Chapter 4

Infrastructure Investment to Boost Productivity

Concerns about the state of our Nation's infrastructure have become commonplace. We systematically face excess demand, quality degradation, and congestion when using our public assets—as, for example, on many of our urban roads and highways. Without price signals to guide the users and suppliers of our Nation's infrastructure, we use our existing assets inefficiently, fail to properly maintain them, and do not invest to add needed capacity. Furthermore, complex, overlapping, and sometimes contradictory rules and regulations deter and delay investors from adding to or improving existing capacity.

The central infrastructure problem facing policymakers is how to resolve this mismatch between the demand for and supply of public sector capital, both by using our existing assets more efficiently and by adjusting long-run capacity to efficient levels. Allowing prices to have a larger role in guiding consumption and investment decisions will be key to achieving the positive growth and productivity effects that infrastructure assets can provide. We estimate that a 10-year, $1.5 trillion infrastructure investment initiative could add between 0.1 and 0.2 percentage point to average annual real growth in gross domestic product under a range of assumptions regarding productivity, timing, and other factors.

To achieve growth at the higher end of this range, we suggest four key actions for policymakers to consider. First, the Federal regulatory structure must be streamlined and improved—while ensuring the achievement of health, safety, and environmental outcomes. Conflicting, unduly complex, and uncoordinated rules and regulations can impede investments in—and significantly delay—the delivery of needed infrastructure, an especially salient issue in the energy and telecommunications sectors, as discussed in this chapter. Addressing these issues will take time but will generate significant public benefits, and several recent Federal actions have begun this process, including President Trump's August 15, 2017, Executive Order to reduce unnecessary delays and barriers to infrastructure investment.

Second, additional resources can be secured for infrastructure investment, turning to some combination of user charges, specific taxes, or general tax revenues. Although public resources are important, this chapter emphasizes the role of user fees based on marginal costs. Such user charges—which typically are set by States and local governments and are collected from those who directly benefit from publicly provided roads, water facilities, and other types of infrastructure—will encourage efficiency in use, provide signals from consumers and to suppliers about the value of future investments, and generate revenues. In the case of roads and highways, for example, fuel taxes have historically acted as imperfect user fees, but conventional funding models are now under pressure from rising fuel efficiency and the use of electric vehicles, and congestion costs are high and rising in many urban areas. Innovations such as user fees for vehicle miles traveled—as are being piloted in Oregon, for example—and highway tolls that vary with congestion can increase efficiency and raise needed revenues to pay for infrastructure improvements and additions to capacity.

Third, the Federal government can support the use of innovative financing options such as public-private partnerships that will more efficiently utilize the total capital available from the public and private sectors and lower its cost. Well-designed financial contracts, compared with conventional procurement methods, can result in lower project costs, shorter deadlines, higher-quality services, and decreased life-cycle costs of provision.

Fourth and finally, policymakers at all levels of government can improve project selection and investment allocations to ensure that the highest-value projects are chosen and funded. Expanding the role of competitive grant programs, such as the Department of Transportation's Infrastructure for Rebuilding America grant program, can increase the productivity impact of any given infrastructure investment. Further, giving State and/or local governments more flexibility in project choice can help ensure that local projects are aligned with local needs and preferences, and encouraging the use of cost/benefit analysis to inform project selection can also increase the efficiency of infrastructure investments. On balance—with appropriate regulatory policies and infrastructure funding, along with financing provisions, in place—the United States can look forward to a productive and prosperous 21st century.

Our Nation has been rightfully proud of its infrastructure—the roads, bridges, waterways, energy facilities, telecommunications networks, and other physical and technological underpinnings that make possible our economic activity, trade, and commerce, both domestically and abroad. However, recent decades have seen sustained growth in the demand for infrastructure services that has not been met with corresponding growth in and maintenance of their supply—so concerns about overuse, congestion, and poor service have become common. The supply of infrastructure has failed to keep up with increases in demand in part because much access to infrastructure is underpriced or, in many instances, provided free of charge to users, which systematically has led to excess demand, overuse, and congestion—as, for example, on many of our urban roads and highways.

In the private sector, congestion and excess demand for goods and services typically cause prices to rise, signaling to consumers that they should curtail their consumption, while these same high prices signal producers about the value of investing and expanding production. However, in the public sector, which funds and often directly provides much of the Nation's infrastructure, investment and allocation decisions are made by tens of thousands of distinct governmental entities based on little or no price information; hence, they have inadequate information about the expected benefits and costs of proposed investments and allocations. Without price signals to guide the users and suppliers of our Nation's roads, highways, waterways, and other infrastructure, we rely on inefficient, nonprice rationing of our existing assets; do not properly maintain existing assets or invest to add needed capacity; and instead often experience rising levels of congestion, delay, and quality degradation. Furthermore, complex, overlapping, and sometimes contradictory rules and regulations deter and delay investors from making capacity additions or improvements, exacerbating the imbalance between the demand and supply of infrastructure.

The central infrastructure problem facing policymakers is how to resolve this mismatch between the demand for and supply of public sector capital, both by using our existing assets more efficiently and by adjusting long-run capacity to efficient levels, a challenge made even more complicated by the fragmented roles of the Federal, State, and local levels of government, and private sectors. In many cases, this will mean expanding or relocating capacity to meet demand. However, in some cases, the opposite will be true: Infrastructure supply can exceed demand, either overall or regionally, and the challenge will be to reduce capacity to efficient levels while ensuring that all Americans have access to the 21st-century infrastructure services they deserve.

In this chapter, we propose features of a more efficiently financed capacity expansion of the infrastructure for the U.S. economy. We consider not only "core" assets—such as roads, bridges, railways, transit systems, and water and wastewater facilities—but also telecommunications and power sector assets. Allowing prices to have a larger role in guiding consumption and investment decisions will be key to achieving the positive growth effects that additional infrastructure assets can provide. We estimate that a 10-year, $1.5 trillion infrastructure investment initiative could add between 0.1 and 0.2 percentage point to average annual real growth in gross domestic product (GDP), under a range of assumptions regarding productivity, timing, and other factors.

To achieve growth at the high end of this range, we suggest four key actions for policymakers to consider. First, the Federal government can take the lead in streamlining, developing, and updating the regulatory environment to pursue appropriate health, safety, and environmental goals without hindering innovation, especially in forward-looking technologies. As explored further below, regulatory impediments and barriers have figured prominently in the energy and communications sectors, and addressing these constraints will have a positive impact on productivity and growth.

Second, additional resources can be secured for infrastructure investment, turning to some combination of user charges, specific taxes, or general tax revenues. Although Federal resources are important, States and localities actually fund most of the Nation's core infrastructure. Thus, increased funding support throughout our governments will be essential, in addition to attracting private sector capital in sectors where most assets are privately owned, such as telecommunications and energy. Additional general tax revenues at the Federal, State, and/or local government levels may be appropriate, especially for infrastructure facilities that provide benefits beyond the borders of the investing jurisdiction, but this chapter emphasizes the role of marginal cost-based user fees. Such user charges—which typically are set by States and local governments and are collected from those who directly benefit from publicly provided roads, water facilities, and other infrastructure—will encourage efficiency in use, provide signals to consumers and suppliers about the value of future investments, and generate revenues. Developing and incentivizing the use of value capture programs would also increase available funding resources, as parties experiencing capital gains (e.g., increased property values) would be taxed to help pay for the costs of the infrastructure investment responsible for these gains.

Third, the Federal government can support the use of innovative financing options such as public-private partnerships that will more efficiently utilize the total capital available from the public and private sectors and promote more efficient infrastructure delivery. Well-designed partnerships can improve incentives to lower project costs, meet deadlines, provide high-quality services, and minimize life-cycle costs of provision compared with conventional procurement methods.

Fourth and finally, policymakers at all levels of government can improve project selection and investment allocations to ensure that the highest valued projects are chosen and funded. Using tools such as cost/benefit analysis can increase overall efficiency, because directing limited investment funds to their most valued uses will make any given infrastructure investment that much more productive. Further, maintaining project selection at the State and/or local government levels can help ensure that projects with limited spillover effects are aligned with local needs and preferences.

We also note that enhanced infrastructure spending may have implications for America's workers to the extent that labor demand rises in infrastructure construction and design occupations and related fields. Although it is difficult to predict the net employment impact of increased infrastructure investment, a demand shift toward these occupations may benefit workers in those fields. The current stock of infrastructure workers in the labor force is disproportionately drawn from the population with a high school degree or less, indicating that enhanced labor demand would disproportionately benefit those with fewer years of formal education, precisely the segment of the population where there is the most excess supply. The Federal government can minimize any remaining labor constraints by easing occupational licensing requirements for infrastructure workers on federally funded projects and by enhancing the retraining options for workers interested in transitions into these occupations.

The chapter proceeds as follows. The first section documents the status quo and the demand and supply imbalances in America's infrastructure, and the second section discusses the economic evidence for the value of increasing public sector capital. The third section considers the roles of Federal, State, and local governments in undertaking the needed capacity expansions or enhancements, with an emphasis on funding resources and financing arrangements. The fourth section examines particular aspects of the value of additional or enhanced capacity in the energy and telecommunications sectors and the inland waterways system. The fifth section concludes.

U.S. Infrastructure's Growing Problem of Excess Demand

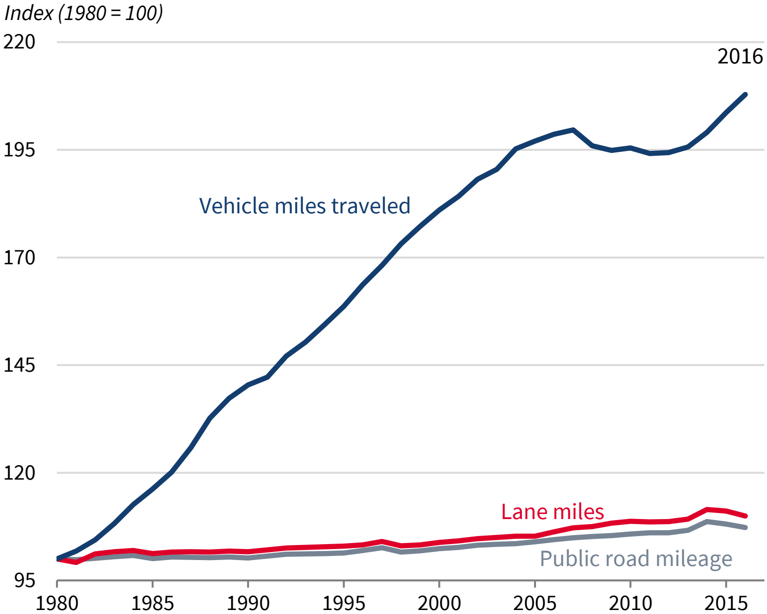
Although the Nation's transportation network, water facilities, communications sector, and energy infrastructure are the envy of many, studies and media reports increasingly point to problems with congestion, service quality degradation, insufficient funding, fairness and affordability, and the lack of coordinated, forward-looking infrastructure management in the public sector (e.g., Rosenthal, Fitzsimmons, and LaForgia 2017; Gregory et al. 2017; Blakemore 2016). The American Society of Civil Engineers (2017) gave the Nation a grade of D+ in its most recent infrastructure report card, little changed from previous years, putting a $4.6 trillion price tag on the needed upgrading of public assets across many sectors, including surface transportation, aviation, water utilities and water resource management, and energy. Though specific conditions vary across sectors and regions of the country, recent overall assessments have identified key infrastructure deficits with real consequences for U.S. consumers and businesses. For example, between 1980 and 2016, vehicle miles traveled in the United States more than doubled, while public road mileage and lane miles rose by only 7 and 10 percent, respectively (figure 4-1).

Unsurprisingly, queuing caused by traffic congestion has risen, imposing both direct and indirect costs on business and leisure travelers alike. The national average annual congestion delay per auto commuter reached 42 hours in 2014, according to the Texas A&M Transportation Institute (TTI 2015). TTI's travel time index reached an all-time high value of 1.22 in 2014, meaning that a trip that would take 30 minutes without congestion ("free flow" conditions) takes 22 percent longer—between 36 and 37 minutes—when roads are congested. Once the value of extra travel time and wasted fuel costs are taken into account, TTI estimates that total congestion costs were $160 billion in 2014, equivalent to 0.9 percent of GDP that year (figure 4-2). Left unaddressed, these estimated congestion costs would total over $1.4 trillion over 10 years' time.

Average highway congestion increased across the country, and congestion has worsened far more in some cities than it has in others. Table 4-1 indicates not only that the auto-commuter-weighted average hours of delay per auto commuter in the Nation's 101 largest cities rose from 33 hours in 1990 to 52 hours in 2014, but also that the range across cities widened considerably during this period, from 61 to 76 hours.

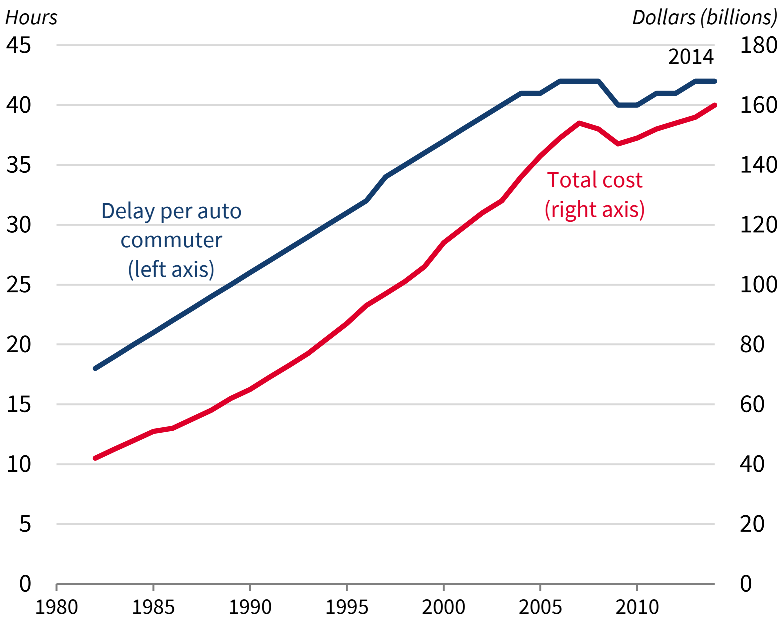
Aside from roads and highways, congestion and service quality problems on our waterways are also evident. Average delays at locks along the inland waterways system have crept up, from under 1 hour per tow in 2009 to nearly 2.5 hours in 2016 (figure 4-3), despite a 9.2 percent decline in the number of vessels served during this period. Similarly, the share of vessels experiencing a delay has risen from a low of 34 percent during the Great Recession to a 2016

Figure 4-1. Road Mileage and Vehicle Miles Traveled, 1980–2016



Sources: U.S. Department of Transportation, Highway Statistics, 2016; CEA calculations.

Figure 4-2. Traffic Congestion Measures, 1982–2014



Source: Texas A&M Transportation Institute.

Table 4-1. Annual Hours of Delay per Auto Commuter, 101 Urban Areas

Year	Auto-commuter-weighted average	Across 101 urban areas			
		Average	Standard deviation	Minimum	Maximum
1990	33	23	10.9	3	64
2014	52	41	13.1	6	82

Sources: Texas A&M, Texas Transportation Institute; CEA calculations.
Note: A yearly sum of all the per-trip delays for those persons who travel in the peak period (6 to 10 a.m. and 3 to 7 p.m.). The developed area (i.e., with a population density of more than 1,000 persons per square mile) within a metropolitan region. The urban area boundaries change frequently (every year for most growing areas), so increases include both new growth and development that was previously in areas designated as rural.

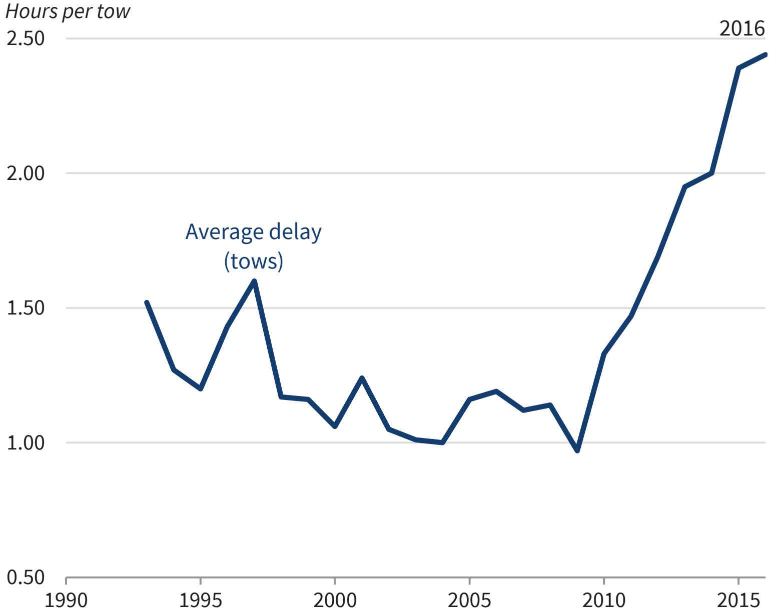
high of 48 percent (USACE 2017a). Such delays can be costly; the American Society of Civil Engineers estimated annual delay costs of $33 billion along the system in 2010; even if delays had not increased since then, that annual cost corresponds to a nearly $300 billion cost over 10 years' time.

Infrastructure needs in the water and wastewater sector are also considerable. The U.S. Environmental Protection Agency (EPA) estimates that $655 billion will be needed over the next twenty years to upgrade and replace infrastructure in the water and wastewater sectors, comprised of $271 billion for wastewater collection and treatment facilities and $384 billion for drinking water facilities. Concerns include water loss from water main breaks, raw sewage discharges into local water supplies, and overall water quality. For example, the EPA estimates the annual cost of water main breaks to be $2.6 billion, implying over $20 billion in costs over 10 years' time. More detailed needs assessments at the regional or local level confirm similar needs but also reflect significant heterogeneity, because some water and wastewater utilities face far greater challenges than that of others, especially in larger cities with declining populations (GAO 2016).

