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Introduction

Edward L. Glaeser and James M. Poterba

In 2017, according to the US Congressional Budget Office (2018), the federal government spent $98 billion on transportation and water infrastructure. State and local governments spent another $342 billion—a total of $440 billion, or about 2.3 percent of gross domestic product (GDP). Although substantial, as a share of GDP this outlay is less than it has been at any time since President Dwight D. Eisenhower launched the Interstate Highway System in 1956. Diverse voices clamor to raise spending. Early in his term, President Donald Trump proposed increasing infrastructure spending by $1.5 trillion, in substantial part using private funding. Advocates of the Green New Deal, which includes a plan to overhaul the transportation system, call for spending more than $10 trillion over an extended period. The American Society of Civil Engineers (ASCE) has a long tradition of assigning weak grades to the state of US infrastructure and claiming that additional spending on infrastructure will yield substantial economic benefits.

In contrast to these calls, transportation economists are likely to call for better use of existing infrastructure before advocating greater spending overall. Pigou (1920) and Vickrey (1952) proposed congestion pricing, which could allow road traffic to flow more quickly during peak periods by requiring travelers to recognize the time-varying congestion externality that they

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impose on others. Meyer, Kain, and Wohl (1965) emphasized the economic advantages of buses over urban rail for passenger travel. Winston (2010, 2020) identified substantial costs associated with inefficient highway policies and urged experimentation with private roads along with expedited adoption of autonomous vehicles, which use highway capacity more efficiently than driver-driven cars.

This essay frames the economic issues associated with infrastructure investment and introduces a collection of studies that offer new economic insights on this investment. The first section discusses three reasons—limited private capital markets, externalities, and potential natural monopolies—responsible for drawing the public sector into the ownership and operation infrastructure projects. Although some of the historic rationales for public investment in infrastructure have diminished over time, many remain, including the presence of externalities related to public health and macroeconomic conditions, and the fear of monopoly power.

The next section considers the forces that determine optimal spending on infrastructure, recognizing that there are both macroeconomic and microeconomic approaches to this question. The microeconomic approach emphasizes the direct benefits to users and a careful consideration of optimal spending mix across modes and infrastructure types. The macroeconomic approach focuses on interest rates, the alleged counterrecessionary benefits of infrastructure spending, and the role that infrastructure capital plays in contributing to economic growth. While Valerie A. Ramey's contribution to this volume casts doubt on the efficacy of infrastructure as a stimulus for growth, there is a need for a unified approach that better integrates the microeconomic and macroeconomic approaches to optimal infrastructure spending. The natural way forward is to quantify the macroeconomic externalities that come from various forms of infrastructure and to incorporate them into standard microeconomic cost-benefit analysis.

After this discussion of optimality conditions, we turn to the management and funding of infrastructure. The two issues are linked because, as the chapter written by Eduardo Engel, Ronald D. Fischer, and Alexander Galetovic emphasizes, some of the incentive problems that arise in private-public partnerships can be attenuated when infrastructure is paid for with user fees that roughly cover its average cost. Funding infrastructure in this way can avoid debates over redistribution and helps anchor project selection. There is less risk of "white elephants" when infrastructure projects are funded only when they are expected to generate revenues that will cover project costs. Such user charges create inefficiencies, however, if the average cost of the infrastructure is far above its marginal cost. This is likely to be the case for many projects, and in this setting, funding mechanisms that rely on other revenue sources to cover part or all of the fixed cost can lead to more efficient outcomes. One particularly interesting funding approach is to exploit revenue tools that capture part of the increase in local property values that flows from infrastructure provision, such as through so-called tax increment financing. Gupta, Van Nieuwerburgh, and Kontokosta (2020) provide an illustration of the potential revenue yield of such instruments in the context of New York City's recent Second Avenue subway project. Revenue instruments like this can get closer to an efficient two-part tariff than average-cost user charges.

While the privatization of infrastructure is currently attracting substantial attention, for the US, the intergovernmental allocation of responsibility for infrastructure is at least as important. Since the 1950s, the federal government has been responsible for paying for highways, but the allocation of funds is largely done at the state level. Public transit authorities are typically governmental agencies, but even those that work within a single locality typically answer to the state government as well. The Port Authority of New York and New Jersey, which is among the largest governmental infrastructure authorities in the world, answers to two state governors. What level of government should provide and control infrastructure, and whether the infrastructure should be controlled directly by the executive branch of government or through an independent public authority, are therefore important questions. The usual fiscal federalism argument suggests that higher levels of government are better able to internalize externalities, while local governments are more accountable. But the move toward federal funding is particularly driven by the federal government's greater comfort with large-scale borrowing, especially during a recession. At their best, independent public authorities have more flexibility and are free from short-term political concerns. At their worst, these authorities operate with little oversight and less accountability than an elected executive.

