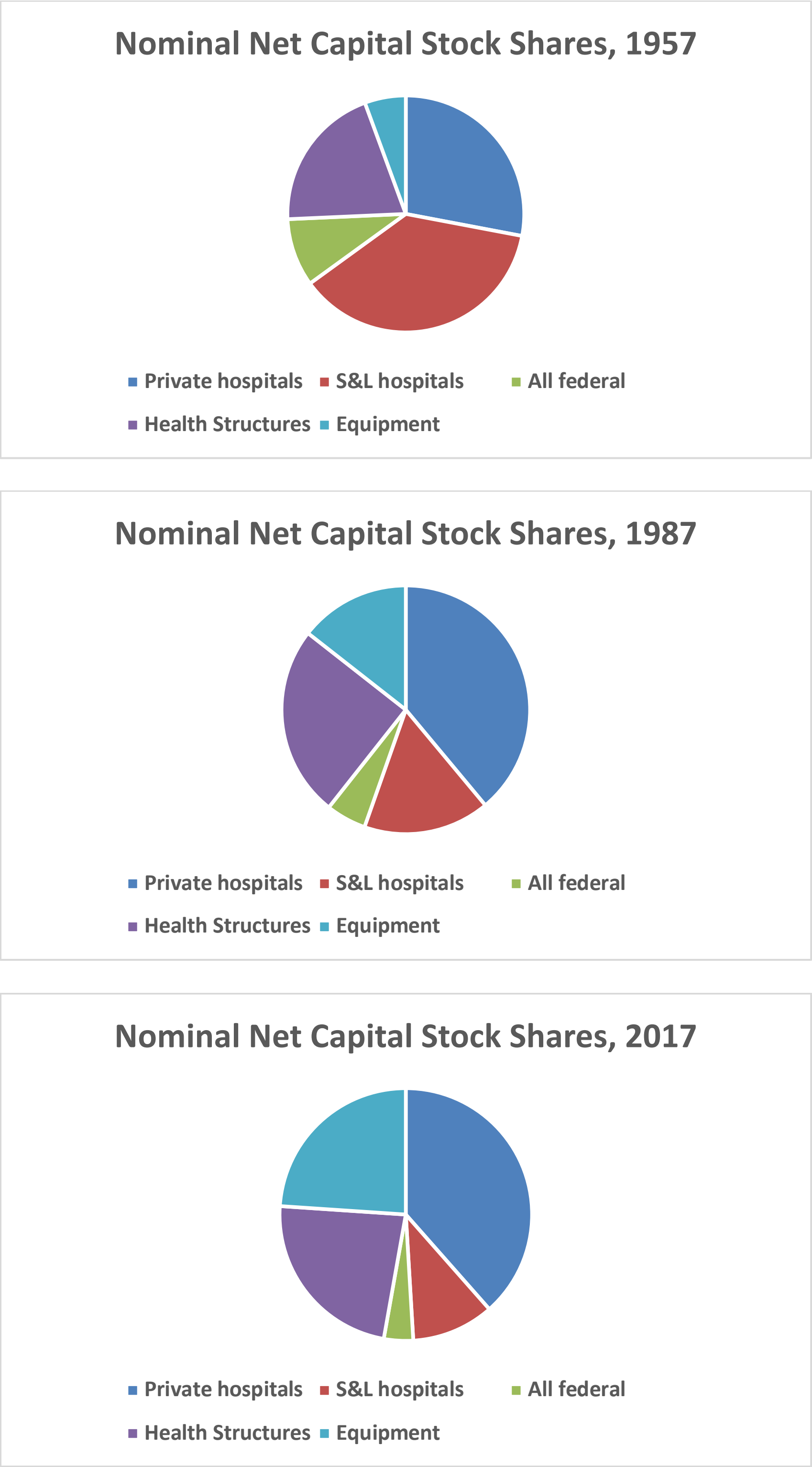

Nominal Net Capital Stock Shares, 1957
Private hospitals
S&L hospitals
All federal
Health Structures
Equipment
Nominal Net Capital Stock Shares, 1987
Private hospitals
S&L hospitals
All federal
Health Structures
Equipment
Nominal Net Capital Stock Shares, 2017
Private hospitals
S&L hospitals
All federal
Health Structures
Equipment