How Increasing the Supply of Infrastructure Supports Economic Growth

The value of adequate public infrastructure in terms of both quantity and quality comes from its role in strengthening the economy's growth prospects. Increases in public capital intensity (public capital stock per worker) can affect productivity and growth through multiple channels. More generally, without sufficient, high-quality infrastructure allocated efficiently across sectors—and indeed, across the country—economic growth will be constrained. The simple, back-of-the-envelope estimates of 10-year costs from delays and quality problems discussed briefly above--$1.4 trillion congestion costs on our roads, nearly $300 billion from delays on our inland waterways systems, over $20 billion lost from water main breaks—point to the value to users of improved

Figure 4-3. Inland Waterways System Lock Delays, 1993–2016



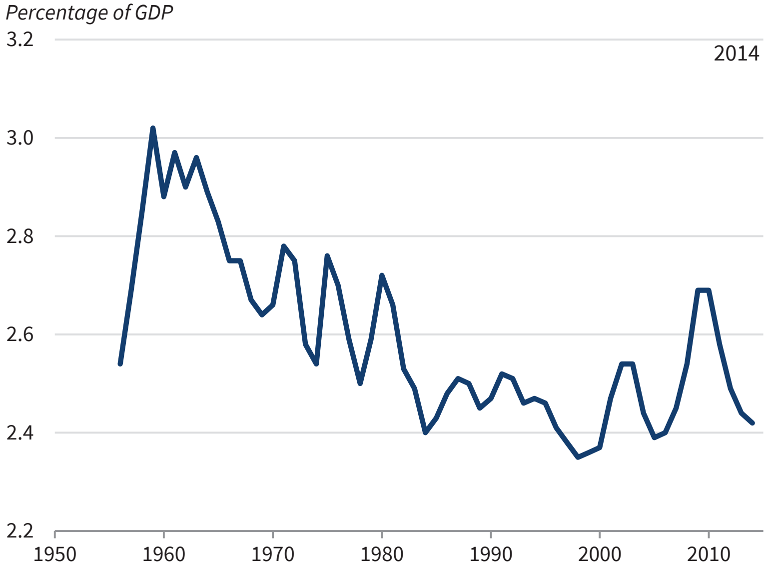
Source: U.S. Army Corps of Engineers, Public Lock Usage Report.

infrastructure in terms of its quantity, quality, and allocation. In general, the gross benefits of these improvements include any revenues users are willing to pay for the improvements as well as any consumer surplus they experience, recognizing that some of the benefits also accrue to nonusers. Assessing these ex ante benefits is relatively straightforward for a specific asset or project, but for the economy as whole, economists often lack direct welfare measures and instead consider the relationship between infrastructure and productivity or output. This section reviews recent trends in infrastructure investment spending and capital accumulation and summarizes the evidence for the links between infrastructure, economic growth, and productivity.

Recent Trends

Two key ideas emerge from a review of recent data. The first is that infrastructure investment spending, as a share of the economy, has remained fairly steady in recent decades; and the second is that States and local governments are more important than the Federal government with respect to the funding, ownership, and management of core infrastructure assets. The Congressional Budget Office (CBO 2015) reports that public spending on transportation and water infrastructure has averaged about 2.4 percent of GDP since the 1980s, with a temporary increase in 2009 and 2010 due to additional spending under the American Recovery and Reinvestment Act (figure 4-4). In 2016, nominal government fixed, nondefense investment spending was 2.5 percent

Figure 4-4. Public Spending on Transportation and Water Infrastructure, 1956–2014



Sources: Congressional Budget Office; Bureau of Economic Analysis; Census Bureau; Office of Management and Budget.

Table 4-2. Average Public Nondefense Investment as a Percentage of Nominal GDP, 1980–2016

Time period	Federal nondefense	State and local	Total
1980–90	0.89	2.06	2.95
1990–2000	0.82	2.13	2.96
2000–2010	0.72	2.34	3.06
2010–16	0.72	2.02	2.74

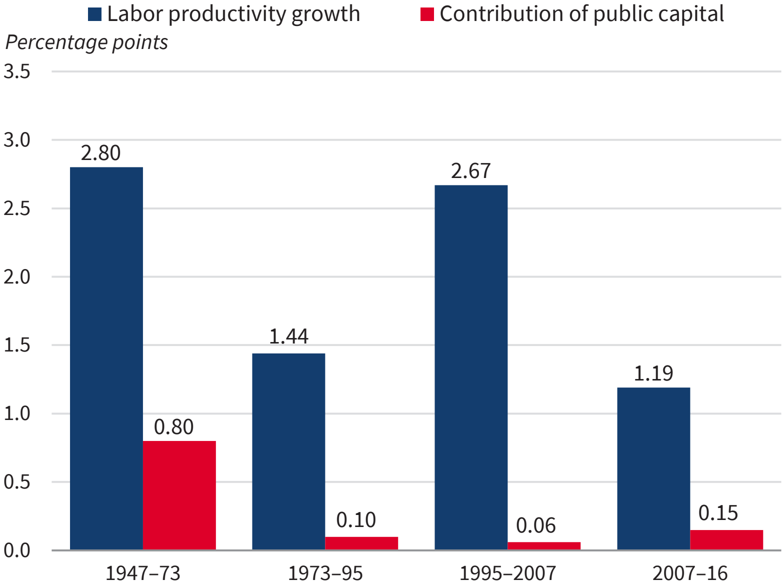
Sources: Bureau of Economic Analysis; CEA calculations.

of nominal GDP, with the structures component accounting for 1.5 percent of nominal GDP.

Table 4-2 shows that average nominal nondefense public investment as a share of nominal GDP has averaged 2.74 percent since 2010, with States and local governments accounting for nearly three times as much spending as the Federal government. In fact, most of the Nation's nondefense public infrastructure is owned by States and local governments; for every $1 in nondefense capital stock owned by the Federal government, States and localities own more than $6 worth of public infrastructure.

Economists typically model the role of public sector capital in the economy by treating it as one factor of production, alongside labor, private capital, and natural resources. Increased stocks of public sector capital mean increased flows of capital services available to the economy's workers, fueling growth

Figure 4-5. Contribution of Public Capital Stock to Productivity Growth, 1947–2016



Sources: Bureau of Economic Analysis; CEA calculations.

through at least two channels. First, by raising the productivity of other factors of production—labor, private capital, and land—increased public capital services encourage firms to increase their own investments and expand economic activity. This indirect, or "crowding in," effect has been identified in numerous studies (e.g., Aschauer 1989; Abiad, Furceri, and Topalova 2016). A second, direct effect works through increases in public capital services per employee hour, or public capital deepening, which typically accounts for between 0.05 and 0.20 percentage point of growth in labor productivity—not nearly as large as the impact of private sector capital accumulation, but nonetheless important.[1] Since 2007, public capital deepening has accounted for 0.15 percentage point of the 1.2 percent growth in labor productivity (figure 4-5).

[1] Recall that labor productivity growth comes from growth in capital deepening, or the amount of private capital services per labor input; growth in the skills of workers—often called a labor composition effect—and increased overall efficiency, calculated as a residual and called total factor productivity. Historically, in the United States, capital deepening has driven a significant share of labor productivity growth, though with a marked slowdown in the post–Great Recession period. From 1953 to 2010, capital deepening accounted for more than 0.9 percentage point of that era's 2.2 percent labor productivity growth, but actually detracted from productivity growth from 2010 to 2015.

Evidence for the Growth Effects of Public Capital

The likely returns to prospective increases in public investment and capital stocks depend on many factors—including the responsiveness of output to increases in public capital, the economy's initial level of capital intensity, depreciation rates, how quickly assets can be installed and brought into productive service, and even how the investments are financed.

Although the evidence discussed here is based on traditional types of infrastructure assets, it is important to note that technological innovation and change will also affect the value of specific infrastructure investments. Transformative and potentially disruptive technologies, such as those used for autonomous vehicles and unmanned aviation systems (or drones), may alter the future use of existing infrastructure, the organization of business activity, and even residential density and location patterns. Adapting the regulatory environment to remove barriers to investment and innovation in these technologies will be key to generating the greatest possible future benefits from their use, and recent regulatory actions move in that direction. In 2016, the U.S. Federal Aviation Administration issued operational rules (Part 107 of 14 the *Code of Federal Regulations*), providing a basic regulatory structure for drones. In addition, a Presidential memorandum issued on October 25, 2017, establishes a three-year pilot program to facilitate the integration of drones into the national airspace and permit more advanced operations of unmanned aviation systems that go beyond the limits set by Part 107, including flying beyond the visual line of sight of the operator and flying over people. The program is intended to facilitate coordination of and collaboration between regulatory authorities, a key step in adjusting regulation to limit barriers to private investment in this sector. Another example comes from autonomous vehicles and related technologies, which may affect future use of roads, highways, and public transit assets and have the potential to improve safety, decrease traffic congestion, and raise productivity (box 4-1). In this sector, too, regulators face challenges in adjusting to the new technology without discouraging innovation. To that end, the U.S. Department of Transportation issued guidelines in September 2017 regarding automated driving systems, establishing principles regarding safety, technological change, and technical issues of deployment. The guidelines are intended to assist Federal, State, and local regulatory authorities as well as industry and consumer stakeholders in maximizing the future benefits of the new technologies.

Turning now to conventional approaches to exploring the relationship between public sector capital, productivity, and output, we note that the CBO (2016b) estimated that a $1 increase in public capital generated an output increase of about 8 percent, somewhat lower than other recent estimates (CEA 2016; Bom and Ligthart 2014). Our current preferred estimate puts the corresponding return at just under 13 percent, which is further explained below.

Box 4-1. Autonomous Vehicles: A 21st-Century Innovation

Autonomous vehicles provide a flexible and hands-free commute during which people can engage in activities apart from driving such as office work or entertainment. A key attraction of these vehicles is their ability to potentially reduce congestion in highways. This is because driverless vehicles would be able to drive much closer to other vehicles in a safe manner, and be able to accelerate and decelerate more quickly. And these vehicles would have the potential to prevent collisions and reduce regular and incident delays by creating a smoother traffic flow.

The widespread adoption of driverless cars in the U.S. can increase economic growth. Winston and Karpilov (2017) estimate that autonomous vehicles would spur growth in the U.S. by reducing congestion. They focus their analysis on California, which is home to 11 of the top 16 highway bottlenecks in the Nation, and then extrapolate their results to other areas of the Nation. They find that highway congestion had adverse effects on the GDP growth rate, wages, and commodity freight flows in California. Their findings corroborate similar results that congestion in the Nation's West Coast ports from 2014 to 2015 led to a 0.2-percentage-point decline in GDP (Amiti et al. 2015), and that highway congestion is associated with slower job growth in U.S. metropolitan areas (Sweet 2014; Angel and Blei 2015). Automobile commuting in congested conditions may also damage physical and emotional health (Fottrell 2015; Knittel, Miller, and Sanders 2016). The benefits of autonomous vehicles depend on market penetration. In a given year, a 50 percent penetration rate (i.e., half the vehicles in the U.S. would be driverless), could add more than $200 billion to GDP, 2.4 million jobs, and $90 billion in wages to the U.S. labor force.

These potential sizable macroeconomic effects of advances in transportation technology are not surprising in light of the historical evidence on the positive benefits to the U.S. of improvements in mobility. Krugman (2009) elaborates on how railroads, by reducing transportation costs, facilitated large-scale production and radically transformed the U.S. economy into differentiated agriculture and manufacturing hubs. Similarly, given their potential to reduce congestion and increase safety, autonomous vehicles are an exciting area of ongoing scientific research.

Calculating the marginal return to public capital requires an estimate of the elasticity of output with respect to public capital, which has been the subject of hundreds of studies since the late 1980s. Aschauer (1989) estimated a U.S. elasticity of about 0.4, suggesting that public sector capital accumulation was historically a key factor driving economic growth. More recent studies have confirmed the finding of a robust qualitative and positive relationship between infrastructure, output, and growth, though with considerable variation across geographies, time periods, and specific infrastructure assets studied. However, most recent studies conclude that this elasticity is well below Aschauer's earlier estimates.

Bom and Ligthart (2014)'s meta-analysis of 68 studies covering the 1983–2008 period yields a short-run elasticity estimate of 0.083 and long-run estimate of 0.122. When restricting their analysis to studies focused on core infrastructure (transportation, water, and sewer facilities), the authors report slightly higher elasticities of 0.131 and 0.170 in the short and long run, respectively, highlighting the point that not all infrastructure is created equal. The authors also report evidence that output elasticities have declined over time, because studies using more recent data find smaller output elasticities. Another recent meta-analysis by Nunez-Serrano and Velazquez (2017) finds 0.13 and 0.16 for short- and long-run elasticities, respectively, somewhat larger than Bom and Ligthart's baseline results. However, Nunez-Serrano and Velazquez do not include more recent studies in their analysis, so their estimates may not reflect recent declines in the elasticity estimates found by Bom and Ligthart.

The CBO (2016b) assumes an elasticity of output with respect to public capital of 0.06, but this is likely to be too low in the present context, in which we consider increased investment in core infrastructure, exactly the asset types associated with higher elasticities (Bom and Ligthart 2014). Given a ratio of public capital to output of about 0.75, the CBO (2016b) estimates that the marginal return to public capital will be about 8 percent (0.06/0.75). However, using Bom and Ligthart's average elasticity estimate of 0.106 and an adjusted capital-output ratio that excludes Federal defense capital assets (0.645 in 2016), we estimate the return to be more than 16 percent. In fact, even Bom and Ligthart's lower short-run elasticity estimate for centrally provided public capital (0.083) still yields a return on public sector capital of 12.9 percent, well above the CBO's estimate of 8 percent. Below, we use 12.9 percent as our preferred estimate.

With these data in mind, we can assess the output consequences for a given increase in public sector capital. A marginal return of 12.9 percent suggests that $100 billion in new public capital stock, when fully installed and productive, would raise output by $12.9 billion, or just under 0.1 percent, each year it was in use; note that this $100 billion in new infrastructure stock would generate decreasing annual returns each year as it depreciates. This supply-side channel for infrastructure investment can be used to estimate the impact of a longer-term, debt-financed program of $1.5 trillion in infrastructure investment spending over 10 years' time. The CEA's analysis of several different models indicates that these supply-side effects alone would cumulatively add 0.2 to 0.4 percent to the level of GDP over 10 years, depending on the marginal return to public capital.

However, as the CBO (2016b) notes, several factors may cause actual output effects to be smaller than predicted. For example, delays in spending additional funds, constructing infrastructure assets, or bringing those assets into productive service will decrease expected returns. Permitting and regulatory delays can also affect returns from infrastructure investments. To address such concerns, on August 15, 2017, President Trump issued Executive Order 13807, "Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure," which pertains to projects in the transportation, water and wastewater, energy, and telecommunications sectors. This Executive Order aims to reduce unnecessary delays and barriers to infrastructure investment; and it outlines a number of steps to streamline regulatory and environmental review processes, establish meaningful deadlines for reviews and related permitting decisions, and clarify the roles of different governmental bodies.

Another potentially important factor affecting the output impact of an infrastructure investment program is the response of States and local governments to an infusion of additional Federal funds for infrastructure investment. Such an increase could lead to reductions in resources provided by States and local governments if Federal money serves to crowd out nonfederal support. The CBO estimates this crowding-out effect at about one-third; applying this value would lower the CEA's predicted impact of a federally funded increase in infrastructure accordingly. Empirical evidence for the sign and size of this crowding-out effect has been mixed. For example, Knight's (2002) study of the Federal Highway Aid program found nearly complete crowding out; under Knight's preferred estimates, States and localities cut back by $0.93 for every additional $1 provided in Federal highway grants during the 1983–97 period. At a marginal return of 12.9 percent, this implies that a $10 billion increase in Federal highway funding would ultimately yield only a $0.09 billion impact on GDP. Although the exact magnitude of this crowding-out effect is uncertain, Federal policymakers may wish to set maintenance-of-effort provisions as a condition for receipt of certain Federal funds, to limit States' ability to curtail nonfederal support in response to an infusion of Federal funds.

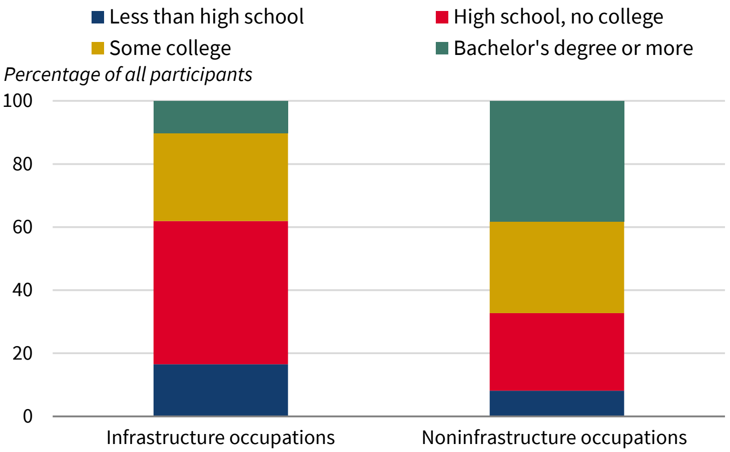
Other effects of increased infrastructure investment. Increased infrastructure investment can also have other important economic effects. Embarking on an ambitious infrastructure program may create improved employment opportunities for some U.S. workers (box 4-2). In addition, such a program could generate meaningful short-run effects that may vary cyclically. In the short run, deficit-financed additional infrastructure spending affects GDP in the year in which the spending occurs, generating direct and possibly indirect ("multiplied") effects on GDP. Depending on the timing, the extent of possible crowding out—or, conversely, multiplier effects—and the marginal product of public capital, the CEA estimates that the 10-year, $1.5 trillion infrastructure investment program discussed above would add an average of 0.1 to 0.2 percentage point to annual growth in real GDP. If investment is front-loaded, there is no crowding out, the fiscal multiplier is consistent with Zandi (2012), and the

Box 4-2. Labor Market Effects of Increased Infrastructure Investment

In addition to raising U.S. productivity and competitiveness, a boost to infrastructure spending may increase demand for the workers needed to build and construct these new public assets. Although it is difficult to predict the net employment impact of increased infrastructure investment, a demand shift to selected occupations may benefit workers in those fields. We term the set of 31 occupations that are most likely to experience an increase in demand "infrastructure occupations"; these occupations account for more than 1 percent of employment in at least one infrastructure-related industry's total private wage and salary employment (as defined in the note to figure 4-i). These occupations include workers who design and carry out infrastructure projects, including engineers, pipefitters, construction laborers, and the like. But it also includes transportation and warehousing occupations, along with workers in installation, maintenance, and repair occupations.