The next section asks whether infrastructure spending and utilization could be made more efficient in three areas: procurement, management, and mitigation spending. With regard to procurement, a growing literature, exemplified by Bajari, Houghton, and Tadelis (2014) and Bolotnyy and Vasserman (2019), estimates structural auction models using data on infrastructure procurement. This research can address, for example, the choice between fixed-price and cost-plus contracts and may ultimately provide lessons on how to raise the cost-effectiveness of infrastructure procurement. With regard to management, many of the most expensive infrastructure investments in the US, including Boston's Big Dig and New York's Second Avenue Subway, cost a multiple of their original estimates because new events led to renegotiations with contractors during the construction process. When cancellation of the project is not an option, contractors have a strong position in the negotiations. Even when the original bid process is a competitive auction, renegotiation is often a one-on-one bargaining process that may put governments at a disadvantage. Since renegotiation is likely to be a constant in future large infrastructure projects as well, we discuss the ways management affects project outcomes and underscore the potential returns to making renegotiation less expensive. The essay by Leah Brooks and Zachary Liscow in this volume suggests that mitigation spending, which in the highway context includes sound walls, the curving of roads, and related features, accounts for a significant part of the increase in the cost of highways between the 1950s and 1980s. Whether a more stringent cost-benefit criterion should be applied to these outlays is an open question.

The next section summarizes each chapter in this volume and explains the interconnections that knit the chapters into a single coherent volume. A final section just before the brief conclusion considers how the COVID-19 pandemic and its aftermath could impact the demand for infrastructure services and the government's role in providing them.

Why Have Governments Invested in Infrastructure? Perspectives from US History

This section reviews three standard arguments for public provision of infrastructure and illustrates each with an episode from US history. Broadly speaking, the public sector has built and managed infrastructure when (1) the scale of investment was thought to be too large for private investors; (2) the infrastructure generated positive externalities including health benefits, nation-building benefits, or counterrecessionary macroeconomic benefits that would not be considered by private investors; and (3) the infrastructure capital could be used by a monopolistic owner to exploit those who need its services. The relative importance of these arguments today helps to shape our discussion of the later questions. For example, if public spending on infrastructure is motivated primarily by the inability to secure sufficient private sector credit, public-private partnerships may be attractive and should be considered when user-fee financing is appropriate. If the public sector's engagement with infrastructure reflects a large gap between average cost and marginal cost of infrastructure services, which will occur when infrastructure is a natural monopoly, then charging user fees dictated by average costs is less appropriate.

The Erie Canal and the Limits of Private Funding

Before George Washington became president of the United States, he served as president of the Patowmack Canal Company. Limited financing slowed the canal's construction. The company tried to build a connection to the Ohio River, but engineering and financial difficulties led the company to embrace a far narrower vision. The link between the Eastern Seaboard and western waterways would be achieved far to the north through the publicly funded Erie Canal.

New York governor DeWitt Clinton was aware of the difficulties of securing enough private funding to create a massive infrastructure project. He therefore established the Erie Canal Commission, which used public funds and public borrowing power to link the Hudson to the Great Lakes. The commission was an early example of an independent public entity overseeing an infrastructure project that relied on public financing. The most famous nineteenth-century canals, such as the Erie, the Erie and Ohio, and the Illinois and Michigan, were funded by states, not the federal government. Although Congress passed an act to provide federal support for the Erie Canal, the legislation was vetoed by President Madison.

The Erie Canal was enormously successful, and user fees quickly funded its costs. In *The Wealth of Nations*, published nearly 50 years before the canal was built, Adam Smith extolled the virtues of user-funded infrastructure projects: "When high roads, bridges, canals, &c. are in this manner made and supported by the commerce which is carried on by means of them, they can be made only where that commerce requires them, and consequently where it is proper to make them" (1776, book V, chap. I, part iii). Smith's remarkable analysis even included recommendations for weight-based user charges for carriages and wagons, to cover the greater maintenance induced by heavier vehicles.

The Erie Canal remains synonymous with infrastructure spending at its best, and the canal surely yielded benefits that went beyond the value paid for by its direct users. Yet the public sector was involved largely because private capital markets were underdeveloped in 1810, and the public sector was the only plausible source of so much funding. Cutler and Miller (2005) document a strong link between public borrowing capacity and the construction of urban water and sewerage infrastructure during the late nineteenth century. America's cities and towns were spending as much on water at the start of the twentieth century as the federal government was spending on everything except the Post Office and the Army. The ability of cities and towns to borrow large sums enabled these massive sanitary investments.

This American story contrasts with pre-1800 English canal building, which involved smaller, flatter distances and private funds. For example, the original Mersey and Irwell Navigation linking Manchester and the Irish Sea was funded and built privately in 1734. When the much larger Caledonian Canal was dug in Great Britain in 1804, public funding was used, but by the end of the nineteenth century, financial markets were sufficiently well developed that the Manchester Ship Canal was a private enterprise.