Figure 23

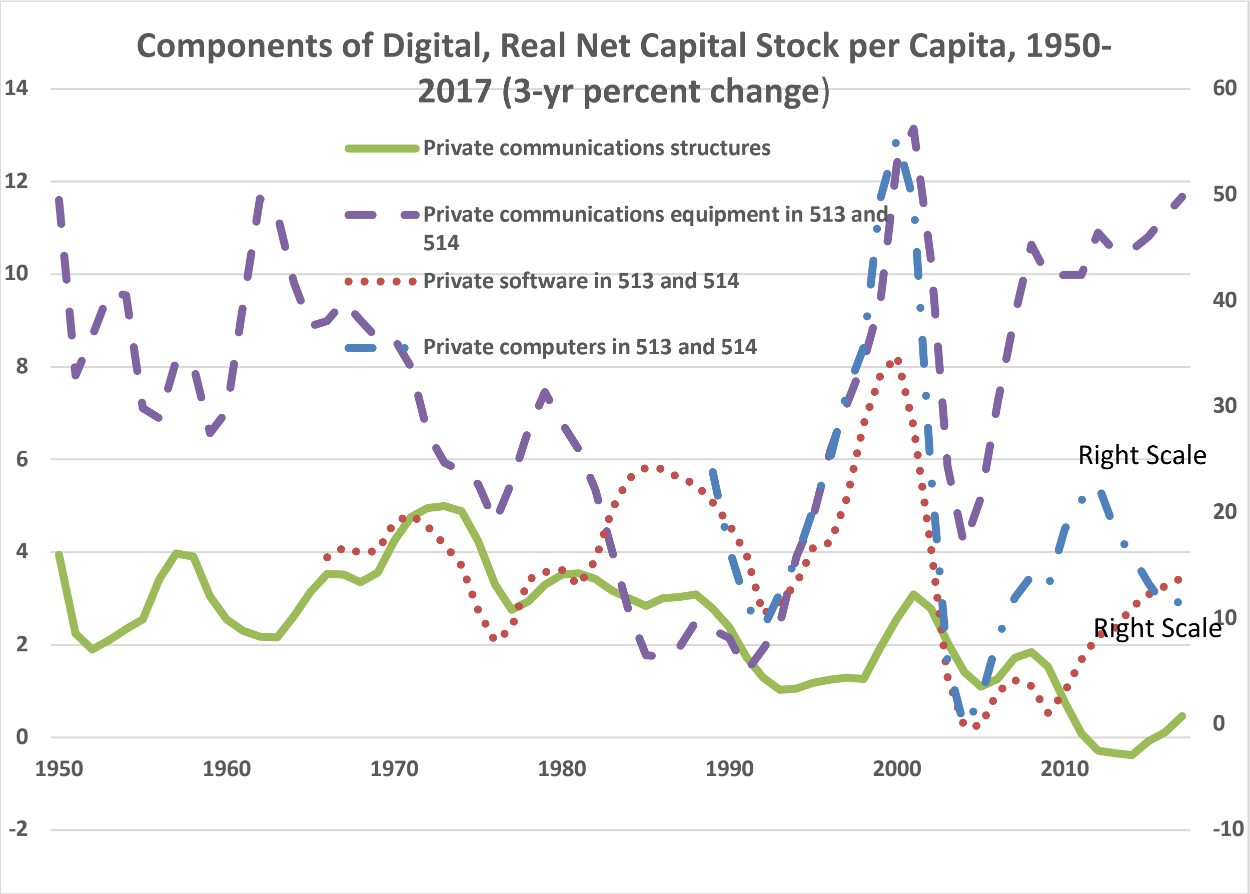
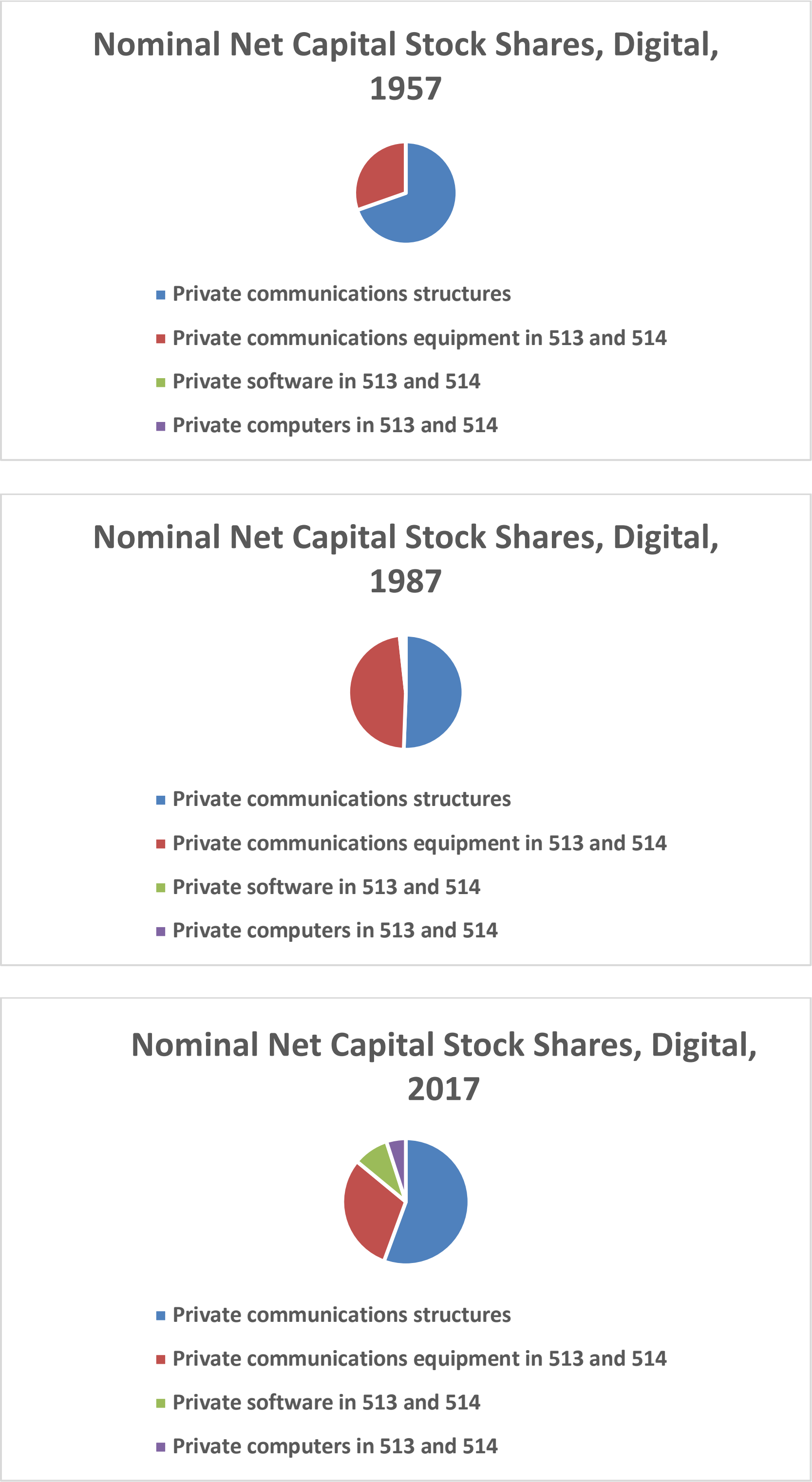