Workers in these occupations are far more likely to have a high school degree or less than the overall U.S. labor force as shown in figure 4-i. The unemployment rate for workers is strongly correlated with educational attainment, and even in the current economic expansion, workers with fewer years of education are disproportionately likely to find themselves unemployed. As of December 2017, workers with a high school degree or less

Figure 4-i. Educational Attainment of Infrastructure versus Noninfrastructure Labor Force Participants, 2017



Sources: Current Population Survey; CEA calculations.
Note: The 4-digit North American Industry Classification System (NAICS) codes, defined as infrastructure industries, include civil engineering construction (all sectors falling under NAICS 3-digit code 237000); other specialty trade contractors (NAICS code 238900); and remediation and other waste management services (NAICS code 562900). Infrastructure occupations are those that make up at least 1 percent of employment in one of these 4-digit sectors.

had an unemployment rate 2.6 percentage points higher than those with a bachelor's degree—4.7 and 2.1 percent, respectively. Our estimates of the unemployment rate for workers who report an infrastructure occupation indicates an even greater disparity; in the Current Population Survey, 6.1 percent of labor force participants who report an infrastructure occupation reported being unemployed in 2017, reflecting an excess supply of nearly 350,000 infrastructure workers relative to the unemployment rate for workers in noninfrastructure occupations.

Despite this excess supply, the geographic footprint and skill needs of expanded infrastructure investments are unlikely to perfectly match those of currently unemployed infrastructure workers, and the Federal government could take an active role in easing the transition of workers into infrastructure employment. One impediment to the free movement of skilled workers into new infrastructure jobs is the country's patchwork set of occupational licensing requirements, which depress the movement of licensed workers across State lines (Johnson and Kleiner 2017). In 2016, 22.2 percent of all labor force participants reporting an infrastructure occupation in the Current Population Survey said they had an active professional license or certification; this is slightly fewer than the average for all participants (24.4 percent) but substantially more than would be expected—given the education distribution across infrastructure occupations, because the probability of occupational licensing increases with educational attainment. Tying infrastructure funds to the loosening of occupational licensing (or to reciprocal agreements between States) could help alleviate the depressive effects of these licenses on geographic mobility. This topic is discussed in greater detail in chapter 2.

Furthermore, the Federal government has additional tools to ensure a skilled workforce for expanded infrastructure activity. One clear disconnect between the needs of the labor market and the supply of America's workforce is the current subsidization of higher education through Pell Grants. These grants, which are generally only available to students without a bachelor's degree and who are enrolled in programs with more than 600 clock hours of instruction over 15 weeks, do not provide support to workers who require shorter-term investments. Workforce Innovation and Opportunity Act funds could be used for these short-term programs, but funds from this program are not dedicated to this purpose and are therefore subject to competing priorities. Although it would require Congressional approval, expanding Pell Grant eligibility to include investments in short-term training (or retraining) programs would help ensure that financial constraints do not prevent workers from pursuing infrastructure occupations.

marginal product of capital is as reported in the 2016 *Economic Report of the President*, we expect the average annual contribution to be at the upper end of this range. With crowding out, no multiplier, and assuming the CBO's estimate of the marginal product of capital, we expect the contribution to growth to instead be closer to 0.1.

In general, the sign and magnitude of these "fiscal multipliers" remains a topic of active research, and recent evidence suggests that spending multipliers exceed zero, meaning that the net impact of additional government spending is positive (Auerbach and Gorodnichenko 2012; Ramey and Zubairy 2017). Auerbach and Gorodnichenko find that these multipliers are larger during recessions, while Ramey and Zubairy find no evidence that multipliers are higher during periods of slack. Abiad, Furceri, and Topalova (2016) and the International Monetary Fund (2014) find that increased infrastructure spending in particular during recessions can raise GDP through demand-side multiplier relationships. In fact, even a study of the Great Depression found that an additional $1 in public works and relief spending per capita between 1933 and 1939 was associated with a 44 cent increase in retail sales in 1939 (Fishback, Horrace, and Kantor 2005)! These short-run demand-side effects of increased infrastructure investment are not unimportant, but infrastructure's long-run effects on productivity and growth may be better guides to policymakers about the effects of future investment programs and policies.

Funding and Financing Needed Infrastructure

Both around the world and in the United States, governmental resources provide and support infrastructure investment to promote both efficiency and equity goals. On the efficiency front, the public goods nature of some infrastructure assets will lead the private sector to underproduce such assets relative to socially desirable levels. These goods are generally characterized by some degree of *nonexcludability*, meaning that it is difficult or very costly to exclude nonpayers from consuming the good; of *nonrivalry*, meaning that one person's consumption does not hinder the ability of others to also consume it; or both. For example, flood control services provided by a system of dams, levees, and reservoirs may provide benefits to a wide geographic area. In this instance, excluding nonpayers from experiencing the benefits would be difficult, and the benefits experienced by one local resident do not impair the ability of other residents to experience benefits as well.

Infrastructure assets may also have other characteristics that lead to inefficient resource allocations under market provision. For example, many assets pertaining to transit, water and sewer utilities, water resource management, energy, and communications are characterized by increasing returns to scale, with high fixed costs and sometimes quite low marginal costs. In these situations, efficiency concerns suggest that the best industry configuration will include one or only a few suppliers. In some cases, these providers may have market power and can price at well above marginal cost, in opposition to efficiency goals; in other cases, these providers may price below marginal cost, making cost recovery and efficiency goals hard to reach. Historically, in these types of situations, government officials have turned to government-run monopolies or regulated utilities to meet efficiency, equity, and revenue goals.

Other sources of market failure may also be present. Some infrastructure assets provide services that generate agglomeration effects, whereby efficiency gains arise from the spatial concentrations of firms and workers—because more efficient labor markets, better matching between firms and workers, and a quicker dissemination of ideas and best practices all increase productivity. Evidence suggests that such economies are present in the transportation, communications, and power sectors. Network effects also characterize infrastructure in transportation and communications, because the value of the network rises as other users join and more nodes and segments are added. A robust transportation network also makes it easier for workers and firms to locate near each other; thicker markets mean better matches between firms and workers, increasing efficiency. Again, these effects can mean that private actors lack the incentives to invest to the desired fully efficient level, motivating the public sector to offer support and/or invest. Given these considerations, the rest of this section describes the fiscal roles currently played by Federal, State, and local governments and explores issues in funding and financing infrastructure investment.

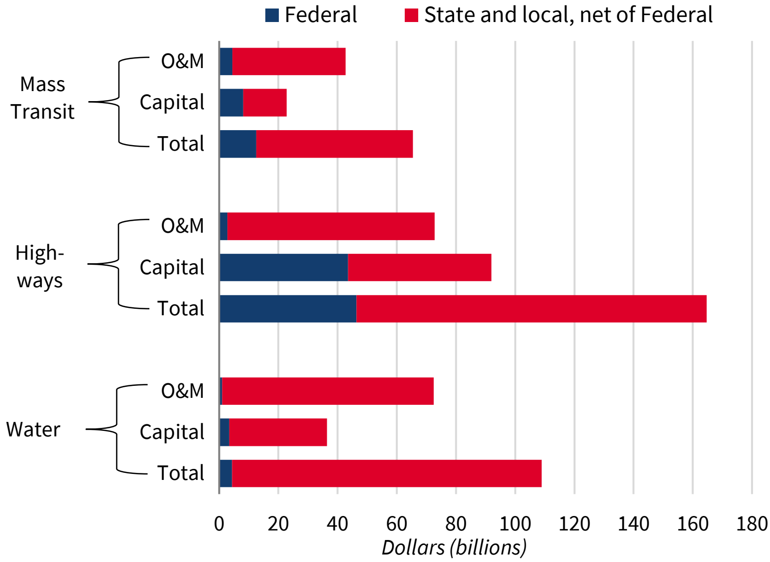
Fiscal Roles for Federal, State, and Local Governments

In the United States, infrastructure investment, operations, and maintenance responsibilities are shared across the Federal, State, and local public sectors, and in some cases, by private sector entities. The CBO (2015) reported that combined Federal, State, and local public spending on transportation and water and wastewater infrastructure was $416 billion in 2014, with the Federal government accounting for 23 percent of the total, and State and local governments for the remaining 77 percent. The allocation of responsibility varied sharply, depending on the category of infrastructure assets. For example, the Federal government funded 28 percent of total highways spending, 23 percent of mass transit and rail spending, and only 4 percent of water utilities spending. Within sectors, Federal support also varies and typically focuses more on capital spending, not spending for operations and maintenance (figure 4-6).

Funding Infrastructure Investment

Given the desire to maintain, upgrade, and expand infrastructure investments in various sectors of the economy, policymakers must consider the best ways of funding these investments. Resources generally come from one of two principal sources: tax revenues or user charges (user fees). In this subsection, we discuss and analyze funding options available to policymakers at different levels of government, with a special focus on the role of user fees for use of

Figure 4-6. Public Spending on Mass Transit, Highways, and Water Infrastructure, 2014



Sources: Congressional Budget Office; CEA calculations.
Note: O&M represents operations and maintenance.

selected infrastructure services, including roads and highways, transit, and water and wastewater services.

General tax revenues are often used to support projects and investments that provide benefits widely or are somewhat nonrivalrous or nonexcludable. Specific or dedicated tax revenues are also commonly used by Federal, State, and local governments—sometimes reflecting a goal of linking those who use the services to the funds collected to pay for them. Governments also rely on direct fees and charges paid by users and beneficiaries of a particular service. The economic incidence of these fees—that is, who actually pays them in the form of higher prices paid by consumers or lower net prices received by suppliers—varies by service, and the revenues collected can be considerable.

A distinct but related revenue source may sometimes also be appropriate. For example, a new transit project (e.g., a new or rehabilitated station along a rapid transit line) may increase economic activity and/or raise property values in the areas near the project. Using "value capture" techniques, such as tax increment financing (TIF), can enable the public sector to access some of the value generated by the public investment, making more revenues available to support the project (Chapman 2017).

User fees in theory. Setting and collecting user fees to fund infrastructure investments helps the government achieve two key goals: ensuring efficiency in the use of public assets, and collecting revenues to defray the costs of providing these assets. If users of the service experience a significant private benefit from doing so, efficiency gains can be significant when user fees are set correctly. As discussed earlier in the chapter, underpriced access to public infrastructure will generate excess demand for use, leading to congestion and inefficient allocations. Without price signals to guide supply and consumption decisions, the public sector struggles to determine how much infrastructure to build and how it should be allocated.

The rationale for imposing user fees is especially strong when the services in question provide significant private benefits relative to the overall public benefits generated by use of the asset. For example, a shipper that sends barges full of grain through locks along the Mississippi River obtains private benefits from using the Nation's inland waterway system. Similarly, an airline that uses gate facilities at a particular airport and accesses the Nation's air-traffic control system is also receiving a private benefit. In these instances, user fees should be a significant part of the funding structure, though not necessarily the only revenue source. Note that though some user fees paid by businesses will eventually be paid by consumers in the form of higher prices, firms using public sector assets will recognize these charges as costs of doing business, thus encouraging efficient choices of production and allocation.

Setting specific fee structures to achieve multiple policy goals can be difficult, and trade-offs between goals are likely. Attaining efficiency goals usually means setting unit prices at the marginal cost of provision, but in sectors with high fixed costs (e.g., water and wastewater, and transit), the revenues generated may not be enough to cover fixed costs. Setting unit prices at average cost can improve revenue generation, but comes at the expense of decreased efficiency, as some users cut back consumption at the margin. Turning to "two-part" tariffs can help achieve efficiency and revenue goals though may raise affordability concerns. Under a two-part tariff, the customer is charged a fixed fee that does not vary with use and a unit price per unit consumed. Essentially, the fixed fee allows service providers to collect the revenues they need to defray their fixed costs, and the unit price acts as a signal to consumers, who will consume up to the point where their benefits and costs are balanced at the margin, contributing to efficiency.

There are many examples of this two-part tariff approach. Water utility customers pay a monthly connection charge, in addition to charges based on monthly water use; and in the power sector, electricity users pay monthly fees along with charges that vary with electricity use. Service providers may use increasing block tariffs, charging low unit prices for low ("lifeline") levels of consumption and higher unit prices for higher consumption levels, a structure that can preserve access for consumers with a low ability to pay. Alternatively, decreasing block tariffs offer a reverse approach, with unit pricing that falls as consumption levels rise; this structure allows offering quantity discounts, which are common in industrial settings. Simple unit pricing includes a constant per-unit charge for all levels of consumption.

In funding for roads and highways, State and local governments already rely on an informal two-part tariff system of quasi-user fees to raise funds to partially cover capital and operating expenses. For example, annual vehicle registration fees and driver's license fees can be viewed as fixed components that do not vary with road use, while gasoline taxes, tolls, and other charges are somewhat connected to usage levels, acting at the margin to affect drivers' choices about consumption.

User fees for roads and highways. With the increasing prevalence of electric vehicles and high fuel economy vehicles, and with some fuel-based revenue sources not being indexed to inflation, the existing financing mechanism is becoming increasingly unsustainable, with funding needs growing faster than dedicated revenues. Here, we explore current funding practices and alternatives, considering the efficiency, equity, and revenue effects of these choices.

At present, the Federal, State, and local governments rely heavily on dedicated fuel taxes and general taxes to pay for roads and highways, with a much smaller role played by direct user fees, such as tolls. Toll revenue collected by State and local governments in fiscal year (FY) 2015 was $14.0 billion, accounting for 6.0 percent of total spending on roads and highways, a share that has crept up only slightly since 1993 (DOT 1993, IV-6; 2015, table HF-10), when the Federal gasoline tax, currently 18.4 cents per gallon, was last increased. Although the administrative costs of toll systems are significant, at between 8 and 13 percent of receipts (Kirk 2017, 7), the economic arguments in favor of using toll revenues to pay for roads and highways are solid. By collecting fees from the direct users of the assets (motorists, commercial carriers, et al.), governments acquire revenues needed to maintain, operate, rehabilitate, and expand the roads, and drivers use the roads up to the point at which their marginal benefits equal the marginal costs they impose when driving.

Federal gasoline and diesel taxes have some characteristics of user fees because the individuals and businesses that buy fuel for vehicles and drive on public roads and highways pay them. However, these taxes are imperfect because they fail to encourage efficient use of existing roadways and to signal the value of any potential additional capacity. Highly fuel-efficient vehicles (including electric vehicles) pay less than the marginal costs generated by their use of roads in terms of wear and tear, congestion, and other external costs. More generally, these taxes do not reflect the crowding or congestion costs generated by drivers. That is, driving 100 miles on low-use rural roads generates the same fuel tax revenues as driving that same distance on high-use urban roads—during rush hour. Furthermore, evidence suggests that heavy trucks in particular do not currently face taxes and charges that are aligned with the negative externalities they generate, which include pavement damage, traffic congestion, accident risk, and emissions. Even excluding emissions, these external costs are significant, with estimates ranging from 2.01 to 4.14

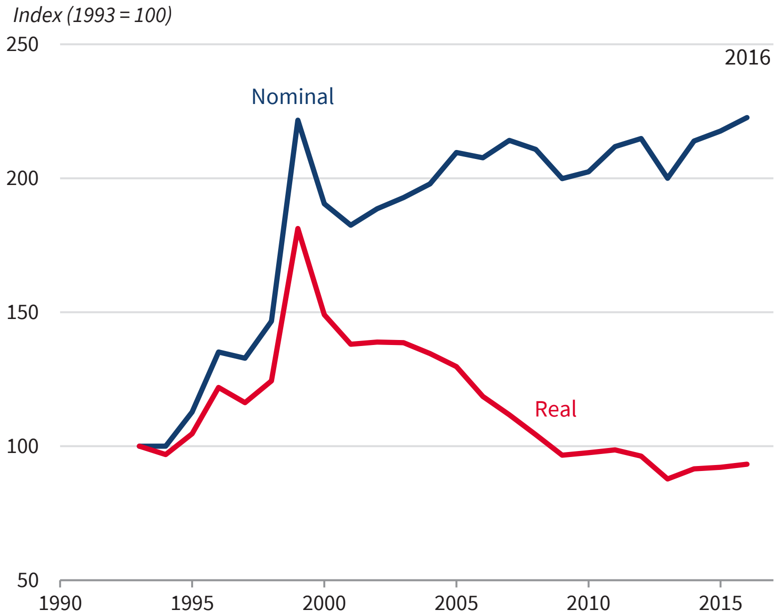
cents per ton-mile, which is equivalent to between 10 and 20 percent of the average price per ton-mile to ship by truck (Austin 2015).