Some recent calls for infrastructure spending have envisioned a small public subsidy that could encourage a much larger volume of private investment. Such calls assume that global financial markets are robust enough to fund almost any feasible piece of infrastructure that can be reasonably expected to pay for itself at the appropriate discount rate. Whether that vision is correct is an open issue. Andonov, Kräussl, and Rauh (2018) report that investment funds that focus on infrastructure projects have cash flow and distribution profiles similar to venture capital funds, seeking to exit investments in 5–10 years, rather than after the decades-long life spans of many infrastructure projects.

Local Externalities and Public Ownership: The Case of Water Supply

In 1793, refugees from the Haitian revolution brought yellow fever to the port of Philadelphia. Dr. Benjamin Rush saw the symptoms and tried to impose a quarantine on ships arriving from the tropics, but limited state capacity made enforcing the regulation impossible. Thousands died from the disease in Philadelphia and across America's Eastern Seaboard. Yellow fever returned to Philadelphia in 1797, 1798, and 1799. Although yellow fever is actually carried by mosquitoes, many at the time suspected unclean water, which was indeed responsible for spreading many other diseases. Philadelphia formed a "Watering Committee," which commissioned Benjamin Latrobe to design a waterworks system. The system was finally completed in 1815. Cutler and Miller (2005) find that the creation of public water systems, like Philadelphia's, during the nineteenth century led to dramatic decreases in mortality across America's cities.

Cholera became an even deadlier scourge of America's cities after 1830, and its epidemiology was discovered by Dr. John Snow in London. Snow's geographic investigation of the 1854 Bond Street cholera epidemic found that a poisoned water pump was at the center of the outbreak. Gradually, the medical profession came to argue that investing in water infrastructure was necessary to prevent the spread of disease. New York City followed a different path after the yellow fever epidemics of the 1790s. Instead of a public waterworks system, the city established the Manhattan Water Company to provide clean water for city residents. The company was subsidized with a franchise to run a bank, a rare privilege at the time. It transpired that the company earned far higher returns by banking than by pumping water, and the Bank of the Manhattan Water Company eventually evolved into Chase Manhattan Bank and then J.P. Morgan Chase.

There were two key market failures related to water production during the nineteenth century. First, an individual who consumed dirty water did not internalize the health consequences to his neighbors of becoming infected with a waterborne disease. Second, consumers could not directly observe whether privately sold water was clean or dirty. Both factors limited the demand for the Manhattan Company's water. After New York City's 1832 cholera epidemic, the city embraced the option of investing in clean public water. The city's leaders created an independent public authority as a way to limit municipal corruption. Work on the Croton Aqueduct began in 1837, and water began to flow in 1842. While the aqueduct provided free hydrants, most users were expected to pay for water connections, and many low-income New Yorkers thought that the price of a water connection exceeded the private benefit of access to clean water. Poorer parts of the city continued to rely on shallow wells, and cholera continued to kill city residents. In 1866, a Metropolitan Board of Health was established; it could fine tenement owners who did not connect to the water and sewer system. This Pigouvian tax (before Arthur C. Pigou) seems to have had an effect; after 1866, death tolls from waterborne diseases in New York City began to decline.

If anything, public sewerage has an even higher ratio of public benefits to private benefits than public water supply. If sewage is dumped on a neighbor's property, the neighbor pays most of the cost, making the need for public subsidies with sewerage even more extreme than with water. Alsan and Goldin (2019) find that early twentieth-century investments in sewers in greater Boston complemented the earlier provision of clean water to reduce death rates.

The saga of the Manhattan Water Company provides a warning against private provision of health-related infrastructure, at least without a robust testing technology that enables consumer quality verification. Troesken's (2004) work on later nineteenth-century water systems finds that the death rates of African Americans declined substantially when cities switched from private to public water provision, which is consistent with the view that private companies skewed their service toward wealthier customers who could pay more. Despite this skew, even the rich were at risk from cholera epidemics that began in poorer neighborhoods.

Local externalities are still a potent justification for public investment in water infrastructure, yet we may question whether financially strapped communities are doing enough to maintain old water systems. Flint, Michigan, famously cut its water spending for budgetary reasons, and the city's emergency manager overruled the city council's vote to pay for cleaner, more expensive water. The poor quality of Flint water expressed itself both in highly elevated lead levels and in the spread of Legionnaires' disease, with associated reductions in the health status of residents. Yet the Flint story is a shocking aberration rather than a sign that communities are seriously debating the pros and cons of investing in clean water. There are still considerable debates about private versus public water provision, but these controversies concern costs more than cleanliness, because private water quality can now be easily monitored.

The local externalities associated with public provision of water supply and sewerage have parallels in the case of transportation infrastructure, notably when there are congestion externalities associated with road overcrowding. One common justification for public subsidies to metropolitan transportation systems is that they may reduce road congestion. Taxing driving is a more direct and efficient means of reducing congestion externalities than subsidizing alternative modes of transportation. Baum-Snow and Kahn (2000) found that newer metro systems in the US have had limited impact on commuting patterns. Declining ridership and chronic budget deficits are important challenges for public transit more generally.