Components of Digital, Real Net Capital Stock per Capita, 1950-2017 (3-yr percent change)
Private communications structures
Private communications equipment in 513 and 514
Private software in 513 and 514
Private computers in 513 and 514
Right Scale
Right Scale
14
12
10
8
6
4
2
0
-2
60
50
40
30
20
10
0
-10
1950
1960
1970
1980
1990
2000
2010

Figure 24



Nominal Net Capital Stock Shares, Digital, 1957

Nominal Net Capital Stock Shares, Digital, 1987

Nominal Net Capital Stock Shares, Digital, 2017

Figure 25

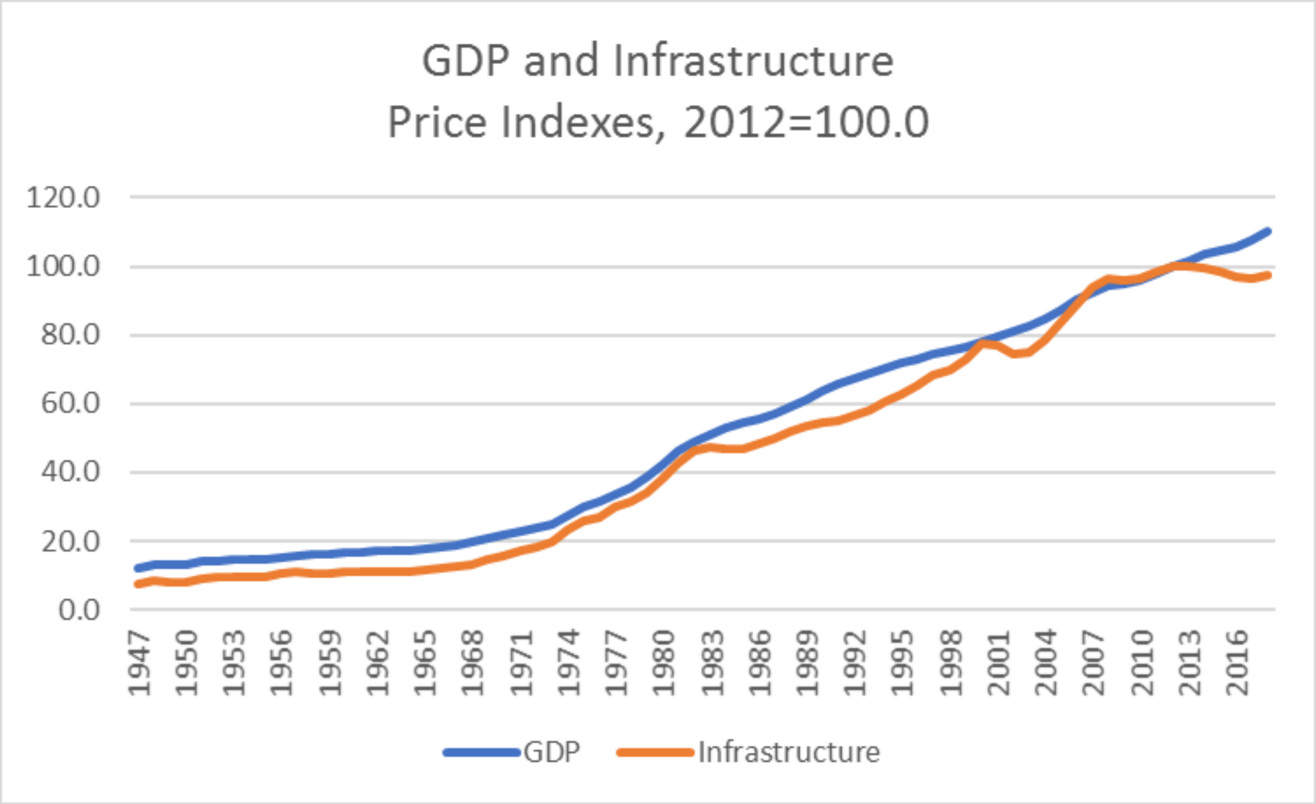


Figure 26