More generally, because fuel taxes do not reflect congestion costs imposed by drivers, scarce road access is not allocated efficiently. Implementing congestion pricing would encourage only consumers with high valuations to use highly congested roads during peak demand times, improving efficiency but also potentially making some drivers worse off, particularly low-income drivers who may be priced out of the tolled lanes (CBO 2009). Using toll revenues to improve other travel options, particularly transit, can counteract this distributional effect, but most discussions of congestion pricing acknowledge its potential to create both winners and losers from the policy. Even so, the lack of appropriate congestion pricing mechanisms creates winners and losers as well, and some evidence suggests that at least some low-income drivers in practice find tolled lanes worth paying for (Federal Highway Administration, n.d.). Furthermore, Hall (2015) shows that congestion pricing can be Pareto-improving, not just potentially Pareto-improving, especially under conditions of bottleneck congestion, which occurs when the number of vehicles that can use the road per unit of time (its "throughput") decreases. An example of bottleneck congestion is when traffic backs up at an exit ramp, slowing down through traffic on the roadway. Tolling a portion of the highway's lanes (value pricing) serves to internalize both motorist travel time externalities as well as these bottleneck effects, raising speeds on both the tolled and nontolled highway segments. When drivers differ in terms of income and valuations of their time, partial time-varying tolls will raise welfare for drivers along both the tolled and nontolled segments as long as high-income drivers use the highway during rush hour. Under the policy, drivers "sort" into the road segments and are better off, even before accounting for how toll revenues are spent.

The recent introduction of dynamic tolling along Interstate 66 in Northern Virginia offers an example of how congestion pricing can improve travel times and raise revenues for transportation projects. Preliminary figures from the Virginia Department of Transportation indicate that morning rush-hour tolls averaged between $8.20 and $12.87 for the 10-mile segment but that peak tolls reached $40.00 for a short time. Further, travel speeds in the tolled lanes were far higher than during a comparable period a year earlier, and travel speed in the nontolled lanes as well as parallel roadways were similar or improved.

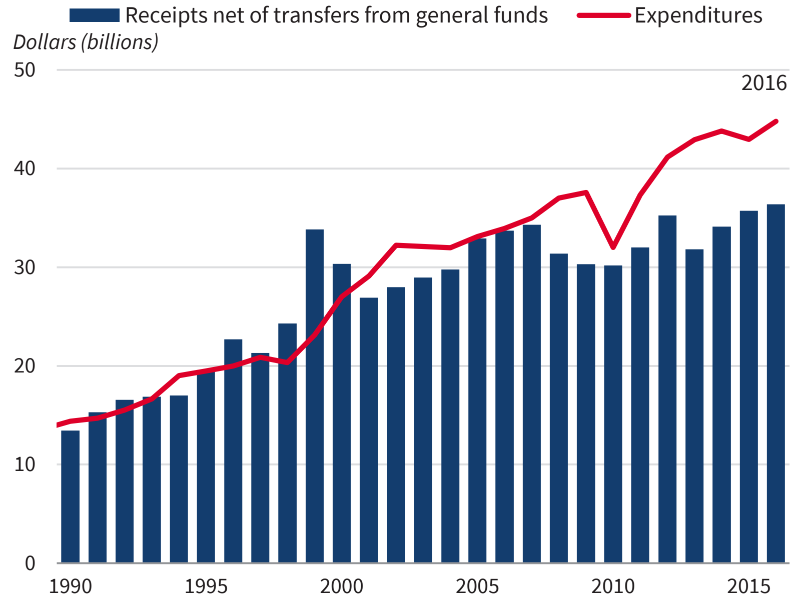
In addition to falling short on efficiency grounds, fuel taxes have seen diminished revenue productivity in recent years, as the twin factors of inflation and increased fuel efficiency have sharply curtailed the growth of the Highway Trust Fund's real fuel tax receipts. The Federal gasoline tax of 18.4 cents per gallon has not been raised since 1993, while construction prices have risen at a 3.9 percent annualized rate. Figure 4-7 shows that in 2016 real Federal fuel tax receipts were only 93 percent of their 1993 levels, even as nominal receipts more than doubled over that period.

Figure 4-7. Federal Fuel Tax Revenues, 1993–2016



Sources: U.S. Department of Transportation; CEA calculations.

Figure 4-8. The Highway Trust Fund's Highway Account, 1990–2016



Sources: U.S. Department of Transportation, Federal Highway Administration; CEA calculations.

These fuel tax revenues have failed to grow as quickly as appropriations for highway spending, putting pressure on the Federal Highway Trust Fund (HTF) used to finance highway and transit projects. As figure 4-8 shows, outlays from the HTF's Highway Account have regularly exceeded revenues since 2008, and the CBO (2017) projects that, absent any changes, the Highway Account's balance will fall below zero by 2021. Because, by law, the HTF cannot incur negative balances, Congress has authorized multiple transfers from general funds to shore up the HTF; the most recent one was in 2016, when $70 billion was transferred—$52 billion to the Highway Account and $18 billion to the Mass Transit Account.

States, too, rely heavily on excise and sales taxes on fuels, with similar revenue pressures arising from inflation and increased fuel efficiency of vehicles. According to Quinton (2017), 26 States have increased their fuel taxes in the last four years to raise more transportation revenues for their roads and highways.

The declining revenue productivity of existing gasoline taxes has led policymakers to consider other options for funding highways. One innovative approach is to consider supplementing or replacing fuel taxes altogether with a user fee more closely related to a consumer's use of the system—such as, in the present context, a tax on vehicle miles traveled. Assessing a charge based on mileage instead of gasoline consumed would link consumers' choices more closely to the costs they impose, including congestion, emission, pavement damage, and so on. Such charges could also be structured to vary with the time of day, region of use, and other factors, including vehicle weight, which has a large impact on pavement wear-and-tear (Sorensen, Ecola, and Wachs 2012; TRB 2012; Kirk and Levinson 2016). Although the design and implementation of such taxes has many challenges, VMT taxes can raise needed revenues in a sustainable way while providing the right signals regarding the value of consumption and supply, helping public officials to understand the value of current uses of roads and highways and to plan for the future.

In the context of freight and commercial shipping, Austin (2015) estimated that a VMT tax on commercial trucks would decrease external costs by $2.1 billion and raise $43.0 billion in tax revenues; including vehicle weight as a factor in the tax and raising diesel taxes in tandem would achieve similar efficiencies but generate revenues of nearly $70 billion annually (in 2014 dollars). Another recent study (Langer, Maheshri, and Winston 2017) finds greater efficiency benefits from a gasoline-tax equivalent VMT tax when the VMT tax is higher in urban areas than in rural areas, reflecting differences in external costs across regions. The intuition here is twofold. First, because the evidence suggests that congestion, accidents, and environmental externalities are higher in urban areas than in rural areas, the differentiated VMT tax gives urban drivers a stronger incentive to cut back on miles driven, improving efficiency. Second, as vehicles' fuel efficiency rises, the VMT tax does a better job than the gasoline

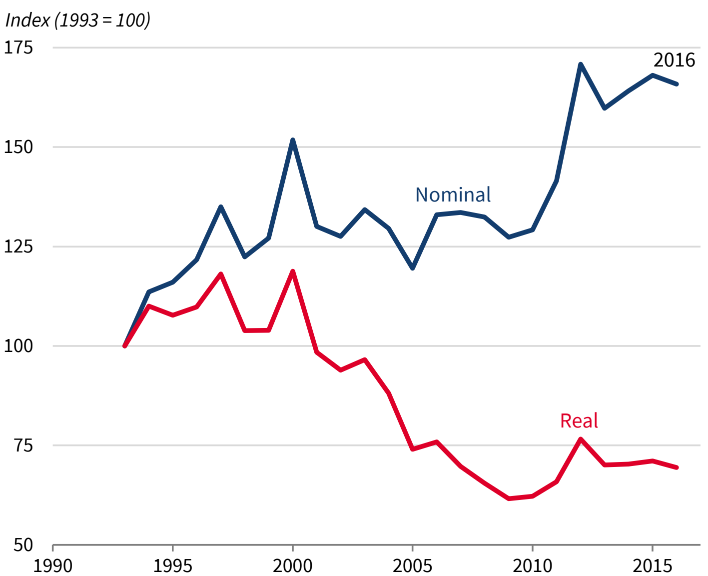
Box 4-3. Oregon's Tax on Vehicle Miles Traveled

Oregon has long been a pioneer when it comes to transportation funding. Oregon was the first State to levy an excise tax on gasoline, setting a tax of 1 cent per gallon in 1919. More recently, Oregon has devoted considerable time and effort to exploring options to replace its excise taxes on fuel to fund its roads and highways. Its OReGO program, which started on July 1, 2015, charges volunteer participants a mileage fee of 1.7 cents per mile for travel on public roads inside the State and provides rebates or credits for State fuel taxes paid. Though small, the program offers tangible evidence that a tax on vehicle miles traveled (VMT) is a promising alternative to relying on fuel taxes (Oregon Department of Transportation 2017).

Motivation and recent history. Like other States throughout the country, Oregon has seen the revenue productivity of its motor fuel taxes diminish as the fuel efficiency of vehicles has improved; also, its State excise tax on gasoline, like that in most States, is not indexed to inflation. Figure 4-ii shows that since 1993, nominal motor fuels sales tax revenues have risen by 65.8 percent, but in inflation-adjusted terms, revenues have fallen by more than 30 percent during this period.

In recent years, the State has moved more aggressively than some others to increase its tax rates to make up for revenue shortfalls. Its excise tax on gasoline of 24 cents per gallon in 1993 was raised to 30 cents per gallon in 2011; and legislation passed in 2017 will increase the excise tax by 4 cents per

Figure 4-ii. Oregon Fuel Tax Revenues, 1993–2016



Sources: U.S. Census Bureau; Bureau of Economic Analysis; CEA calculations.

gallon in 2018, with additional increases planned through 2024. Furthermore, the State has continued its exploration of using taxes on VMT to supplement and perhaps in the future replace the excise taxes now in place. In fact, the Oregon Department of Transportation (2017) estimated that continued reliance on motor fuel tax revenues over the next 10 years would lead to a $340 million revenue shortfall relative to what could be raised by a "road usage charge" or a tax on VMT.

Pilot programs. In 2001, Oregon established the Road User Fee Task Force (RUFTF) to examine alternative revenue sources to fund construction, repair, operations, and maintenance of Oregon's roads. The task force established criteria that a new revenue source or structure should meet, including the "user pays" principle discussed above. Revenue adequacy, system transparency, and enforceability were also important. Ultimately, the RUFTF recommended to the State legislature that Oregon develop and test mileage-based fees (i.e., road usage charges, RUCs) for this purpose, and the State created and ran its first pilot project in 2006. For 12 months beginning in 2006, 285 volunteers used on-board equipment to measure mileage traveled inside identified zones and to transmit data to fuel pumping systems where participants bought fuel. No specific location data were collected or transmitted, so only the general zone and accumulated mileage were recorded and used to determine fees. The fee was collected at the point of sale, as the current gasoline tax was collected, and participants received immediate credit for fuel taxes paid.

After concluding the program and reviewing its performance, the RUFTF began to develop a second pilot program, which ran from November 2012 to March 2013. The goals of the second pilot included using an open architecture, ensuring better and more flexible use of technologies then and in the future, giving motorists choices about how mileage was reported, and including private sector vendors as part of the administrative structure. Most important, however, the RUFTF also wished to provide motorists with the option of avoiding the usage of global positioning system–enabled devices if they desired, allowing users more control over their private information and data.

After concluding these two pilot programs, officials developed the small, voluntary OReGO program, which currently operates in the State. Initially, volunteer drivers were charged 1.5 cents per mile traveled on the State's public roads, receiving credits/refunds for fuel taxes paid and for miles driven on nonpublic roads or out-of-State roads. For a car with fuel efficiency of 20 miles to the gallon, the charge amounted to 30 cents per gallon, the then-current State excise tax. As of January 1, 2018, the road user charge rose to 1.7 cents per mile, aligned with an increase in the State's gasoline tax from 30 to 34 cents per gallon. The program enrolled 1,307 vehicles between June 1, 2015, and December 31, 2016, though only 669 vehicles remained active as of December 31, 2016. Note that the program restricts the number of participating vehicles with low fuel efficiency (below 17 miles per gallon), whose drivers would be likely to pay less under a VMT than under a regular gasoline tax.

Lessons learned and future plans. Oregon officials have a program that allows consumer choice, is based on an open technological platform, and is administratively feasible. The program is small, however, and it is unclear how a scaled-up program would affect revenue generation, efficiency, and equity. McMullen and others' (2016) prospective analysis of a close-to-revenue neutral RUC found that the RUC was less regressive than the gasoline tax—and that restricting the RUC payment option to owners of new cars or high-fuel-efficiency vehicles would make the RUC even less regressive. McMullen and others also found that the effects of moving from the gasoline tax to the RUC varied across regions of the State; areas with drivers who drove more miles on average tended to fare worse under the RUC than under the gasoline tax. Although OReGo is not yet ready to bear the full burden of funding Oregon's road expenditures, it has given policymakers some real experiences on which to base future policy and program decisions.

tax in giving all drivers the right incentives about their use of the roads. In terms of distribution, Langer, Maheshri, and Winston (2017) find that the differentiated VMT tax imposes the largest welfare losses on high-income drivers compared with low-income drivers, because high-income drivers are more likely to live in urban areas (and are more likely to drive highly fuel efficient vehicles), mitigating concerns about the equity effects of VMT taxes.

Thus far, the actual U.S. experience with VMT taxes and other alternatives to gasoline and diesel fuel taxes has been limited. Concerns about privacy risks and administrative and implementation costs have hindered program development, despite technological advances that have made it easier to record, report, share, and manage the information that is needed to administer such taxes. Oregon has been a pioneer in this space, having conducted two pilot programs for VMT taxes on motorists and established an ongoing, small-scale program called OReGO (box 4-3). California, too, facing significant funding shortfalls for its roads and highways, has experimented with VMT taxes, testing a program with simulated, though not actual, road use charges of 1.8 cents per mile for volunteer drivers (California Department of Transportation 2017).

A few States—including Kentucky, New Mexico, New York, and Oregon—do impose alternative taxes on heavy vehicles, via weight-distance or ton-mile taxes. These taxes depend on distance traveled as well as vehicle weight. For example, Kentucky's "Weight Distance License" system imposes a tax of $0.0285 per mile traveled on the State's roadways for all carriers with a combined license weight 60,000 pounds or more (TRB 2012); this tax generated $79.1 million for the State in FY 2015, about 5.2 percent of all Road Fund revenues that year. Thus, a truck weighing 30 tons would face a tax of 2.85 cents per mile, far less than Austin's (2015) estimates of unpriced external damages per ton-mile—at 3 cents per ton-mile, about the midpoint of Austin's estimates excluding emissions damages, a 30-ton vehicle would face a charge of 90 cents per mile.

Distance-based road user charges are more common in other countries, most of which levy such taxes only on freight traffic, not individual drivers. For instance, in 2001 Switzerland—motivated by concerns regarding traffic, wear and tear on roadways, and emissions—established a distance-based charge system for heavy commercial vehicles. Under this system, heavy vehicles pay fees for travel on all Swiss roads based on distance traveled, permissible total weight, and emission category, and the charges are substantial; in 2001, a 34-metric-ton truck (almost 75,000 pounds) faced charges ranging from $0.90 to $1.27 per mile, depending on the emission category. Luechinger and Roth (2016) estimate that the introduction of the tax decreased truck traffic in Switzerland by between 4 and 6 percent, with some evidence suggesting a corresponding mode shift to rail. Direct estimates on external effects were mixed, with evidence suggesting significant declines in nitrous oxide emissions but no impact on accidents. Kirk and Levinson (2016) report that the administration costs of this fee system are between 5 and 6 percent of total receipts, which compares favorably with the costs of toll collections.

Germany also taxes heavy commercial trucks using its main highways. The charges, called *LKW-Maut*, vary only with distance, not weight, but are assessed and collected in real time using a complex system of on-board units, global positioning system technology, web payment portals, and payment kiosks at gas stations and highway rest stops (Kirk and Levinson 2016). Some empirical evidence suggests that the introduction of the charge in 2005 was followed by improved efficiency, as shippers adjusted by routing fewer empty trucks and by loading trucks up to their maximum allowable weight. Doll and others (2017, 33) report that the costs of running the charging system were 12.4 percent of its revenues in 2015.

User fees for transit. Public transit sector ridership and fare revenues have come under increasing pressure from the entry and expansion of ride-sharing services, low gasoline prices, and other factors. Transit services are primarily provided by local governments and agencies, but funding comes from all levels of government, and public subsidies are significant. Direct user fees, primarily in the form of farebox revenues, do not cover total operating expenses, let alone contribute to covering capital costs. Passengers are typically charged fares far below the true marginal operating cost of providing service, leading to inefficiency in the form of congestion, overuse, and queueing as well as revenue shortfalls. In 2016, passenger fares covered 32.0 percent of operating expenses, with the next largest shares coming from localities (31.6 percent) and States (24.4 percent). Federal support was modest, at 7.2 percent of operating expenses. Capital expenditures, however, receive significant Federal funding, which covers 40.7 percent of capital expenditures; passenger fares and other revenues directly generated by transit agencies themselves cover only 11.7 percent of all capital expenditures. In a few cases, new transit projects have been funded with value capture (e.g., TIF) funds; for example, the Chicago Transit Authority plans to combine Federal grant funds with TIF revenues as the primary funding sources for its Red–Purple Line Modernization project, with the TIF revenues directed toward repaying debt issued to finance the project. Other value capture examples are described in the EPA's (2013b) study of several recent large-scale, transit-oriented development projects across the country.

Overall, the sector faces significant challenges, facing long-deferred maintenance needs, changing transit use patterns, and continued reliance on public subsidies. Raising passenger fares significantly, especially for expensive rail service, would improve both efficiency and cost-recovery but, in principle, present affordability problems for some low-income users. In practice, many transit riders are not low-income, so equity concerns regarding fare increases may be overstated. For example, the American Public Transportation Association (APTA 2016) reports that high-income households (those with incomes of $100,000 or more) make up 12 percent of all bus users but 29 percent of all rail users.