If congestion pricing is politically infeasible, then whether it is appropriate to subsidize public transit becomes an empirical question. The appropriate subsidy for each public transit trip equals the reduction in driving caused by that trip multiplied by the external benefits of reducing the number of drivers, including both congestion and deaths from traffic accidents. If public transit takes the form of buses, then this optimal subsidy can be estimated using experiments with bus service to determine the impact on rides, traffic, and accidents. The number of buses can then be scaled up or down depending on the appropriate subsidy. If public transit means a fixed rail system, however, then ex post alterations to pricing can still be made, but it is difficult to change the quantity of subway lines after building finishes.

Congestion externalities also potentially justify building more highways, but any new construction must recognize that more highways often generate more driving. Indeed, a fundamental law of highway traffic, suggested by Downs (1962) and supported by Duranton and Turner's (2011) empirical analysis, suggests that the level of traffic may be roughly independent of the number of roads, since vehicle miles traveled seem to scale up roughly one-for-one with highway miles built. If that law holds, then new highway construction raises welfare by allowing more trips but does not materially reduce congestion on existing highways.

Nation Building

In the nineteenth century, Henry Clay and the Whig Party advanced a program called the "American System," which was meant to strengthen the nation by imposing tariffs on imports and subsidizing internal improvements such as transportation infrastructure. The Cumberland or National Road was the most visible example. That macadamized road ran from the Potomac to Illinois. The Whig's Republican successors used federal land grants to subsidize a privately built intercontinental railroad, also with the hope of binding the nation together.

Nation building has at least three coherent economic interpretations. First, it may refer to general equilibrium impacts of transportation that are not internalized by railroad builders. Building new infrastructure may raise land values. Firms may benefit from cheaper inputs. Donaldson and Hornbeck (2016) and Hornbeck and Rotemberg (2019) document that the US railroad system yielded significant and far-flung benefits. This finding is not inconsistent with Fogel's (1962) claim that American economic development could have proceeded without the railroads; Fogel focused exclusively on the cost saving for users of prerail transportation modes, thereby neglecting gains in productivity and innovation in other sectors.

Second, nation building may refer to protecting or expanding a nation's territory. In the nineteenth century, the US had border disputes with Mexico, Great Britain, and Native Americans. A more developed transportation network, and the migration that the network would induce, could have been viewed as strengthening the nation's political hold over the central North American land mass. In this case, nation building would be associated with political benefits for the US that come at a cost to other nations and peoples.

Third, nation building may mean creating a coherent sense of national unity. By increasing economic interdependence between regions, transportation infrastructure could potentially limit future secession movements and reduce the interregional strife that led to the Civil War. There is some evidence, for example, that the strong transportation linkages between New York City and the US South made some New York merchants more sympathetic to the Southern cause during the Civil War. While the benefits of national coherence are hard to quantify, the costs of fighting over national dissolution were enormous and many leaders, including Abraham Lincoln, saw the cause of preserving the Union as paramount.

Today, the second nation-building motive, defending borders, is no longer relevant for the US. The nation's borders have been essentially fixed for 150 years. The other two motives still matter. Trade economists build general equilibrium models to quantify the national economic gains from better connections. In addition, infrastructure's role in national cohesion has evolved. While nineteenth-century infrastructure advocates argued that simply connecting to dispersed areas would help build the country, twenty-first-century advocates emphasize that infrastructure can help bring prosperity to poorer regions and allow residents of those regions to feel like fuller partners in the national economy.

While arguments for infrastructure-led economic development are often made, whether new infrastructure projects can substantially increase economic activity in poorly performing regional economies is uncertain. In the context of US regional policies, two studies find that infrastructure improvements, notably low-cost electricity and an expanded highway network, have had positive effects in the low-income southeastern United States. Kline and Moretti (2014) find that the infrastructure projects associated with the Tennessee Valley Authority raised average incomes, largely by shifting employment from agriculture to manufacturing. Jaworski and Kitchens (2019) estimate that the Appalachian Highway Development System, which built about 2,500 miles of highways, raised income in Appalachia by about $22 billion. This translates to an income gain of nearly $10,000 per road mile. Even with such initiatives, however, Appalachia is still quite poor after 50 years of extra investment. It is particularly difficult to assess the long-run effects of infrastructure projects, given the potential range of confounding factors.

Macroeconomic Externalities

Another potential rationale for national spending on infrastructure is the provision of macroeconomic externalities. Herbert Hoover pioneered the view that public infrastructure investment can offset downturns in the national business cycle. In 1921, as commerce secretary, Hoover organized the President's Conference on Unemployment, which urged state and local governments to undertake construction projects during the downturn. Hoover, a mining engineer by training, believed that the costs of such construction would be lower during the recession because labor was cheap and that such projects would reduce unemployment by boosting the demand for labor. As president, Hoover wanted an infrastructure act as early as 1930; he eventually signed the Emergency Relief and Construction Act of 1932. Hoover's early efforts were expanded by Franklin Roosevelt, and infrastructure spending was a significant part of the New Deal. President Obama's American Recovery and Reinvestment Act of 2009 followed this path and included $105 billion of infrastructure spending, split equally between transportation and energy projects. Proposals to increase infrastructure spending are frequently offered during economic downturns as a potential tool to reduce unemployment and boost aggregate demand.