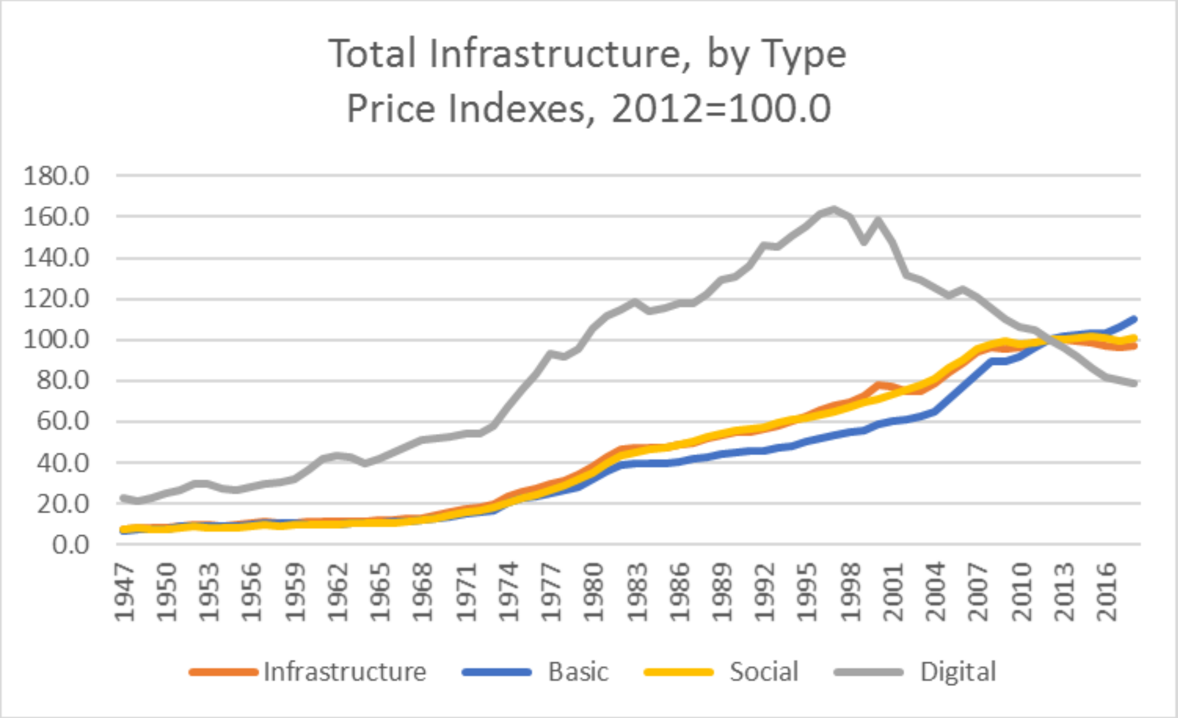


Figure 27

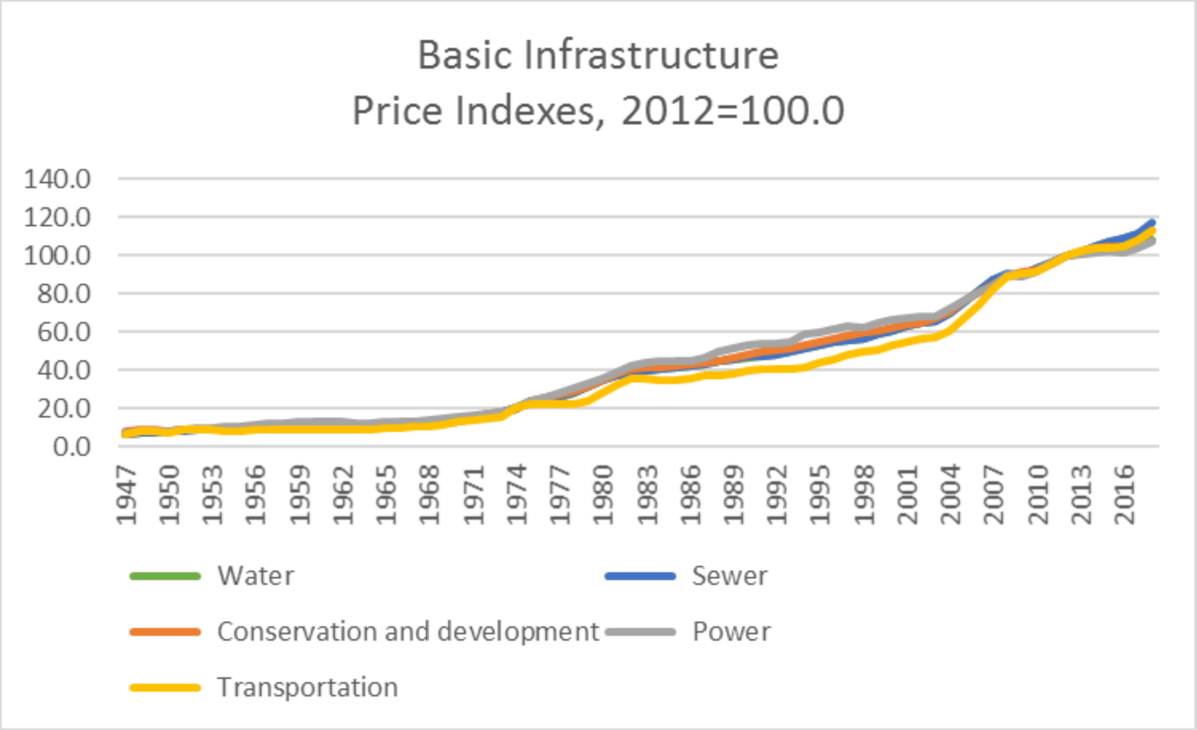


Figure 28

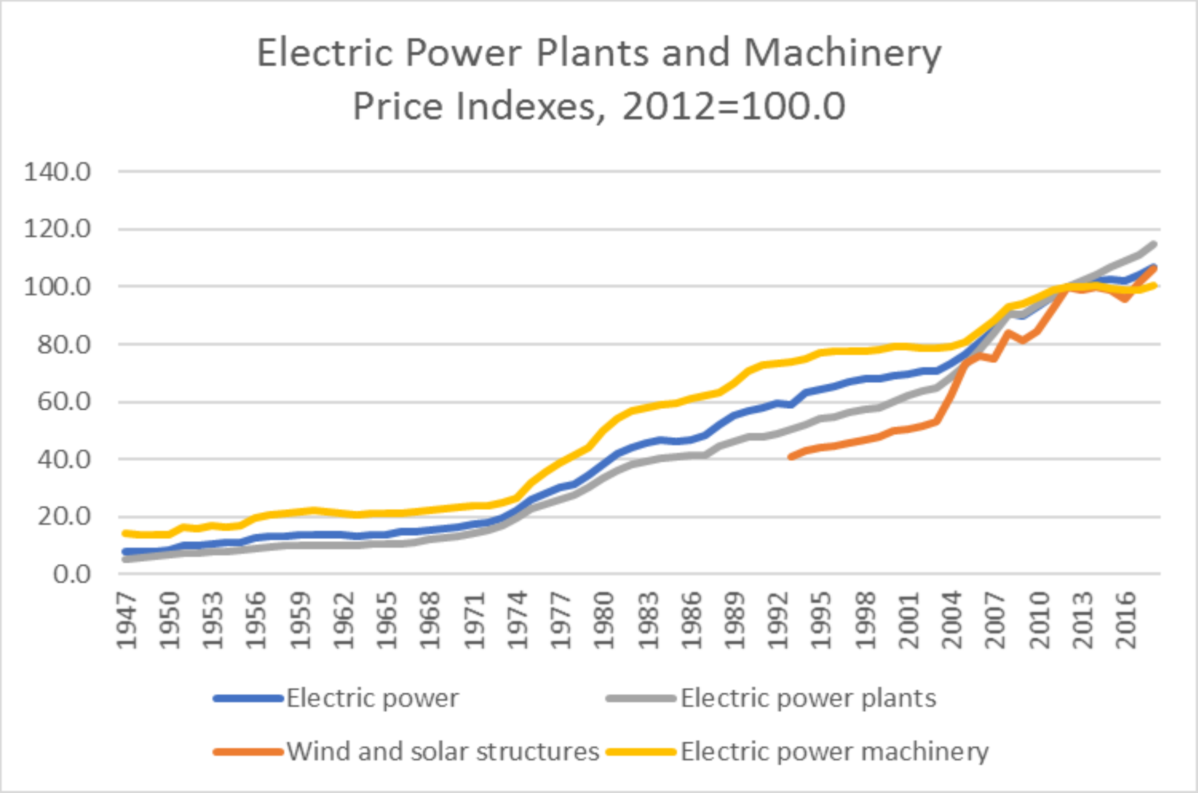


Figure 29