At least one transit agency has implemented ORCA LIFT, an income-based transit fare system. The program was introduced in March 2015 in Seattle, and it now operates in both the city (via King County Metro Transit) and the wider metropolitan area (via Sound Transit), charging reduced fares to adults with household incomes below 200 percent of the relevant Federal poverty threshold. Because previous evidence suggested that low-income riders were more likely to ride in off-peak hours, officials had few concerns about increasing peak hour congestion. In effect, these reduced fares offered a way to engage in peak-load pricing, which can increase revenues and improve allocative efficiency. Overall, Sound Transit (2016) reports that passengers paying ORCA LIFT fares accounted for 1.4 percent of system fare revenues and 2.8 percent of all boardings, with an average fare paid of $1.00 (table 4-3). In contrast, reduced fare passengers, who qualify based on categorical measures (age, disability status, etc.), accounted for 2.3 percent of revenues but 6.4 percent of boardings, paying an average fare of $0.70 per trip. Pursuit of equity objectives costs revenues, as the average fares paid indicate.

The biggest risks and opportunities facing the transit sector, however, likely come from the rapid technological change and disruptive entry of new transportation services and providers in cities across the country. The introduction of autonomous vehicles and "smart" road and highway infrastructure will surely influence transit use and patterns in the years ahead, and the entry and expansion of ride-sharing services presents another challenge. Transit use

Table 4-3. Sound Transit Fare Revenues and Boardings, 2016

Aspect	Ticket fare category: Adult	Youth	Reduced fare	Low income	Total
Revenues ($)	75,251,549	2,268,649	1,877,999	1,162,107	80,560,304
Boardings	36,230,074	1,825,594	2,682,736	1,165,727	41,904,131
Revenue per boarding (average, $)	2.08	1.24	0.70	1.00	1.92
Percentage of revenues (%)	93.4	2.8	2.3	1.4	100.0
Percentage of boardings (%)	86.5	4.4	6.4	2.8	100.0

Sources: Sound Transit, Fare Revenue Report 2016; CEA calculations.
Note: Figures represent sums over three principal transit programs: ST Express, Sounder, and Link.

and farebox revenues are under pressure in many cities. The Federal Transit Administration (FTA 2017) reports that 2016 transit ridership was 10.2 billion unlinked passenger trips, down 3.7 percent from its peak in 2014, and ridership in the first 10 months of 2017 was down 2.5 percent from that same period in 2016. At the same time, some local agencies report far larger declines in ridership and revenues. Some observers have argued that the entry and expansion of ride-sharing services by firms such as Uber, Lyft, and others are to blame.

More generally, the entry of these firms has had wide-ranging welfare and transit effects across the country. Some evidence suggests that the services provided by Uber, Lyft, and other firms have made consumers better off with the introduction of more affordable and reliable transportation options, especially in traditionally underserved areas of cities (Hall, Palsson, and Price 2017), and at least one city, Boston, has piloted a paratransit program with Uber and Lyft. In principle, ride-share services could complement transit's fixed-route, fixed-schedule service by extending its reach and flexibility, making transit more attractive and increasing ridership. On the other hand, these services could directly substitute for transit trips, as consumers can enjoy taxi-like service at reduced prices. Systematic evidence to date is limited, but Hall, Palsson, and Price 2017 find that Uber's entry into metropolitan statistical areas (MSAs) across the country does not have a statistically significant impact on transit ridership. However, over time, as Uber's presence grows, transit ridership slowly increases, suggesting that Uber acts as a complement, not substitute, for transit service. However, these effects differ by size of the MSA and transit agency: Uber reduces transit ridership in smaller MSAs, where transit's inflexibility makes Uber an attractive substitute, but Uber increases ridership in larger MSAs, where its ability to extend the transit system's reach makes it a good complement to transit. The researchers also find that smaller transit agencies, especially those in large cities, saw increased ridership after Uber's entry. For larger transit systems, Uber's impact was to decrease transit use by an estimated 2 percent.

Ultimately, Uber's overall effects on welfare will include multiple effects on consumer surplus, transit use and farebox revenues, congestion and safety, and public officials will need to monitor and respond to these technologically driven forces. Further, States and localities may need to adjust their tax and regulatory regimes to insure that all users of public roads and transportation infrastructure pay for congestion costs generated, including ride-sharing companies (Povich 2017). Chicago, Portland, and Seattle are among the cities who have already begun regulating and taxing ride-sharing services, which should aid in internalizing congestion effects as well as providing revenues for transit system improvements.

User fees for water, wastewater, and storm water utilities. Although customers of water and wastewater utilities are accustomed to paying for the services they receive, user fees and charges have often fallen short of raising adequate revenues and/or giving customers the right incentives regarding their consumption levels (Stratton et al. 2017). The sector is characterized by high fixed costs, and pricing structures typically rely heavily on volumetric charges. Without significant fixed monthly customer charges in place, providers often cannot earn enough revenues to cover their fixed costs. Furthermore, the sector is highly fragmented, with most individuals in the United States being served by one of 50,259 community water systems. Most of the systems are very small and serve only a few customers; the 431 largest systems, those serving 100,000 or more, serve 142.2 million individuals.

Overall, the sector faces three key challenges. First, because users rarely face the true marginal costs of their water use, consumption decisions are distorted, water is directed to low-valued uses, and providers do not perceive the true value of additions or improvements to water and wastewater infrastructure. The second challenge, mentioned above, is the sector's significant infrastructure needs, without corresponding sustainable revenues to pay for them. Finally, though providers have raised rates in recent years to better cover their costs and incentivize customers to use less water in some service areas, higher rates have become burdensome in some communities, leading to increased affordability concerns.

Culp, Glennon, and Libecap (2014) argue that charging water and wastewater utility customers true marginal costs of provision will increase incentives to use water efficiently. They propose improvements in the definition and enforcement of property rights in water to allow transfers between parties, directing water to its more valuable uses, a key step in addressing ongoing drought conditions in the American West. The authors also note wide variations in water pricing across regions of the country, with agricultural use often priced below urban use and few instances of full cost recovery. In complementary work, Ajami, Thompson, and Victor (2014) argue that full-cost, increasing block pricing will help expand water supplies via innovation, as water suppliers will respond to high customer valuations by increasing investments in research and development in “smart water,” purification, desalination, conservation, and other technologies. They further propose implementation of a usage-based “public benefit charge” whose revenues would be directed toward innovation and research in the sector. Furthermore, both the studies by Culp, Glennon, and Libecap (2014) and by Ajami, Thompson, and Victor (2014) emphasize the role played by Federal, State, and local government regulations, recommending revisions to simplify and streamline rules and to allow markets for water rights to function more smoothly.

In practice, water and wastewater pricing structures are often variations on two-part tariff structures. Using data from the 2014 survey conducted by the American Water Works Association, Mack and Wrase (2017) report that most utilities use either an increasing block structure (50 percent) or uniform volumetric charges (29 percent), with the rest using a decreasing block structure or some other tariff structure. Water and wastewater rates have increased significantly in recent years. The U.S. Department of Energy reported average annualized growth rates of 4.1 percent for water rates and 3.3 percent for wastewater rates between 2008 and 2016, compared with annualized growth of only 1.4 percent in the Consumer Price Index for All Urban Consumers but 5.6 percent in the Consumer Price Index’s subindex for water and wastewater.

As residential rates have increased, affordability concerns have increased as well. Mack and Wrase (2017) find that meeting the EPA’s affordability guidelines would require household income of at least $32,000, based on average monthly water consumption of 12,000 gallons. They estimate that as of 2014, 13.8 million households, or 11.9 percent of all households, would face bills higher than this affordability threshold. Both the Bipartisan Policy Center (2017) and the Government Accountability Office (GAO 2016) have identified similar patterns and concerns. In addition, the GAO found that utilities in shrinking large and midsized cities utilities had responded to financial stress in part by raising rates, deferring maintenance, and “right-sizing” their water facilities to match their shrinking populations—by decommissioning plants, for example. Such efforts to align capacity with demand may entail disinvestment in some areas.

Many water and wastewater service providers have responded to affordability concerns by establishing or expanding a variety of customer assistance programs. The EPA (2016b) reports that 228 of 795 water and wastewater utilities reviewed had one or more such programs in place, with wide variation in program features such as eligibility criteria and structure of assistance. In some cities, utilities are moving toward explicitly linking rates to income, so that low-income users face a low or even zero marginal cost for increasing consumption (Circle of Blue 2017; Philadelphia 2017).

User fees and equity/efficiency trade-offs. Charging user fees linked to income instead of marginal cost of service provision can improve equity but comes at the expense of efficiency and, in some cases, cost recovery, as seen above in the context of roads, transit, and water utilities. On one hand, encouraging efficiency in use requires that consumers face true marginal costs, along with possible fixed charges to help defray fixed costs. On the other hand, high volumetric and/or fixed charges may discourage low levels of consumption at the intensive or even extensive margin, detracting from efficiency, equity, and cost recovery goals. Resolving these tradeoffs can be difficult, and preferred options may differ by the service at issue.

For example, policymakers may be willing to impose road usage charges for their substantial efficiency and revenue effects, because there are often close substitutes such as nontolled roads or transit that are available to serve transportation needs, and, as Hall (2015) has argued, in some cases, time-varying road tolling does not even create a tradeoff between efficiency and equity. Similarly, increasing transit fares would improve efficiency and cost recovery in addition to providing valuable signals to policymakers about optimal capacity. In the water sector, some policymakers may prefer below-marginal cost pricing for lifeline residential water consumption, giving up some efficiency and revenue gains in exchange for increased equity; the sensitivity of users to price will determine the efficiency "price" of achieving equity goals. On balance, policymakers wishing to maximize social surplus may wish to limit price distortions by encouraging true marginal cost pricing and addressing equity concerns via pro-growth policies and progressive tax and transfer programs as needed, recognizing that residential mobility will limit the ability of local and sometimes State governments to engage in too much redistribution.

Financing Infrastructure Investment

Once revenue sources are identified to support particular infrastructure projects or categories, financial plans must be developed. Creative financial structures do not negate the need to identify adequate and appropriate funding resources, but they can be used to better allocate risk, align incentives, and lower costs of infrastructure investments and service provision. Recall that overall, States and localities own, fund, and manage most of the Nation's infrastructure assets, contributing 77 percent of all public spending on transportation and water infrastructure (CBO 2015). This suggests that the Federal role, though important, is limited. That said, Federal support for infrastructure spending takes several forms, including grant funding for States and localities; access to subsidized credit through direct or indirect loan programs; and the favorable tax treatment of municipal securities. In this subsection, we briefly discuss these three tools.

Federal grant funding for States and localities is a key financing source for their infrastructure programs, and direct Federal spending is quite limited.

For highways, most grant funds are distributed based on statutory formulas, which can include factors such as population, lane miles, and other factors. The 2015 Fixing America's Surface Transportation (FAST) Act authorized $207.4 billion in grants under the Federal-Aid Highway Program for the FY 2016–20 period, all of which are apportioned by statutory formula (FHA 2017). States must generally contribute $.20 for every $.80 provided in Federal funds, but less ($.10 for every $.90 in Federal funds) for interstate highways. Substantially less Federal grant funding is allocated on a competitive basis; Lew (2017) estimates that the U.S. Department of Transportation's (DOT's) largest competitive grants accounted for less than 2 percent of DOT's budget. In fact, only $4.5 billion was authorized for FY 2016–20 for the competitive Infrastructure for Rebuilding America (INFRA) grants program, which is intended to provide assistance for projects of national or regional significance, far less than the amount directed to formula highway grants. Another competitive grant program, DOT's Transportation Investment Generating Economic Recovery program, known as TIGER, which seeks to support projects having a "significant impact on the Nation, a metropolitan area, or a region," is also relatively small, with a $500 million appropriation for FY 2017.

For water and wastewater infrastructure, the Federal government's primary support has come through EPA grants to the States to capitalize State-administered revolving loan funds, which in turn provide low-cost loans to service providers for infrastructure projects. Federal appropriations for the revolving loan funds have been essentially flat for nearly 20 years; in FY 2017, the Clean Water State Revolving Fund allotments totaled $1.394 billion and the Drinking Water State Revolving Fund allocations totaled $824 million. Like the highway grant programs, these EPA programs typically require a 20 percent match against federally provided funds (Vedachalam and Geddes 2017). The loans themselves are repaid with revenues raised from customers along with general tax revenues collected from local taxpayers.

Because grant funding is such a big component of resources used by States and localities to fund infrastructure projects, the Federal government has great opportunity and scope to shape nonfederal decisionmaking in several ways. One obvious way is through the strategic choice of matching requirements. Grant programs requiring a 20 percent matching of Federal funds essentially offer cheaper funding than those requiring, say, a 50 percent matching of Federal funds, and Federal officials can require grant recipients to meet certain conditions—for example, a maintenance-of-effort provision—to receive more generous matches. Alternatively, Federal officials could require grant recipients to devote some minimum amount of resources to maintenance and repair, or to resiliency and disaster recovery planning, as conditions of receiving Federal support.

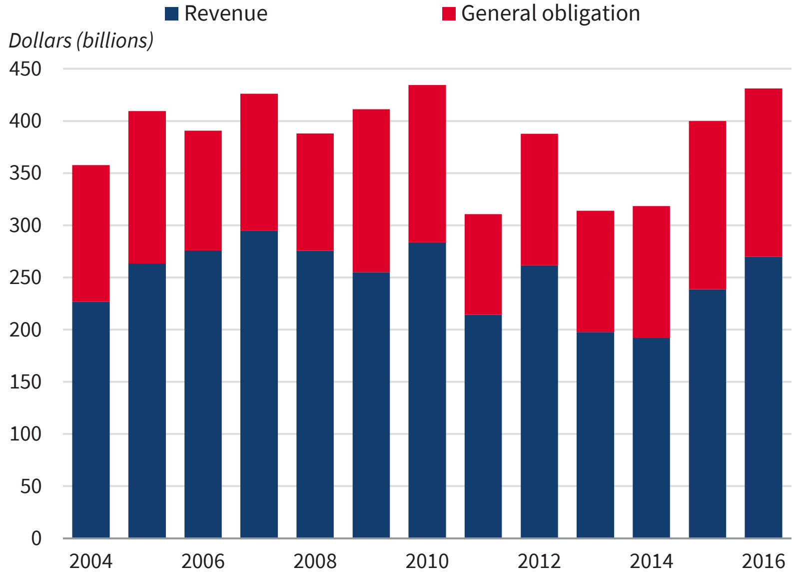
Another option is to incentivize better project selection by grantees and direct more grant dollars to competitive instead of formula-based programs, which could in principle increase the effectiveness of any given amount of Federal grant funding. For example, the INFRA competitive grant program requires the preparation of a cost/benefit analysis of the proposed project, but the amount of funding at issue is relatively small. The CBO (2016a) also highlights the importance of directing Federal dollars toward projects with the greatest returns, as evidenced by cost/benefit analysis. In some instances, the CBO (2016a) indicates that such a redirection would entail spending more on major road and highway repairs, especially in urban areas, and less on overall system expansion. Kahn and Levinson (2011) and Glaeser (2017) all emphasize the value of maintenance spending and the importance of applying cost/benefit analyses to project selection at the State level.

Finally, policymakers should recognize the potential costs that come with accepting Federal grant support for projects. Federally funded highway projects, for example, come with Federal requirements related to environmental reviews, prevailing wages, and Buy America provisions, and Federal aid dollars cannot be used on local roads (urban or rural) or rural minor collector roads. Some States have established programs in which local governments can exchange, at a discount, some of their Federal grant funding from the Federal Highway Administration for less encumbered state funding. Kansas, for example, established its "Federal Fund Exchange" program in 2010, allowing local public agencies to exchange $1 in Federal funding for 90 cents of state funding. This gives these agencies more flexibility in project selection, and the State uses the Federal funds for projects on State-owned roads and highways. Other States (e.g., Indiana, Nebraska, Oregon, and Utah) have similar programs, with exchange rates ranging from 75 cents to 94 cents on $1. The existence of these programs and similar "after markets" for Federal grant funding indicates that the cost of accepting Federal funds can be material and that local officials value flexibility so they can direct funding to the projects best for local constituents.

In addition to providing grants to States and localities, the Federal government also provides a variety of credit resources to States and localities, ranging from direct loans to loan guarantees and other instruments intended to facilitate low-cost access to capital markets. DOT's Transportation Infrastructure Finance and Innovation Act (TIFIA) program provides secured loans, loan guarantees, and/or standby letters of credit for projects of regional and national significance. The FAST Act authorized up to $1.4 billion in TIFIA funding over the FY 2016–20 period. TIFIA loans must be secured by "dedicated revenue sources," which can include tolls, user fees, TIF revenues, and other tax revenues pledged to repayment.

The Federal government took a similar approach in the area of water infrastructure when, in 2014, the Water Resources Reform and Development Acts established a pilot program called the Water Infrastructure Finance and Innovation Act. Under this program, the Federal government may provide direct loans and loan guarantees for eligible borrowers, aiming to support larger

Figure 4-9. New U.S. State and Local Government Debt Issues, 2004–16



Source: Federal Reserve Board.

projects than are usually funded by State revolving fund loans. Vedachalam and Geddes (2017) argue that the program can lower debt service costs for participating borrowers. Eligible projects related to drinking and clean water must have costs exceeding $20 million for large community projects (areas with more than 25,000 people) and $5 million for small community projects (areas with less than 25,000 people).