Ramey's contribution to this volume calls into question the efficacy of infrastructure as antirecessionary spending. Other studies, analyzing historical experience, reach similar conclusions. Garin (2019) found that transportation spending generated only small increases in employment. The macroeconomic case for infrastructure remains among the most important and least well-developed aspects of the economic analysis of infrastructure spending.

Monopoly Power and the Regulation of Railroads

Intercity railroads in the US were built by private companies, many of which received subsidies for nation-building purposes. Although in some markets multiple railroads competed actively, this competition often gave way to consolidation. In other markets, the railroads had local monopolies. Over time, the railroads were criticized for alleged abuse of their monopoly power. The public policy response to natural monopolies in industries like railroads has taken one of two forms in most countries: regulation of private operators or public ownership. The US initially followed the regulatory approach.

In 1887, the Interstate Commerce Commission (ICC) was created and given authority to regulate the rates charged by railroads. The 1893 Railroad Safety Appliance Act gave the ICC further control over safety issues; Glaeser and Shleifer (2003) argue that the motive for the legislation was in part the belief that traditional tort remedies for damages were insufficient given the railroads' legal muscle. Subsequent legislation, the Hepburn Act of 1906 and the Mann-Elkins Act of 1910, strengthened the ICC's controls over rate setting. In 1917, as part of the World War I mobilization effort, President Woodrow Wilson nationalized all US railroads. The US Railroad Administration oversaw all railroad operations, including scheduling, investment, labor compensation, and locomotive design. Railroads were returned to private control in March 1920. The Esch-Cummins Act, enacted that year, further expanded the ICC's regulatory powers.

Changes in the passenger and freight transportation industry over the subsequent 50 years, culminating in the bankruptcy of the Penn Central railroad in 1970, combined with a broader trend toward deregulation in the 1970s, led to a rollback of the ICC's authority. Starting in 1976, with the passage of the Railroad Revitalization and Regulatory Reform Act, the ICC's role in regulating railroads was restructured and reduced. It was finally eliminated in 1995. By the mid-1970s, concerns regarding railroad monopoly power had been replaced by the prospects of railroad insolvency. The ICC had restricted railroads' ability to abandon unprofitable routes and to adjust to competitive realities. In the early decades of ICC regulation, many farmers had few alternatives to shipping their harvest by rail. By the 1970s, the relatively competitive trucking industry provided a viable alternative for many shippers. Deregulation allowed the remaining railroads to focus on their profitable lines of business, to close poorly performing ones, and in some cases to focus on moving goods rather than moving people.

Penn Central's bankruptcy was one of the events that led to the consolidation of US passenger rail into Amtrak, a quasi-public entity subsidized by tax dollars, and to the creation of Conrail as the provider of rail freight services in the Northeast Corridor. The lightening of regulatory rules allowed Conrail to limit route structure and to innovate in ways that ultimately restored profitability and supported Conrail's sale to CSX and Norfolk Southern. In addition to loosening ICC regulation, the 1976 legislation also provided funds for Amtrak to acquire railroad assets in the Northeast Corridor. The evolution of passenger railroads from private companies to public entities repeats the movement, beginning before World War II, of municipal transit systems from private to public ownership as once profitable local transit companies lost ridership to automobiles. Public ownership of transit companies became a means of avoiding bankruptcy.

The economic cases for Amtrak, which today provides nationwide intercity rail service, and for local public transit systems are rarely articulated. The standard argument for public subsidy reflects the congestion externalities associated with driving. Yet that argument can hardly explain why Amtrak continues to provide service with relatively low ridership in areas other than California and the Eastern Seaboard. Another argument holds that rail and bus service are natural monopolies with marginal costs of use below their average costs, which implies that charging below average cost is efficient and requires subsidies. Winston (2013) presents some evidence that the social benefits of these services may fall short of current taxpayer support; this issue warrants further analysis.

What Determines the Optimal Level of Public Infrastructure Spending?

Calls from politicians for increased spending on infrastructure are sometimes echoed by macroeconomists who see countercyclical benefits of spending on infrastructure and perhaps also benefits for long-term growth. Transportation economists, in contrast, are generally more skeptical of these calls. This section contrasts the microeconomic and macroeconomic approaches to determining optimal infrastructure spending. We do not develop a grand synthesis of the two approaches, but we sketch a research agenda that might lead to one. We then turn to microeconomic concerns that shape the optimal level of infrastructure spending, discussing both engineering reports and optimal allocation across modes, a topic explored further in this volume's chapter by Gilles Duranton, Geetika Nagpal, and Matthew A. Turner. We end with a discussion of macroeconomic issues that shape optimal infrastructure spending.