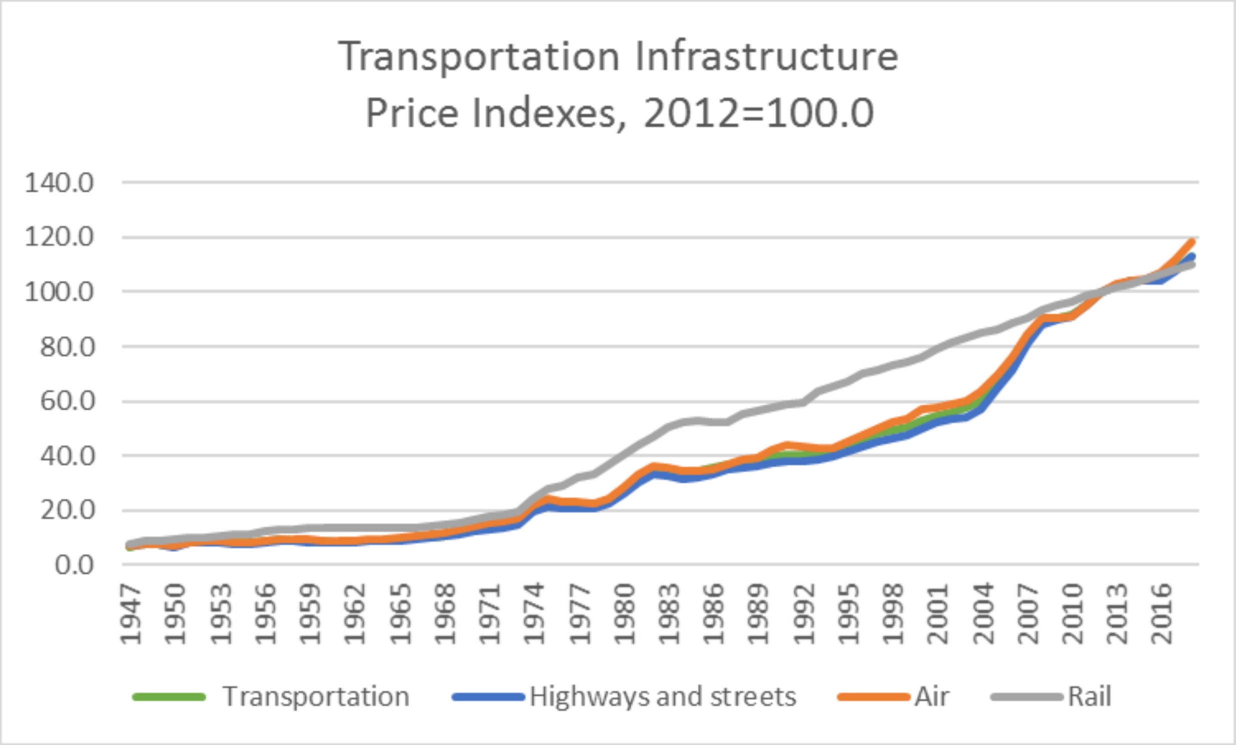


Figure 30

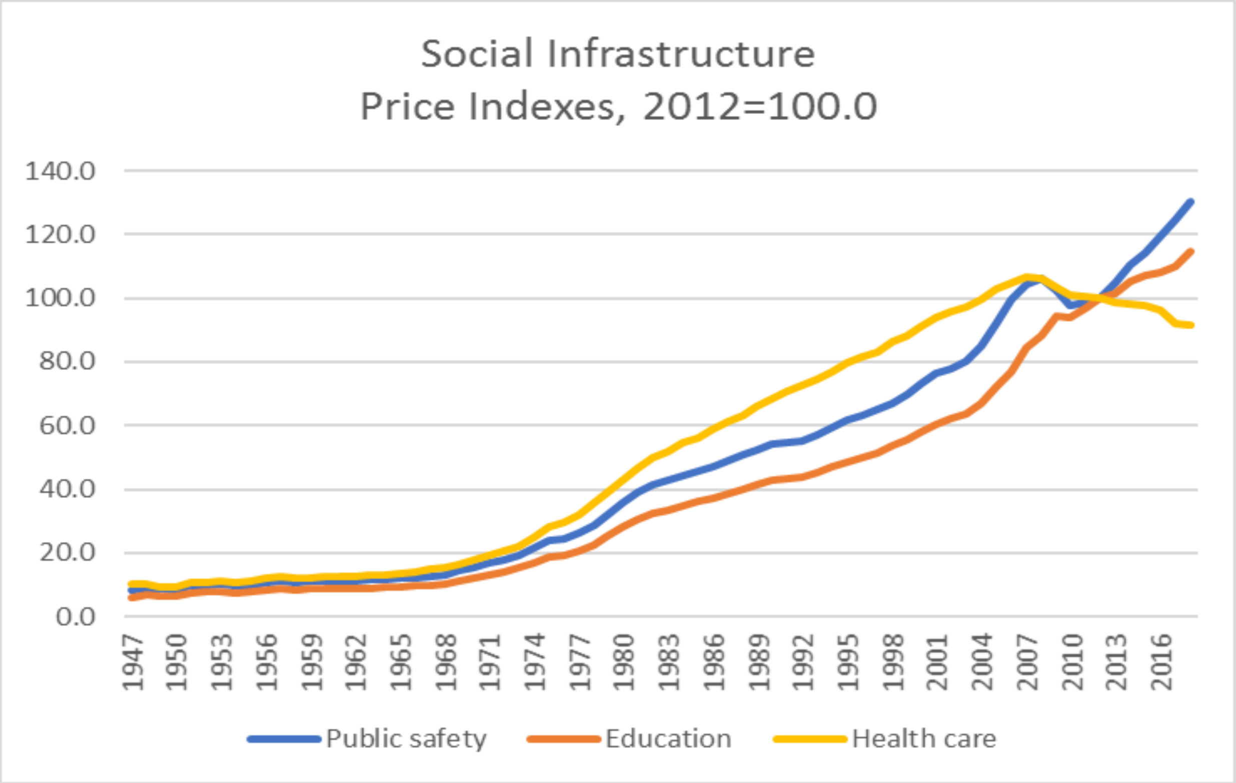


Figure 31

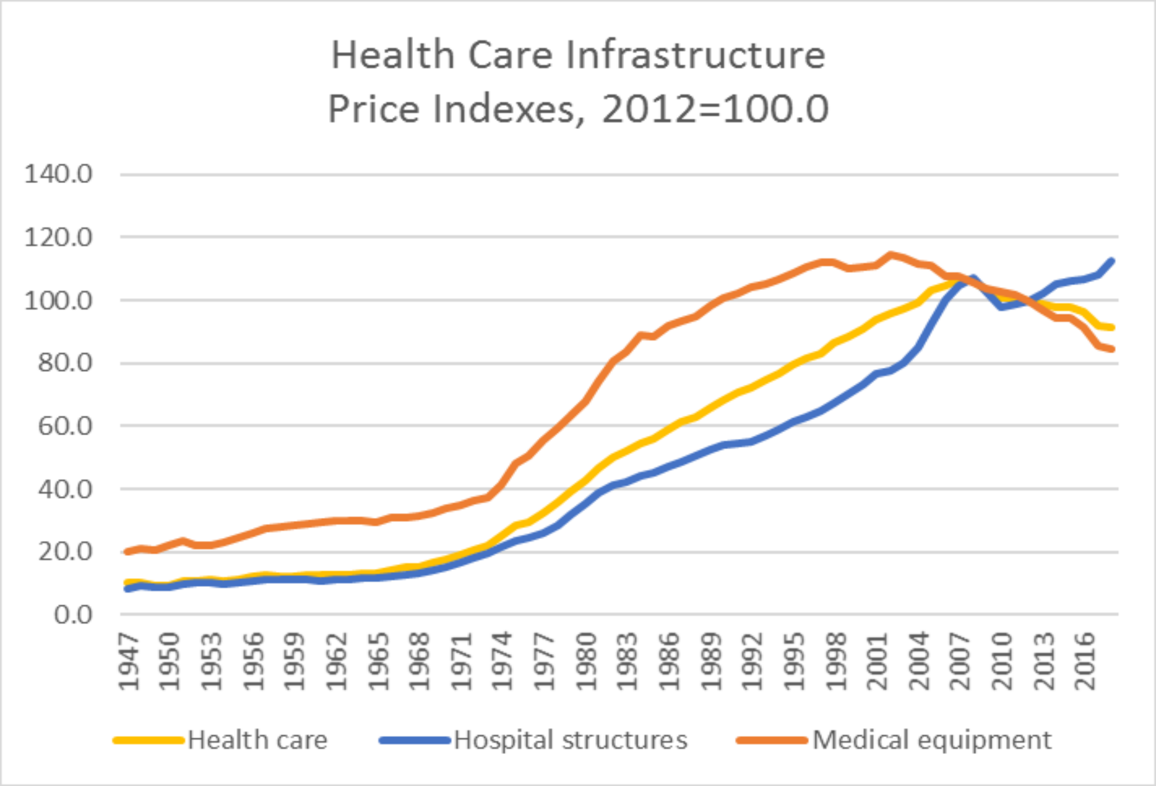


Figure 32

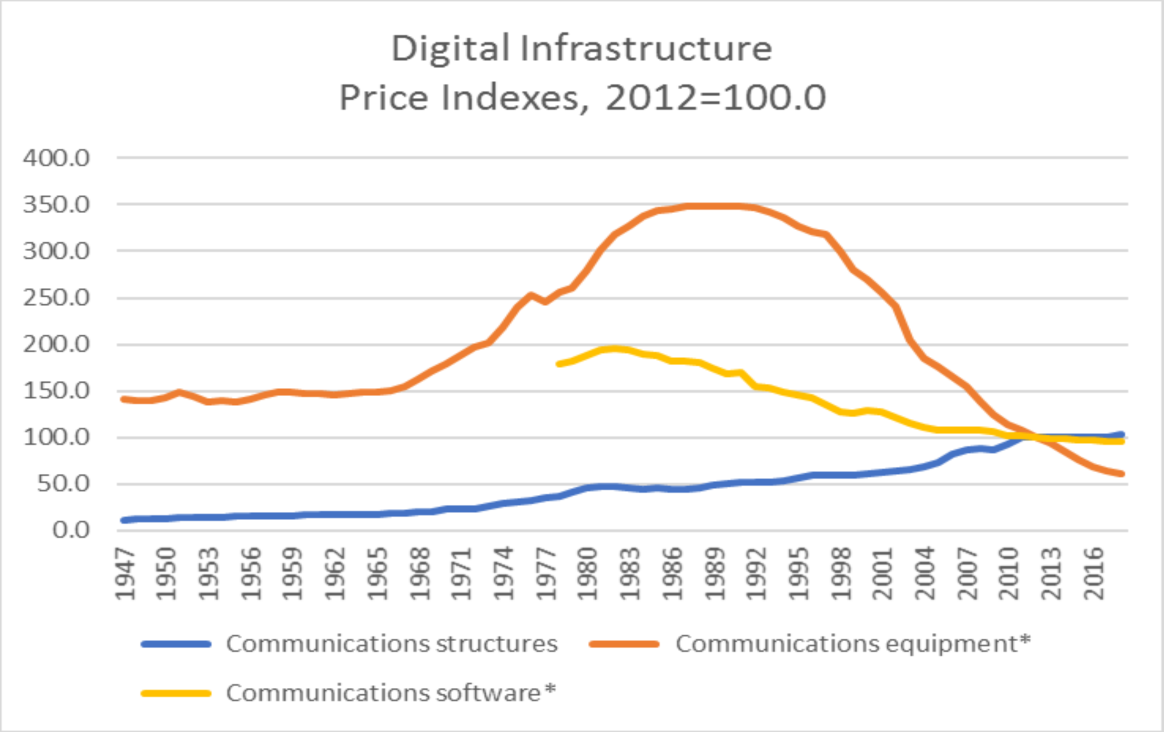