The third key Federal support for infrastructure investment involves the tax treatment of municipal debt. State and local governmental entities rely heavily on borrowed funds to finance their public investments—and in doing this, they benefit from the preferential tax treatment of municipal bonds issued for governmental and qualified private purposes. In brief, the tax payments made to owners of such debt are not taxable for Federal income tax purposes, allowing municipal bond issuers to pay lower interest rates in equilibrium than they would otherwise need to pay. The rationale for this exemption is that some infrastructure provides benefits beyond the boundaries of the jurisdiction making the investment. Without a mechanism to internalize these externalities, States and localities could underinvest relative to efficient levels.

The tax exemption for municipal bonds cost the Federal government $28.9 billion in forgone tax revenues in 2016 on an outstanding stock of over $3 trillion in securities issued by States and local governments (Federal Reserve 2017). Figure 4-9 shows that State and local bond issuance has risen in recent years, reaching $431.3 billion in 2016. Revenue bonds, which are secured

Box 4-4. Public-Private Partnerships

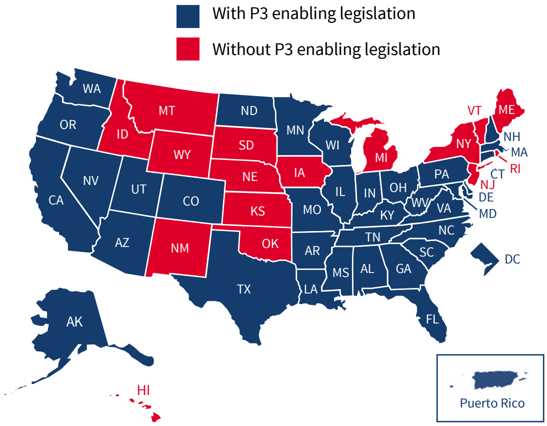
Public-private partnerships (P3s) allow for innovative and efficient, though not free, procurement of infrastructure projects. When State and local government leaders work with private partners to address infrastructure deficiencies, there are potential synergies for both parties. Large, complex projects with dedicated funding sources supported by tax revenues, user charges, or other revenue sources can be provided more efficiently using P3s rather than traditional procurement methods. Projects that offer meaningful opportunities to decrease life cycle costs by combining design, build, operate, maintain, and sometimes finance services into one contractual relationship are good candidates for P3s, as private partners can contribute capital, project management expertise, and risk management in return for revenues from the government partner.

Traditional procurement deals typically give private contractors little incentive to consider the lifetime costs of a project, whether monetary or opportunity. Under traditional procurement methods, for example, a design team contracted for a project would typically not be responsible for building, operating, or maintaining the facility over its lifetime, thus would have little incentive to consider processes that would streamline the construction process, accelerate project delivery, or minimize maintenance needs over the project's lifetime. In a P3 partnership, the private partner could be responsible for designing, constructing, and maintaining the project. Therefore, incentives are aligned for efficiencies throughout the process, for both private and public sector parties.

P3s can also decrease risk related to uncertain future demand, cost overruns, construction delays, and the like, though it is important to note that reducing public sector risk will be priced into the P3 agreement. More generally, P3s allow risk to be borne by the party best equipped to handle that risk. For example, regulatory risk (the risk that a project may be scuttled due to regulatory or permitting actions) is likely best borne by the governmental partner, while the private partner likely has greater project management and construction expertise and is therefore in the best position to manage that risk. Demand, or revenue, risk may be shared or borne in full by one party or the other, depending on the project's particular features.

Despite these benefits, P3 partnerships are uncommon in the United States. A report published by the U.S. House of Representatives' Transportation and Infrastructure Committee finds that from 1989 to 2013, 98 highway P3 projects totaling $61 billion were completed. These projects equal only 1.5 percent of approximately $4 trillion spent on highways during that period by all levels of government. Currently, 34 U.S. States, the District of Columbia, and one U.S. territory have enacted statutes that enable the use of various P3 approaches for the development of transportation infrastructure, as shown in figure 4-iii.

Figure 4-iii. P3 Enabling Legislation, by U.S. State and Territory



Source: U.S. Department of Transportation, Federal Highway Administration.

Moreover, a 2016 report from Moody's Investors Service finds that though growth of infrastructure P3s in the United States has been slow and fragmented, the market remains positioned to become one of the largest in the world. One key provision in accomplishing this target is the recently passed FAST Act, which created the Build America Transportation Investment Center, intended to cultivate P3s by helping them access Federal credit and navigate Federal permitting and procedural requirements.

Examples of P3s. In 2012, the General Assembly of the Commonwealth of Pennsylvania amended Act 74 to Act 88, which allows private entities to develop and operate qualifying transportation facilities and to submit solicited and unsolicited proposals; encourages investment by private entities; and enables the procuring agency to accept offers above the lowest price offer. Additionally, the act allows terms of up to 99 years for P3 agreements; authorizes user fees for the subject transportation facility; and requires that public bargaining unit covered employees displaced by the P3 project be offered employment with the development entity on terms essentially identical to those in the relevant collective bargaining agreement for its duration.

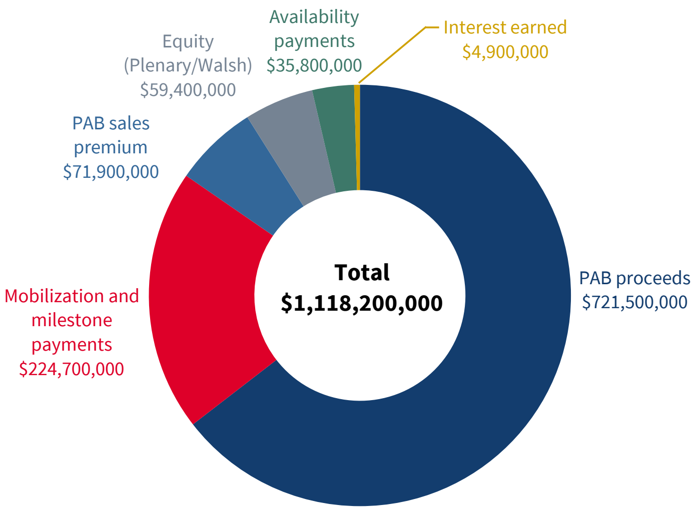
Through this new mechanism, in 2014, Pennsylvania formed a partnership with Plenary Walsh Keystone Partners (PWKP) to replace 558 structurally deficient bridges across the commonwealth. As of 2016, 19.8 percent of all bridges in Pennsylvania were considered structurally deficient (compared with 9.1 percent across the United States). The Pennsylvania Department of Transportation (PennDOT 2014) chose the P3 structure to accelerate the replacement of the bridges and facilitate efficiencies in design and the construction of bridge components; the selected bridges could be replaced using a limited number of standardized sizes, designs, and components, making this bundled approach an efficient one. PennDOT estimated that this approach will speed up project completion and save 20 percent over the life of the concession period, compared with PennDOT's replacing the bridges itself.

The P3 agreement calls for PennDOT to make milestone payments during the construction phase of the project and availability payments during the concession period, with clear standards in place for keeping the bridges in good operating condition; noncompliance with the standards results in deductions from the payments made to PWKP. To provide the revenues needed for these payments, the Commonwealth of Pennsylvania laid the groundwork in 2013, when it enacted Act 89 (HB 1060). When fully implemented, this law is intended to raise an additional $2.3 billion per year, including $1.6 billion for roads and bridges highways and at least $476 million for transit, primarily by increasing the sales tax on gasoline as well as a number of registration and licensing fees.

The financial structure of the agreement is depicted in figure 4-iv. Including financing costs, the total cost of Pennsylvania's Rapid Bridge Replacement Program is $1.1 billion, which includes a record $721.5 million in private activity bonds (PABs), which are discussed in this chapter's main text.

Another noteworthy P3 has been the partnership between the City of Phoenix and American Water Enterprises, Inc., executed to build a new water treatment plant designed to serve 400,000 homes. The Lake Pleasant Water

Figure 4-iv. Pennsylvania Rapid Bridge Replacement Program Project Cost



Source: U.S. Department of Transportation, Federal Highway Administration.
Note: All values are in nominal U.S. dollars. PAB represents private activity bonds.

Treatment Plant was completed in 2007 and has a capacity of 80 million gallons per day, with a potential capacity of 320 million gallons per day (UNC Environmental Finance Center 2016). The P3 agreement was structured as a design-build-operate contract, which required Phoenix to pay $228.8 million for the design and build phases and regular service fees during the 15-year life of the agreement. The city issued tax-exempt bonds to finance its payment to the private partner, secured by the revenues generated by the water system from user fees and charges. Through this P3, the city largely met its goals of reducing project risk and achieving life-cycle savings and efficiencies. Furthermore, the city was ultimately able to renegotiate the contractual agreement when lower-than-anticipated water demand and consumption left the city collecting less water system revenues than planned.

The Path Forward. The future is clear with regard to P3s. There is not one single actor; instead, the success of P3s depends on coordination and shared responsibility among multiple entities. States and local governments may wish to adopt broad P3 enabling legislation and establish offices to provide technical and administrative assistance for private investors as well as local governments. Well-structured P3s that provide incentives for efficiency, allocate and price risk appropriately, and protect the public interest can be an effective way to leverage the skills and resources from the private sector to accomplish public sector infrastructure goals that would benefit all Americans.

by identified revenue streams—such as specific taxes, user fees, and other charges—made up more than 60 percent of total bonds issued in 2016, with general obligation bonds, backed by the issuer's faith and credit, accounting for the rest.

The favorable tax treatment of municipal bonds is only available to debt that serves governmental (public) purposes or qualified private purposes. Bonds that pass both the "use test" and the "security test" are governmental bonds that can be issued without Federal limitation (Congressional Research Service 2016). Municipal bonds that fail one or both of these tests are not eligible for the Federal tax exemption. However, Congress has long recognized that some infrastructure projects provide both private and public benefits, and since 1968, bonds used to fund certain eligible types of projects and activities are deemed "qualified" private activity bonds (PABs), which can and do receive the Federal tax exemption. Currently, 22 categories of projects may be funded with qualified PABs, and Congress caps the total amount of debt capacity available each year, with different caps applying to different project categories. Qualified private activities include exempt facilities projects (airports; water, sewage, and solid waste facilities; educational facilities; and surface transportation), industrial development bonds, and student loans. In 2016, States and

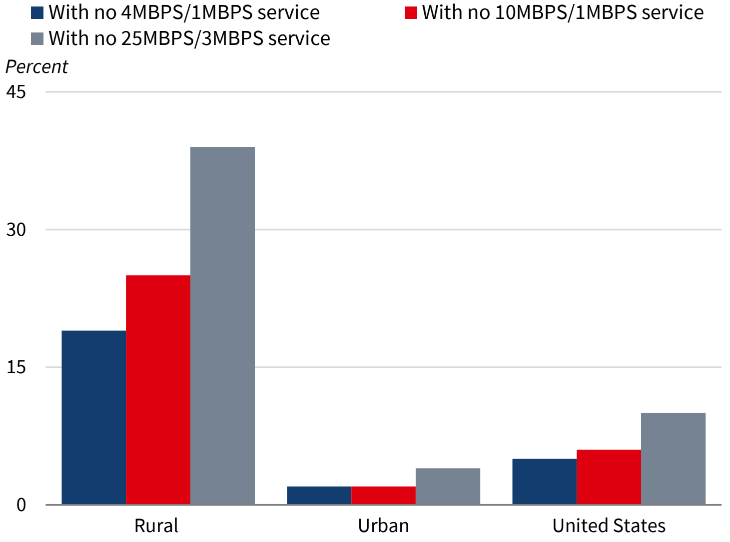
Box 4-5. Bridging America's Digital Divide

During the past decade, high-speed Internet service has transformed the global economy and changed how Americans live their lives. Access to broadband—defined by the Federal Communications Commission as a download speed of at least 25 megabits per second—is increasingly necessary for modern commerce, community engagement, job creation and matching, education, healthcare, and entertainment. Today, many of even the most common household Internet tasks require a high-speed connection, due to the rising sophistication and heavy graphics content of many websites; paying bills, online banking, shopping, research for homework assignments, and registering a car can be worse than frustrating for those who rely on dial-up access.

However, though just 4 percent of urban Americans lack access to broadband speeds via fixed terrestrial service, 39 percent of rural Americans cannot obtain it, as shown in figure 4-v. Low population density, challenging geographic features like mountainous terrain, and exposure to harsh weather in certain areas increase the per-customer cost of service delivery, acting as a disincentive for broadband providers to expand service into rural communities. In addition, broadband providers often face bureaucratic obstacles to building a network, including arduous application processes and burdensome regulatory reviews.

Even when broadband service is available, rural Americans in general face a more limited choice set of service providers than their urban counterparts, and tend to adopt at lower rates. According to the Congressional

Figure 4-v. Access to Fixed Terrestrial Broadband Service, 2014



Source: Federal Communications Commission.

Research Service (Kruger 2016, table 4), though 44 percent of urban Americans reside in areas that offer a choice between providers, just 13 percent of rural Americans do. A Pew Research Center survey of home broadband usage identified several persistent disparities in broadband adoption, including the fact that rural Americans tend to adopt broadband at lower rates; 63 percent of adults in rural areas said they have a high-speed broadband connection at home, compared with 73 percent of Americans in urban areas. (Similar gaps in adoption are reported by the National Agricultural and Rural Policy Development Center, and by the Department of Commerce; Kruger 2016, 6.)

Nonadopting respondents cited cost—of computers and of the service—as an important reason for not subscribing. And the GAO found that nonadoption is principally driven by unaffordability, a lack of perceived relevance, and low computer skills. Interestingly, the Pew study also showed that between 2013 and 2015, the share of urban Americans with terrestrial broadband service declined moderately. This trend toward fixed-line disadoption was accompanied by an uptick in smartphone adoption; 13 percent of Americans now rely on the smartphone for online access at home (Kruger 2016, 6–7).

This gap in e-connectivity not only prevents many rural Americans from participating in the global marketplace but also restricts their ability to improve other parts of their lives, from their job prospects, placement, and training, to education and healthcare. Access to broadband is key for modern private enterprise, and a lack of available infrastructure prevents investment in rural communities. Several studies show that broadband availability confers important economic benefits on a community (Kruger 2016, 9). Recognizing that rural America's economic recovery from the Great Recession has been far slower than that of the rest of the country, in April 2017 President Trump established the Interagency Task Force on Agriculture and Rural Prosperity via Executive Order. In its final report, the task force identified the expansion of e-connectivity as an important path to prosperity for rural America, and prioritized identifying funding sources, streamlining the broadband deployment process, and reducing barriers to high-speed infrastructure buildout.

Provision of broadband in the United States is largely privately organized. Private firms of today face many of the same basic problems that hindered infrastructure development to expand electrification and telephone service to rural areas during the early part of the last century: challenging geographical features and a lack of scale economies in regions with low population densities. The Federal government currently uses two vehicles to direct funds to broadband deployment: the Universal Service Fund programs of the Federal Communications Commission, and the broadband and telecommunications programs of the U.S. Department of Agriculture's Rural Utilities Service (Kruger 2016, 12).

There are many options for improving the deployment and adoption of high-speed Internet connections to unserved and underserved areas, but a key consideration is striking the right balance between providing Federal assistance where private options are unavailable or unaffordable and minimizing the detrimental effects that government intervention can have in the private marketplace. A wide array of instruments are available to policymakers—from loans and loan guarantees, to infrastructure grants and universal service reform, tax incentives, direct assistance to taxpayers, and regulatory and deregulatory measures (Kruger 2016, 23). In deciding on the appropriate method(s), however, it is important to proceed with an understanding of the availability of next-generation and mobile broadband technologies, because these may prove less costly and more desirable to consumers in the long run. To advance the goal of increased access, the Federal government recently announced that the Department of the Interior will make some of its real property assets available for deployment of rural broadband assets.

Box 4-6. Transitioning to the 21st Century: The Case of 5-G Wireless

Maintaining a competitive economy into the 21st century will require not only upgrading, expanding, and enhancing conventional infrastructure assets but also investing in new, innovative, and potentially disruptive technologies. These technologies have the potential to profoundly alter economic relationships and increase productivity throughout America and across industries, thereby supporting economic growth. Although the private sector is likely to lead investments in many of these technologies, the public sector will shape future investment choices made via its regulatory and other policies. The example of 5G wireless technology highlights some of the risks and opportunities of these technological innovations.

Industry analysts project that the 5G market will develop rapidly. Deloitte expects 5G trial markets to materialize by the end of 2017 and develop into a “full, mass market” by 2020. Whereas the cellular infrastructure of the past relies in its entirety on large towers, this new 5G cellular infrastructure will require the deployment of smaller cellular transmission devices (often referred to as “small cells”) to augment traditional cellphone towers (Gupta and Kumar Jha 2015). Due to the nature of wireless transmission, the addition of these smaller cellular devices will enhance the capacity of wireless networks to transmit data. With improved capacity and speed that improve connections of digital technologies, 5G may support the flourishing of the “Internet of Things”—including driverless cars and high-technology healthcare systems. Such technologies are projected to boost connectivity, productivity, and output. By 2035, IHS (Campbell et al. 2017) projects that 5G could support $12.3 trillion in global economic activity.

Industry analysts also expect 5G to boost high-wage employment, lowering job search, match, and telecommuting costs, perhaps of special value in distressed communities with limited job opportunities. In addition, various traditional infrastructure sectors may benefit from the deployment of 5G service, including energy and utilities (e.g., energy-consuming devices in a grid) and transportation (e.g., 5G-powered traffic management systems), as well as public safety (e.g., integration of video surveillance).