Macroeconomic versus Microeconomic Approaches to Optimal Infrastructure Spending

Microeconomists approach infrastructure spending project by project with the well-worked tools of cost-benefit analysis. Benefits are determined primarily by effects on infrastructure users, although sometimes the analyses incorporate rising local property values or business profits. Costs are largely construction costs. This approach typically yields only modest returns for most new large-scale infrastructure projects. Returns for maintenance of existing infrastructure are typically much higher.

These arm's-length analyses often differ from the cost-benefit calculations that are provided for policy purposes, sometimes by entities that stand to gain financially through the construction of new infrastructure. For example, Parsons Brinckerhoff prepared an optimistic cost-benefit analysis for high-speed rail in California in 2014 and received a $700 million contract to manage the program the next year. Cost projections for this ongoing initiative have already moved far beyond those included in the report. Kain (1990) and others have also argued that skewed cost-benefit analyses often radically overstate reasonable projections of future ridership of rail projects. The relatively low returns to many projects reflect, in part, the advanced level of infrastructure in the US today. In 1816, it cost as much to move goods 30 miles overland as it did to cross the Atlantic Ocean; consequently, the Erie Canal provided a stunning reduction in transportation costs. Today, passengers can fly or drive from Los Angeles to San Francisco, and so the benefits of rail are far more muted.

The most exciting recent development in cost-benefit analysis for transportation projects has been the introduction of general equilibrium models from trade theory. Allen and Arkolakis (2019) provide an excellent example of this work. Their estimates suggest that the benefits from expanding some highway corridors, especially around New York City, are particularly high. Yet, the political and financial costs of such expansions may also be very high. Infrastructure projects in dense urban areas, such as the Big Dig in Boston, have proved particularly expensive in recent decades.

In contrast to the microeconomic approach, the macroeconomic approach to infrastructure starts with objectives linked to either stabilization or growth. Keynes (1936) wrote, "I expect to see the State, which is in a position to calculate the marginal efficiency of capital-goods on long views and on the basis of the general social advantage, taking an ever-greater responsibility for directly organizing investment" (164). Keynes feared both excessive speculation and "crises of confidence," which would lead private markets to either overinvest or underinvest in capital. He distrusted the ability of private markets to get the overall level of investment right or to target that investment toward its most productive use. He did not specifically mention infrastructure, but he saw public sector investment as an antidote for the vagaries of financial markets.

Keynes's general skepticism about private investment has had less impact than his advocacy of public spending during a recession: "The employment of a given number of men on public works will (on the assumptions made) have a much larger effect on aggregate employment at a time when there is severe unemployment, than it will have later on when full employment is approached." He goes on to provide a numerical example in which adding 100,000 workers on public works projects leads total employment to rise from 5.2 million to 6.4 million because of the multiplier.

While Herbert Hoover's enthusiasm for countercyclical spending predates Keynes's work, the latter's writing inspired subsequent generations of economists and policy makers to consider spending on public works as a way to reduce unemployment. Aschauer (1989a) added a longer-term macroeconomic rationale for infrastructure spending by empirically linking public infrastructure spending and economic growth in US economic time series. Aschauer (1989b) showed the connection between public infrastructure and growth across the G7 nations between 1965 and 1985. Gramlich's (1994) skeptical response to Aschauer's work is widely embraced by microeconomists, but Aschauer's views retain considerable currency among many policy-oriented macroeconomists. The reason may be that the difficult-to-explain decline in aggregate US productivity growth is roughly contemporaneous with the decline in infrastructure spending relative to GDP.

While the microeconomic approach yields clear policy tools for selecting infrastructure projects, the macroeconomic approach often yields only general advice to spend more on infrastructure during a downturn. A much-needed reconciliation of the two approaches could start with a clear quantification of the macroeconomic externalities associated with providing different forms of infrastructure. This might be accomplished using any of a number of standard macroeconomic models. There is probably more debate about the choice of the right model for the macroeconomic externality analysis than about the choice of discount rate and other parameters for the microeconomic approach. While both calculations rely on various assumptions, by unifying the two and acknowledging the resulting uncertainties it should be possible to move forward in evaluating the total return to infrastructure projects.

The most obvious employment-related externality is the fiscal externality. Employed workers pay taxes. Unemployed workers receive benefits. Any infrastructure that moves workers from being unemployed to being employed generates fiscal benefits equal to the sum of the benefits saved and the tax payments collected. The fiscal benefit from each employed worker is easier to estimate than the employment impact of infrastructure spending. The tax and benefit payments can be plausibly estimated, and so it is relatively easy to multiply the change in employment by that number.