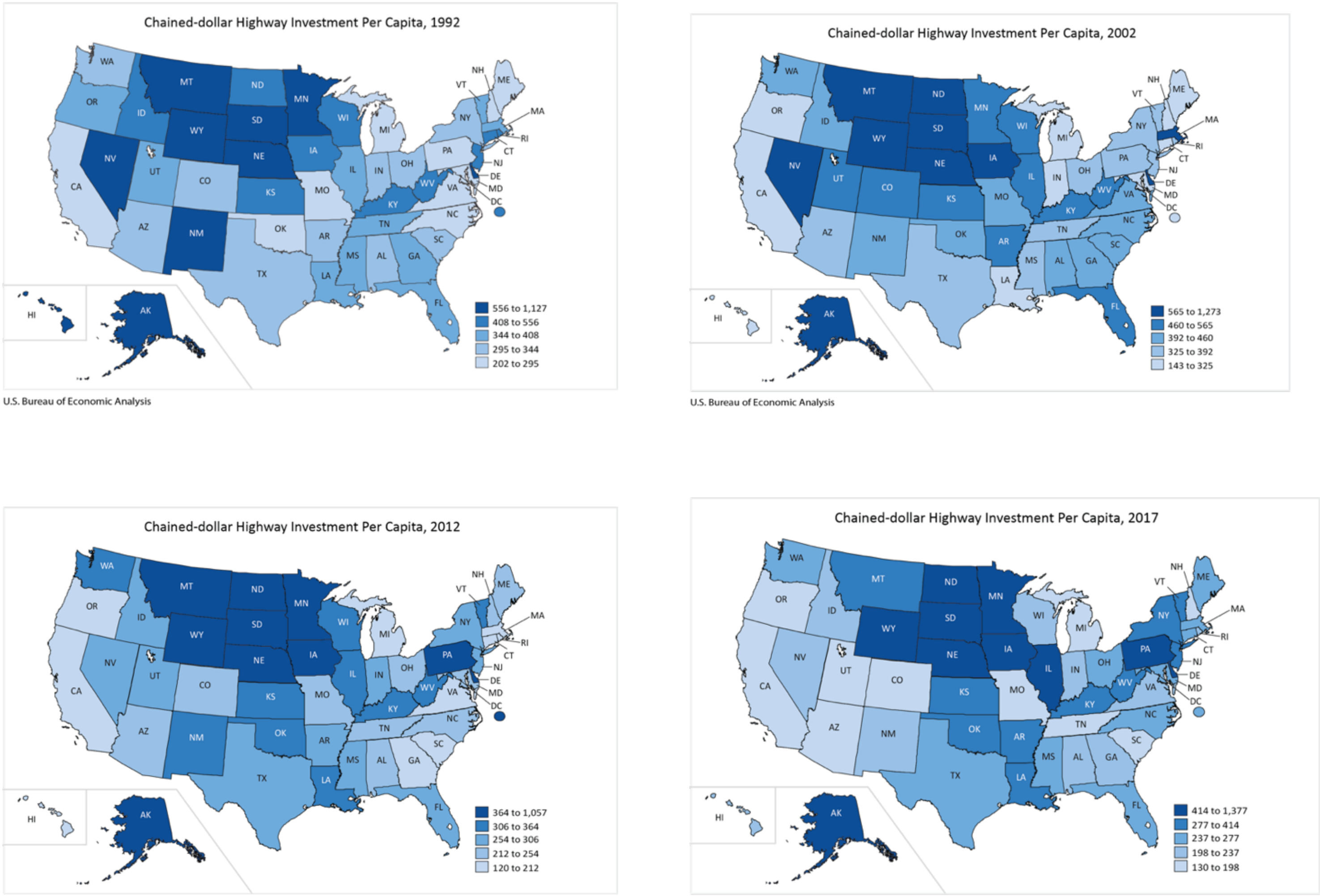


Figure 33
Gross Highway real (chained) investment per capita heat maps: 1992, 2002, 2012, 2017



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