There are two main challenges for 5G development. The first challenge is standards. Attracting private sector investments will require clarity about the future path of the technology itself. Setting specific technological standards for 5G wireless facilities and operations enables interoperability and compatibility and will shape future investment choices by firms. Directly, a country with a dominant industry share may crowd out similar telecommunications exports from other countries because of compatibility and standards issues. Given the high fixed costs in the industry, the countries and their companies that initiate the standard may gain first-mover advantage, making it difficult for new entrants with different standards to enter. For example, industry sources indicate that the adoption of China's Polar Code Error Connection technology for encoding 5G in November 2016 is a symbol of China's rising leadership in 5G technology (Rogers 2016; Lucas and Fildes 2016). Indirectly, the dominating nation may have preferential access to foreign intellectual property that is using the 5G network, which could enable theft of this property, an issue that is discussed in chapter 7.

Standards for 5G technologies are developed by multistakeholder organizations, such as the 3rd Generation Partnership Project (3GPP), and are ultimately codified at the International Telecommunications Union, a United Nations agency that coordinates global telecommunications operations and services. To date, the U.S. has pursued a standard-setting approach led by the private sector, whereby product standards are generally set through voluntary, private organizations. In contrast, many other countries engage in active governmental direction of standard-setting activity. For example, the Organization for Economic Cooperation and Development (OECD 2010) notes that there is active participation by European governments in the Global System for Communications' mobile phone standard. Similarly, in the context of the telecommunications industry, Linden (2004) notes that China maintains rights "to involve government in all standard-setting decisions." Heavy government involvement in international standard setting may be concerning if it crowds out private actors due to governments' larger economies of scale and capital or if such involvement is coordinated to disproportionately benefit particular nations.

The second challenge for 5G development is regulation. Establishing a flexible and adaptive regulatory structure will be needed to support future 5G deployment, with coordination across Federal, State, and local government levels. Specifically, the April 2017 Notice of Proposed Rulemaking, issued by the Federal Communications Commission (FCC) regarding “accelerating wireless broadband deployment by removing barriers to infrastructure development,” sought comments on two sections of the Communications Act, Sections 253 and 332. Section 253 delineates the rights of State and local authorities to collect “fair and reasonable compensation from telecommunications providers” but also prevents any State or local government from prohibiting “intrastate or interstate” telecommunications service. Local authorities can stymie rapid deployment of infrastructure by delayed disposition of requests for local rights of way and siting approvals. Section 332 requires that State and local governments not discriminate between service providers who want to site cellular infrastructure, refrain from setting prices, and respond to such requests within “a reasonable period of time.” However, many local authorities may not be equipped to understand the impact of small cell deployment, which does not disturb the public rights of way as traditional wireless infrastructure, such as cell towers. Though the FCC has solicited input on the subject, it has yet to implement decisions about how it will balance the interests of the different stakeholders involved in the physical rollout of 5G.

Governments may also ensure that 5G service providers have access to the appropriate spectrum, or the radio frequency waves over which the signals are transmitted. Unlike the large cell towers of traditional wireless infrastructure, 5G’s “small cells” transmit electromagnetic waves at a variety of frequencies, ranging much higher than those on which previous wireless data services have relied. To generate economic value from 5G infrastructure, providers must have access to appropriate spectrum frequencies. To ensure the availability of spectrum, the FCC voted in July 2016 to authorize the use of spectrum bands in the millimeter wave ranges relevant to 5G. These bands may eventually become available through overlay auctions and the secondary market and will benefit both 5G operators and current owners of these rights.

Thus, though investment funding and asset ownership in this sector are currently dominated by the private sector, Federal officials have opportunities to make policy decisions that will shape the environment for future private investment in this sector, allowing the United States to take best advantage of the benefits offered by this new technology.

localities issued $20.4 billion in qualified PABs, of which about two-thirds were directed toward affordable multifamily housing projects (CDFA 2017, 9).

PABs have proven to be especially valuable in projects structured as public-private partnerships (P3s). The Safe, Accountable, Flexible, Efficient Transportation Equity Act of 2005 authorized the issuance of up to $15 billion in PABs for use in transportation P3s. As explained in box 4-4, P3s offer an alternative to traditional project procurement, whereby a private sector entity or consortium contracts with the relevant State and/or local governmental bodies to design, build, finance, operate, and/or maintain infrastructure facilities. Allowing private entities to issue tax-preferred PABs to finance such projects is simply the equivalent of allowing the public sector to issue governmental purpose bonds.

On balance, the Federal government has a key, if limited, role to play in both funding and financing of infrastructure investments. Increasing investment to address infrastructure needs will take additional resources from Federal, State, and local government taxpayers as well as the direct beneficiaries of the assets. On the funding side, reliance on user fees to pay for investments has its limits, but significant efficiency gains can still be achieved through careful expansion of their use. On the financing side, the Federal government can use grant funding as an incentive to encourage States and localities to be more efficient when undertaking infrastructure investments and can promote the use of bonds to support additional infrastructure investment. The Federal government can also continue to support the use of innovative financing structures such as P3s to reduce the overall costs of infrastructure investments.

How Core Infrastructure Ensures a Competitive Economy

The U.S. economy of course also depends on services from assets in sectors other than surface transportation and water and wastewater. Maintaining a competitive and productive economy for all Americans requires a reliable, robust, and resilient energy sector, multiple transportation modes and systems, and an advanced, productive telecommunications sector. These infrastructure sectors support trade and economic activity and display significant economies of scale and network effects; yet infrastructure is primarily privately owned in some instances but publicly owned in others. Therefore, as this section explains, it is not surprising that barriers to needed infrastructure expansion and upgrades differ across sectors, with regulatory issues appearing paramount in some cases but funding challenges being the key issue in others.

For example, consider the telecommunications sector, for which most infrastructure is privately owned. In some segments of the market, the key issues are the costs of service relative to revenues collected from users, along with regulatory concerns, and box 4-5 explores the market for rural broadband service from this perspective. In the case of 5G wireless technology and investment, issues of regulatory barriers, technological standards, and international competition are more salient. Box 4-6 explores these issues in greater detail, and highlights recent regulatory actions serving to simplify and clarify regulatory roles of States and local governments in the wireless broadband industry and to facilitate markets in which spectrum and transmission rights can be bought and sold. Aligning regulatory policies with the Nation's growth objectives will help ensure that these technologies provide the greatest possible boosts to productivity and growth for all Americans in the years ahead.

In the rest of this chapter, we discuss recent developments in the energy sector and the inland waterways system, identifying opportunities and challenges for getting the right infrastructure assets in the right places. We particularly explore the roles of regulation and funding in shaping investment decisions in these sectors—and, subsequently, America's competitiveness and productivity in the 21st century.

The Energy Sector

Energy infrastructure in the United States is the envy of the rest of the world, for both fuels and power—if for no other reason than its sheer extent. The United States has over 2.5 million miles of natural gas pipelines and 207,000 miles of petroleum pipelines, according to 2017 data from the Pipeline and Hazardous Materials Safety Administration. By some estimations, the North American electricity grid is the largest such facility in the world. It has 697,000 miles of high-voltage transmission lines and 6.4 million of miles of feeder and distribution wires (Giles and Brown 2015). These giant networks have been built piece by piece over a long period, under a range of prevailing market and regulatory conditions. Addressing the economic and regulatory constraints on infrastructure investment ensures that future expansions and modernizations of theU.S. energy networks will be both prudent and timely.

Because energy infrastructure is long-lived, the United States lives with the legacy of the past. Its electricity grid—which was built by regulated, vertically integrated utilities—differs from the grid that would be built in a restructured market that depends heavily on intermittent generation by renewable sources, like wind and solar power. Changing market conditions, such as the restructuring of electricity markets, are an important consideration for infrastructure investments. Restructuring has aimed at aligning investment incentives, but risks remain for new projects. For instance, when it opened in 2009, the Rockies Express Pipeline (REX) was heralded as a bold, new 1,663-mile link in the U.S. natural gas system, delivering abundant Western gas to hungry Eastern markets (Carr 2013). Five years later, the flow in the Eastern reaches of the $3 billion REX pipeline was reversed to allow newly discovered Eastern gas to flow to the West.

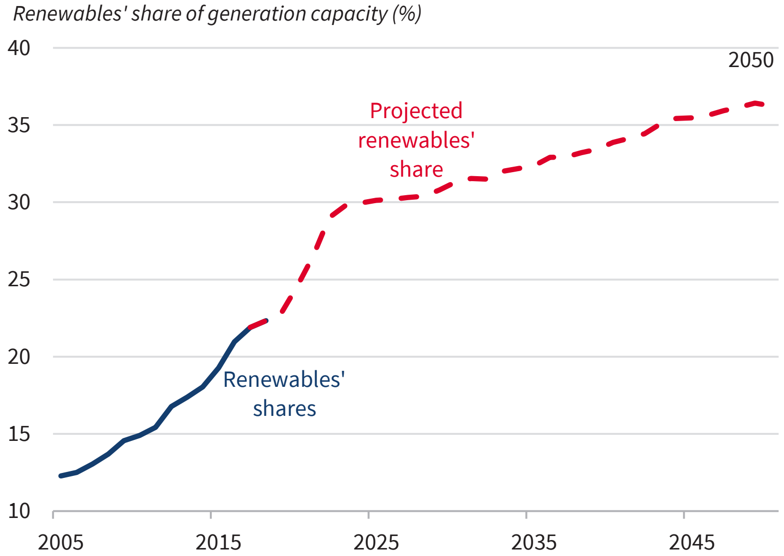
The REX experience underscores the specificity problem of infrastructure—once it has been built, it cannot be moved. Specificity could lead to concern about underinvestment, but it also opens the door to natural monopoly power. The high fixed costs and low marginal costs mean that it is socially optimal to have a single network rather than competing ones. The natural concern is that the operator would charge high prices to take advantage of monopoly power, and the traditional remedy has been rate regulation—with Federal oversight only when infrastructure crosses State lines.

Most energy infrastructure—power lines and pipelines, along with the necessary plants and terminals to serve them—is privately owned; as of 2015, 3.5 of the 6.4 million miles of distribution lines were owned by private utilities, while the remaining 2.9 million were owned by Federal, State, and municipal utilities (Giles and Brown 2015). Pipeline infrastructure for both gas and oil is further skewed toward private ownership; in 2016, 91 percent of pipelines, by capacity, were owned by corporations. Energy infrastructure is excludable—enabling suppliers to charge customers for services and access provided; oil producers to pay for pipeline capacity, electric consumers to ultimately pay for power to be delivered via wires, and exporters to pay port fees and lading charges. These user fee revenues ultimately provide the resources needed to maintain, upgrade, and add capacity, so funding resources are rarely the limiting factor in energy infrastructure investment. Instead, regulatory oversight has often proved to be the greater hurdle to modernizing and expanding infrastructure (Borenstein, Bushnell, and Wolak 2000).

Pipelines and transmission infrastructure. New technical abilities to extract natural gas and oil from previously unprofitable regions and States, such as North Dakota, have increased demand for new pipeline capacity. In the short term, the lack of available pipeline capacity has increased demand for alternative forms of transportation, including rail. In the electricity sector, the falling cost of renewable generation technologies, like wind and solar power, has increased installations and required transmission facilities that can accommodate the intermittent nature of these technologies. For both fuel and power infrastructure, the demand for more transmission capacity in new regions has made issues related to gaining regulatory permission more salient. For example, the Keystone XL and Dakota Access crude oil pipelines were delayed, at least temporarily, by regulatory and legal challenges (see chapter 2 for a related discussion). Significant investments are currently on hold, awaiting regulatory action; at the end of October 2017, Federal approvals for new or expanded natural gas pipelines were pending for 15 billion cubic feet per day across a total of 1,630 miles of pipe (FERC 2017).

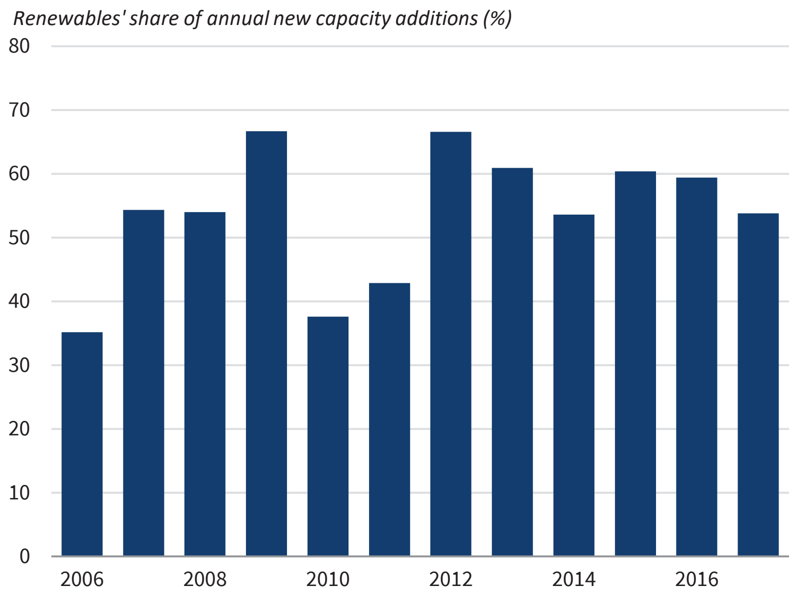
In the renewables segment of the sector, production and investment tax credits as well as State-level renewable portfolio standards have encouraged investments in solar, wind, and geothermal power. With the adoption of these incentives, as well as improvements in generation technologies, renewables' share of total generation capacity has risen considerably since 2005 (figures 4-10 and 4-11). Renewable growth accounted for 54 percent of new capacity additions in 2017, and it has averaged 55 percent of all new capacity additions since 2005. The share of electric generating capacity contributed by renewables has climbed from 12 to 22 percent since 2005, and the Energy Information Administration predicts that this trend will continue through 2050, when renewable capacity will exceed 35 percent of installed capacity. Falling costs for renewable electricity generation have triggered an increase in demand

Figure 4-10. Renewable Energy's Current and Projected Share of U.S. Generation Capacity, 2005–50



Sources: U.S. Energy Information Administration, Annual Energy Outlook and Annual Electricity Reports.

Figure 4-11. Renewable Energy's Share of Annual Generation Additions, 2006–17



Source: U.S. Energy Information Adminstration, 860 Detailed Data.

for complementary electricity transmission infrastructure. The United States completed or began construction of 9,277 miles of transmission power lines between November 2016 and November 2017 (EIA 2017).

Historically, the primary tax incentives for renewables have been the Renewable Energy Investment Tax Credit, which was introduced in 1978, and the Renewable Energy Production Tax Credit. Currently, a 30 percent tax credit is available for investments in solar energy property, fuel cells, and small wind systems, while a 10 percent tax credit is available for geothermal systems, microturbines, and combined heat and power property. The Tax Cuts and Jobs Act of 2017 limits some of the benefits of these credits, however, so their future value is uncertain.

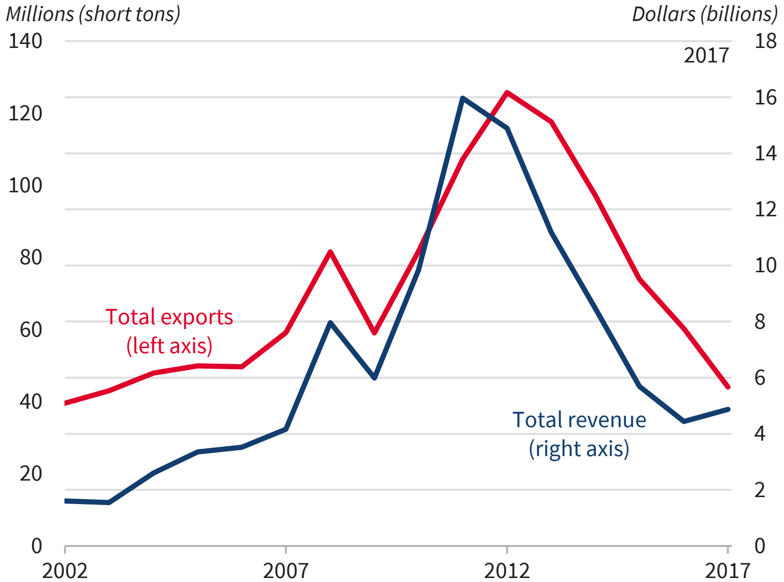
Port infrastructure. Increasing energy exports is an integral part of the Nation's energy dominance vision, but this requires additional infrastructure. Although shipments to Canada and Mexico are possible using pipelines and rail, port facilities are required for exporting to other countries. Port facilities require shoreside links—pipelines for natural gas and petroleum, and rail for coal. Also, for the pipelines and transmission infrastructure facilities discussed above, regulatory concerns shape the investment environment.

One example is the struggle to construct a West Coast coal exporting facility so that U.S. coal producers can gain access to the Asian market. Without such a terminal, expanding exports to Asian markets is effectively out of reach. In a nutshell, too little of the relevant port infrastructure is on the Nation's West Coast and too much is on the East Coast, whose Atlantic ports accounted for 90 percent of the coal exported by the U.S. to China through the first half of 2017 (EIA 2017). Several coal companies have expressed interest in sites in Washington and Oregon for a new, privately funded coal terminal. The prospect of local tax revenues and employment from such a facility has not yet overcome State and local opposition to the local disamenity of a coal terminal and broader environmental opposition to facilitating increased coal usage.

This geographic misallocation of port-related infrastructure limits opportunities to expand coal exports. Figure 4-12 shows how both volume and revenue from U.S. coal exports have declined over the past several years. No significant expansions of coal exporting facilities in the United States are currently under construction, despite the opportunities to increase exports to Asian markets from West Coast facilities.