Ramey's contribution in this volume makes clear that no consensus has been reached in the empirical literature on the employment effects of infrastructure. Many researchers doubt that most forms of infrastructure spending affect aggregate employment. An added challenge is that infrastructure spending is slow to plan and implement. Even if an infrastructure spending package is pushed at the start of the recession, the money may not flow until after the recession is over, when the employment benefits of the spending package will no longer be as valuable. Counterrecessionary maintenance spending is easier to manage than outlays on new projects, but even then there may be some social losses from basing maintenance schedules on the state of aggregate employment rather than the condition of the infrastructure capital stock. New large-scale projects are particularly hard to initiate during downturns. Planning for California's high-speed rail began with federal funds spent during the Great Recession, but continuous construction activity began only in 2015, and further work on most of the system was indefinitely postponed in 2019.

Growth-related benefits are harder to conceptualize and quantify than short-run macroeconomic effects. Aschauer (1990) treats government capital as a form of productive capital, and he estimates high economic returns to it. Leaving aside a number of empirical issues surrounding the measurement of the government capital stock as well as concerns about measuring the rate of return that government capital generates, such as the correlation of government spending with unobserved determinants of productivity, this approach yields little clarity about which forms of infrastructure are likely to yield the most benefit.

At some point, it may be possible to combine the estimated macroeconomic effects with the network and other microeconomic effects of particular projects. If the connection between firms and transportation infrastructure is directly incorporated in a spatial equilibrium model, then the model could be expected to match any observed relationship between the level of public infrastructure and overall economic activity. This model could then generate an empirically grounded estimate of the productive benefits of different road segments that incorporates the larger growth estimates, permitting welfare statements about different forms of infrastructure investment.

The most difficult macroeconomic concern to include within infrastructure planning may be Keynes's skepticism about the rationality of private investment. If the market misperceives the value of additions to the capital stock, private spending could be stimulated or taxed through the tax code, or public planners could raise or lower the level of infrastructure spending. It is not clear whether these planners can outguess the private sector and correctly compute the long-run marginal efficiency of public sector capital.

Microeconomic Analyses of Optimal Infrastructure Spending

The microeconomic approach to infrastructure investment generally proceeds on a project-by-project basis and correspondingly yields results on whether an investment should be undertaken at this disaggregate level. There are at least two major aggregate scorecards, however, that adopt a microeconomic approach to infrastructure assessment and provide widely followed assessments of the infrastructure capital stock. One report, the *Infrastructure Report Card*, is prepared by the American Society of Civil Engineers (ASCE). The other, prepared by the World Economic Forum, is *The Global Competitiveness Report*. The ASCE's *Infrastructure Report Card* is the work of 28 civil engineers who assign grades based on their assessment of the current state of infrastructure. *The Global Competitiveness Report* is based on surveys of business leaders.

The overall grade for the US in the ASCE's 2017 report card is a D+, which implies that infrastructure is "poor" and "at risk." Roads received a straight D; bridges received a C+, which indicates that they are "mediocre" and "need attention"; and drinking water received a D. The ASCE methodology is often misinterpreted as an engineering assessment of the physical condition of existing infrastructure, and the language may cause confusion. A bridge that is "structurally deficient" need not be unsafe, but it may not meet all current standards for bridge construction. Moreover, while assessments of the structural status of existing infrastructure capital are a component of the grade, there are also a number of other elements, such as funding, future need, and innovation, that include either forecasts or subjective elements. One consideration is "what is the cost to improve the infrastructure, [and] will future funding prospects address the need?" Another is "what new and innovative techniques . . . are being implemented to improve the infrastructure?" Both questions go well beyond current physical condition. The score for an infrastructure category could be pulled down by limited current public funding relative to anticipated future needs or by the absence of the latest technology, even if the capital's current physical condition is satisfactory.

An important limitation of the grading rubric is the assumption that the only way to address projected growth in infrastructure demand is to build more of it. Alternative approaches, such as adopting congestion pricing to use existing infrastructure more efficiently, do not feature in the analysis.

The ASCE's approach is likely to overstate the potential shortfalls in future infrastructure capacity and to bias the grades for existing infrastructure downward.

Taken at face value, these grades suggest that the US needs to spend more on its infrastructure, although some might observe that civil engineers might have a financial interest in making the case for more spending on such projects. Moreover, it is hard to reconcile a grade of D for drinking water given the rarity of outbreaks of waterborne diseases. The catastrophe in Flint, Michigan, is correctly seen as terrible disaster, not the routine state of affairs. Duranton, Nagpal, and Turner's chapter in this volume shows that Interstate Highways in the US have become smoother over time, which makes the grade of D for roads difficult to understand, especially since the report card gave the much rougher highways of 1988 a grade of C+. While there may be challenges reconciling the ASCE grades with some data on the service flow from infrastructure capital, the engineers are most likely to know whether bridges are in danger of imminent collapse or whether other components of infrastructure have reached the end of their design lifetimes and need to be repaired or replaced.

The heterogeneous grades by sector and state offer the hope of incorporating more engineering into public infrastructure decisions. To make these estimates usable, they need to be combined with estimates of the harm of failing to maintain particular assets. Estimates of the current state of infrastructure need to be turned into assessments of the risk of various failures, and these can in turn be multiplied by the social costs of an infrastructure failure. For example, bridges may be in better shape than roads, but if bridges fail, the loss of life may be far more terrible than anything that would result from a failure to maintain roads. That comparison should feature in the calculation of replacement or maintenance expenditures on bridges versus roads.