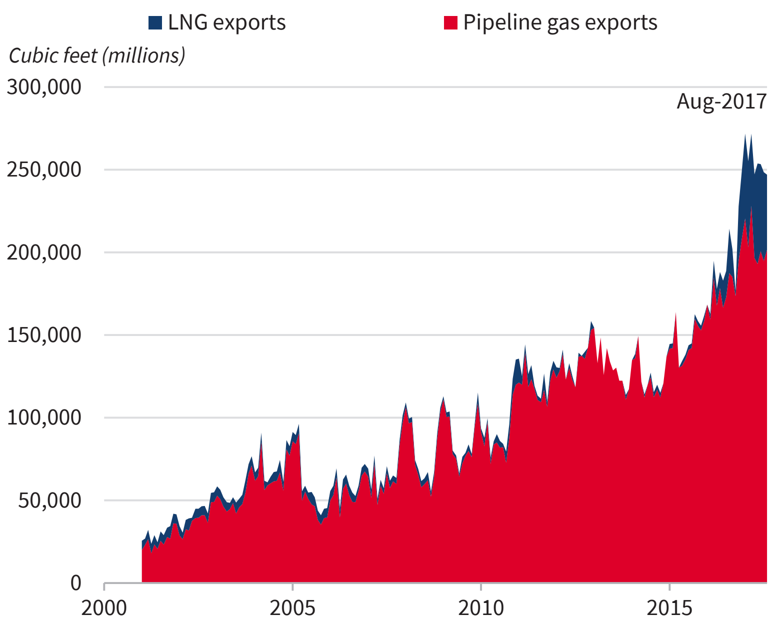
U.S. natural gas producers face a similar problem in gaining access to Pacific markets. There are currently no liquefied natural gas (LNG) export facilities in the Northwest, despite significant commercial interest in building such facilities. Environmental groups and landowners have opposed a proposed LNG export facility and an associated pipeline in Oregon, and although development has continued, some of the required permits have not yet been acquired. Thus, though natural gas exports and capacity utilization rates rose significantly between 2007 and 2016, future growth in exports, capacity, and

Figure 4-12. Total Coal Exports by Weight and Revenue, 2002–17



Sources: U.S. Department of Commerce, Census Bureau.

Figure 4-13. U.S. Annual Natural Gas Exports, 2001–17



Source: U.S. Energy Information Administration.

capacity utilization is constrained by a lack of facilities needed to export, especially in the rapidly growing LNG market segment (figure 4-13). (The Federal Energy Regulatory Commission has approved several LNG export facilities, which are currently under construction, but none yet are on the West Coast.) Export capacity utilization was at 59 percent of potential as of 2017, up 7.5 percentage points from the previous year. LNG's share of total gas exports has expanded rapidly in the past decade. In the 2001–10 period, LNG averaged less than 0.5 percent of total U.S. natural gas exports; by August 2017, LNG accounted for 20 percent of total gas exports. There remains a large international market for LNG, in which the United States has not yet carved out a share proportional to its production capabilities. According to data from the Energy Information Administration, the United States accounted for 1.2 percent of global LNG exports in 2016, despite being the largest gross extractor of gas in 2015 among all nations. The U.S. is drastically underrepresented in the global LNG market; and by expanding its LNG export capabilities, it most likely could rapidly gain market share.

Modernizing America's Waterways

The Nation's inland waterways system (IWS) is a crucial component of its transportation network, linking the producers of agricultural and energy commodities to domestic and international markets. But this system is aging, and its users are suffering from increasing lost transportation time. Unlike other freight modes, where the costs are mostly borne by system users, for historical reasons the government pays almost the entire cost of operating the IWS. The existing funding structure actually disincentivizes making timely repairs and does not align system costs with the parties that most benefit from IWS usage. A more robust system of user fees—possibly in the form of multipart tariffs that include licenses, location-specific fees, congestion fees, and fuel taxes—is the most promising approach to achieving revenue adequacy and sustainability, facility reliability, and economic efficiency. By providing signals of system component value, such fees would also guide operators and policymakers in deciding where to focus capital expenditures and how to prioritize repair efforts.

The IWS includes more than 36,000 miles of navigable rivers, channels, and canals across the United States, and directly serves 41 States (Clark, Henrickson, and Thomas 2012; TRB 2015). Upstream and downstream movement of cargo is enabled by lock infrastructure managed by the U.S. Army Corps of Engineers (USACE). Movement of goods and people over inland waterways was an important factor in the Nation's early economic growth, and the system remains a small but stable part of the United States' commercial transportation system, accounting for between 6 and 7 percent of all ton-miles (TRB 2015). Water transportation contributes about $15 billion in value added to U.S. GDP, about 0.1 percent of the total size of the economy. According to DOT, inland waterways support more than 270,000 jobs.

For many commodities—particularly those that are heavy and transacted at relatively low prices—the waterways system is an important component of their transportation network, including coal, petroleum, chemicals, and agricultural products. For example, grain is shipped via rail from the interior, loaded onto waterside grain elevators along the Upper Mississippi River, transloaded first onto barges, and then moved downstream to southern Louisiana, where it is then transloaded onto deepwater vessels that sail to export markets around the globe. Compared with truck or rail, water transportation is in many cases a less costly means of moving goods (USACE 2016).

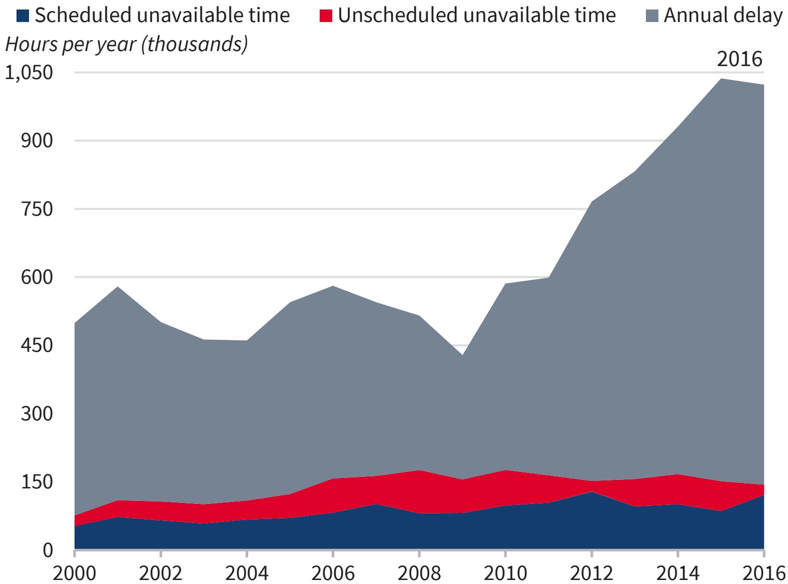
Freight traffic across the system is highly variable; about 22 percent of the total waterway miles account for about 76 percent of the cargo ton-miles transported (USACE 2013). However, low-use tributaries can be critical sources of transportation for freight systems that are organized around the low-cost water transportation of bulk commodities on these segments; few economical alternatives exist for these industries if low-use segments are no longer operable for commercial navigation (TRB 2015, 42). The Upper Mississippi, Illinois, and Tennessee-Tombigbee rivers, and the Gulf Intracoastal Waterway, have high-use locks in moderate or even low-use waterway sections, due to seasonal peaks in the movement of certain commodities, like harvested agricultural commodities, or because of seasonal navigation closures (due to recurring weather conditions like ice and flooding).

The cost of poor infrastructure. According to USACE (2014), waterways' infrastructure in the United States is operating at an overall satisfactory level. However, the average age of system locks is increasing, even when adjusted for date of last major rehabilitation (TRB 2015, 44). Furthermore, though systemwide traffic is flat or declining, delays and scheduled lock outages (to proactively address maintenance issues) are actually increasing, as shown in figure 4-14. Shipping delays and lost service are positively correlated with tonnage handled, indicating that investments are necessary to improve this transportation system.

Delays are typically longer at locks with greater demand for transportation during the harvest period for U.S. agriculture, so these are in part driven by seasonal congestion; in addition, locks experiencing the largest number of delays are concentrated along medium- and high-use segments of the system (TRB 2015).

Several studies have estimated significant cost effects of shipping delays and outages. The University of Tennessee's Center for Transportation Research and the Engineering Center for Transportation and Operational Resiliency at Vanderbilt University (CTR 2017) have estimated the effects of unscheduled lock outages on additional transportation costs, and focused on four locks. Calcasieu Lock is critical for inland navigation between Texas and Louisiana, and the vast majority of its traffic is dominated by petroleum and chemical products. CTR estimated that an unscheduled outage at Calcasieu would

Figure 4–14. Lost Transportation Time across the Inland Waterways System, 2000–2016

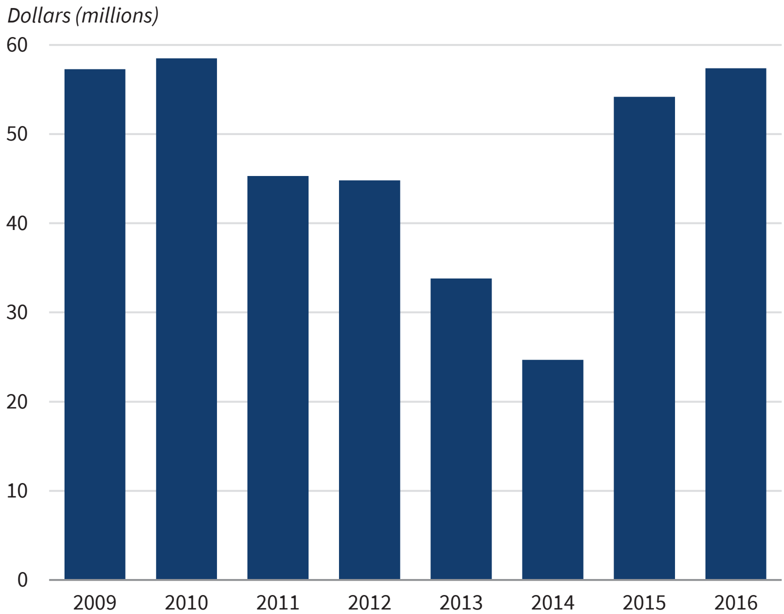


Source: U.S. Army Corps of Engineers.

increase transportation costs for these products by more than $1.1 billion. LaGrange Lock and Dam and Lock & Dam 25 are both primarily dominated by Gulf-destined, down-bound flows of corn and soybeans; 20 million tons of farm products flow through these two locks each year, six times greater than the volume of farm products that are moved by rail through the same corridor. CTR estimates the cost of an unscheduled closure at either LaGrange or Lock & Dam 25 at $1.5 billion. Yu, English, and Menard 2016 estimate that a one-year closure of Lock & Dam 25 would reduce economic activity from corn and soybean production by $2.4 billion, leading to the loss of 7,000 jobs and $1.3 billion in labor income. Traffic at Markland Lock is primarily composed of short-haul coal movements, chemicals, and petroleum products; CTR estimates that an unscheduled closure of the lock would increase the shipping costs of these commodities by $1.3 billion.

Funding the Inland Waterways System. The Federal government's role in managing and funding the IWS is far larger than it is for other freight modes. Although it is responsible for about 28 percent of highways spending and almost none of the cost of pipelines and railroads, the federal government contributes about 90 percent of the IWS's cost (TRB 2015). Waterways costs are mainly funded via the USACE budget. Operations and maintenance (O&M) costs constitute $631 million (69 percent) of the total FY 2017 budget of $917 million, with only $243 million (26 percent) devoted to construction (USACE 2017a). The Trump Administration's inland navigation system's FY 2018 budget

Figure 4-15. Inland Waterways Trust Fund Balance, 2009–16



Source: Inland Waterways Users Board Annual Report, December 2016.

requests that 77 percent of projected expenses be devoted to O&M expenses, which include repair costs up to $20 million and are fully funded from Federal general revenues. Construction costs, including repairs over $20 million, are funded through a combination of a direct tax on barge fuel and matching general funds from the Federal government.

The current funding framework presents challenges in several dimensions. On the capital front, tax revenues have not kept up with increased needs to substantially rehabilitate facilities, echoing the situation in highway funding. In 2015, the barge fuel tax—which is not indexed to inflation—was raised from 20 cents per gallon to 29 cents per gallon (the first increase since 1995), leading to an increase in fuel tax revenues and reversing a several-year decline in end-of-year balances of the Inland Waterways Trust Fund (Inland Waterways Users Board 2016) (figure 4-15). Even so, the revenues generated by the fuel tax are estimated to be only $112 million annually, compared with total annual IWS expenses of nearly $1 billion and an estimated $4.9 billion projects backlog.

O&M spending is supported by general funds and must compete with other priorities in the Federal budget. System managers have an incentive to delay repairs until they reach the point of being classified as capital expenses—because those can be covered by fuel tax revenues—reducing system reliability by leading to delays and closures. Eliminating the funding wall between fuel tax revenues and O&M expenditures is an obvious step that would both improve the reliability of O&M funding streams and counter the incentives problem that now serves to exacerbate the deterioration of facilities.

Beyond improving revenue generation and permitting the system to cover its own costs, imposing increased fees on barge operators for using the IWS and its facilities would enhance its economic efficiency. Ideally, these fees would be set to match the marginal costs generated by usage of the existing system. With facilities already in place, short-run marginal costs are those associated with operating and maintaining locks and dams, and maintaining channel depths. However, because new construction in the system is characterized by high fixed costs, short-run marginal cost pricing would likely not be sufficient; fees could need to be set higher to cover current and expected total system costs.

Such charges could take the form of additional fuel taxes, lockage fees (charges for passing through individual locks), segment fees, annual license fees, and/or congestion fees (TRB 2015). Fuel taxes are aligned to usage, but they apply equally across the IWS, even though some sections are more costly to operate than others; so if used alone, they would create complicated cross-subsidies. Variable, location-specific fees can be designed to better match actual marginal costs, but facility-based pricing by itself may not be sufficient to cover the O&M costs of the shared components that are deemed to be essential to the national freight transportation system; in this case, systemwide user fees or licenses can be employed. Finally, congestion charges can act as a demand-management tool similar to peak-load prices in other settings, helping to ration access to the existing infrastructure more efficiently at times when seasonal use of the system rises—as in the case of agricultural harvests; congestion fees also signal system operators and policymakers about the normal and seasonal value of the facilities.

In fact, similar issues of fees, cross-subsidies, and revenue adequacy arise in the context of maintenance and operation of the Nation's coastal and inland harbors. Dredging and other costs are covered by the Harbor Maintenance Trust Fund, which is largely supported by shippers, which pay harbor maintenance taxes of 0.125 percent of the value of cargo loaded or unloaded from commercial vessels; these taxes made up 88.5 percent of all the Trust Fund's revenues in FY 2017. Fund balances have risen over time, reaching $9.1 billion by September 30, 2017, as annual appropriations have consistently fallen short of revenues despite significant dredging needs in many harbors and ports. Further, tax revenues generated have little connection to the costs required to maintain the harbors, leading to concerns about the distribution of tax burdens across harbors. As in the case of the IWS, policymakers must assess the impact of collecting user fees or taxes on those who pay them but also on the Nation's transportation system as a whole.

More generally, the willingness of users to pay charges for access to different segments or facilities of the inland waterways system can signal their appropriateness for investment, guiding future decisions about which segments or facilities managers should upgrade, maintain, and/or abandon. Indeed, given funding constraints, the Transportation Research Board (TRB 2015, 80) indicates that more consistent application of systemwide cost/benefit analysis—including ranking projects in order of urgency—would better prioritize construction projects. In practice, combining these options in the form of multipart tariffs may be the most promising approach to achieving revenue adequacy and sustainability, facility reliability, and economic efficiency. The President's FY 2018 Budget includes a proposal to "reform the laws governing the Inland Waterways Trust Fund, including by establishing a fee to increase the amount paid by commercial navigation users of inland waterways."

Conclusion

Policymakers have considerable scope and opportunities to shape the Nation's growth prospects by improving its infrastructure. Making more efficient use of increased, higher-quality capacity can make meaningful contributions to economic growth. Under a range of assumptions, we estimate that a 10-year, $1.5 trillion infrastructure investment initiative could raise average annual real GDP growth by between 0.1 and 0.2 percentage point. Although more funding may be needed from both public and private stakeholders to conduct such a program, this chapter has also discussed other levers and options available to policymakers, who must confront and manage the threats and opportunities around conventional uses of public infrastructure and sources of funds across varied sectors. For example, technological change and disruption in the transportation sector threaten conventional funding models for roads and transit services, and increased congestion and overuse of some assets suggests that the efficiency and revenue benefits of more creative and consistent implementation of congestion pricing will be considerable.

More generally, governments should be encouraged to generate needed revenues from user charges on those who benefit from publicly provided roads, water facilities, and other infrastructure. These user fees should reflect the true marginal costs of service provision, serving to increase allocative efficiency, provide signals about the value of future capacity additions and improvements, and raise needed revenues to defray the costs of provision. Policymakers should be sensitive to possible trade-offs among efficiency, equity, and revenue goals but recognize that nonmarginal-cost pricing distorts incentives and decreases overall surplus. Developing and incentivizing the use of value capture programs where appropriate would also increase available funding resources for infrastructure investment, as parties experiencing capital gains (e.g., increased property values) would help pay for the costs of the infrastructure investment responsible for these gains.

The Federal government also has other tools at its disposal. It can support the continued use of innovative financing options such as public-private partnerships and private activity bonds to increase the availability of investable dollars and lower the cost of debt service. And it can enhance the capabilities of State and local governments to allocate scarce investment funds efficiently by encouraging the use of cost/benefit analysis and continuing project selection by States and local governments whenever possible, allowing local officials to make infrastructure investments of greatest benefit to their constituencies. Better project selection will be important in driving growth throughout the country.

Finally, the Federal regulatory structure must adapt to ensure the pursuit of health, safety, and environmental goals without distorting investment incentives. Conflicting, unduly complex, and uncoordinated rules and regulations can impede investments in needed infrastructure and limit the productivity of existing assets, as described above in the context of water markets, rural broadband and 5G-wireless technologies, and the energy sector. Addressing these issues will take time but generate significant public benefits, and several recent Executive Orders and other regulatory actions begin that process.

On balance, with appropriate infrastructure funding, financing, and regulatory policies in place, the United States can look forward to a productive and prosperous 21st century.