The Global Competitiveness Report does not claim to utilize the civil engineering expertise embedded in the ASCE report card, but the World Economic Forum's report does have the virtue of global compatibility. The report contains a significant section on infrastructure and splits the infrastructure scores into transportation and utilities. Overall, the US score on infrastructure in 2019 was 87.9, which placed 13th in the world. While this score (a high B?) is considerably higher than the ASCE's D+, many are still troubled that infrastructure in the US no longer rates as among the best in the world.

The two worst infrastructure scores for the US appear in the railroad sector: 41.3 in railroad density—48th in the world—and 69.2 in the efficiency of rail services. These low scores reflect the reality that since the deregulation of rail services in the 1970s, the US has not significantly invested in passenger rail. Yet generations of transportation economists since Meyer, Kain, and Wohl (1965) have argued that passenger rail is relatively inefficient both within and across cities. A low score in the rail categories may well be optimal.

In other areas, connectivity in the US is superb, but maintenance is less good. The US is the global leader in road and airport connectivity. One hundred percent of the US population has access to electricity, and the nation ranks eighth in "liner shipping connectivity." The quality of road infrastructure, however, is rated only 74.5, 17th in the world. The efficiency of airport and port services ranks 10th. *The Global Competitiveness Report* gives the US a 100 for water safety, somewhat belying the ASCE Report Card's D, but only an 86.1 for water reliability.

The World Economic Forum's report lends support to Gramlich's (1994) conclusion that the US invested in the most productive forms of infrastructure first. Subsequent investments yielded lower economic returns. Consequently, for the US, the highest social returns come from maintaining existing infrastructure rather than from new projects. This has been a mantra for microeconomic transportation economists ever since. Winston (2013) calls attention to the inefficiencies in road maintenance policies, suggesting that public expenditures to achieve improvements in road quality have been larger than needed.

Decisions about new infrastructure can be divided into within-mode choices and choices across modes. Tools similar to those that are used to explore expanding network capacity can be used to estimate the returns to adding capacity in different airports. Duranton, Nagpal, and Turner provide a simple framework for optimal investment across modes. They maintain that the marginal benefit of public spending needs to be equalized across modes of travel. If the marginal benefit is proportional to the average cost of each mile of travel, public spending per mile traveled should be equalized across modes. While Duranton, Nagpal, and Turner's assumed relationship between marginal benefit and average spending is unlikely to be literally correct, they find that the marginal product of spending on Interstate Highways is three times the marginal benefit of spending on buses and more than twice the marginal benefit of spending on rails. While Duranton, Nagpal, and Turner do not incorporate any redistributive benefits of favoring transit for lower-income individuals, their work highlights the fact that the US currently spends far more per passenger mile on rail and buses than on highways. This pattern may in part reflect historical path dependence: many components of the rail network were built before auto, truck, and air competition constituted a viable alternative to rail travel.

While rail and buses look similar in the calculations of Duranton, Nagpal, and Turner, there are two major differences between these modes. Buses are particularly skewed toward the poor and are also a flexible mode of transportation. Consequently, providing extensive bus service may impact individuals on the margins of employment, which can encourage working and generate fiscal externalities. The flexibility of bus transportation also means that bus service can be scaled up or down in response to new information. Such adjustments are much harder with fixed rail investments.

Macroeconomic Determinants of Optimal Infrastructure Investment

The macroeconomic approach to infrastructure typically emphasizes two measurable variables: the interest rate and joblessness. This approach could also include the effects of infrastructure spending on economic growth, but there is little evidence on these effects for different types of projects. The benefits of infrastructure investment occur over time; consequently, the discount rate determines the net present value of the flow of these investments. Lower interest rates mean that the future benefits are valued more highly. All else being equal, a decline in the discount rate implies that the optimal level of infrastructure investment should rise. Equivalently, if the repayment of infrastructure debt is timed to coincide with future usage and user fees, then lower long-term interest rates imply that future taxpayers will have a lower tax or user-fee burden for any fixed level of infrastructure spending.

This logic, which is true for any form of capital investment, lies behind the calls from Furman and Summers (2019) and many others for spending more on infrastructure in the current environment of low interest rates than in previous higher-interest-rate settings. The basic logic of these calls is unassailable, since many infrastructure projects have up-front costs and future benefits that must be discounted. However, even when the interest rate is zero, it does not make sense to invest in a project with a negative undiscounted sum of net benefits. In addition, some forms of infrastructure involve future costs as well as benefits; lower rates raise, rather than lowering, the present value of those costs.

The chapter by Deborah Lucas and Jorge Jimenez Montecinos addresses the issue of risk adjustment when discounting the stream of net benefits from public infrastructure projects. The widely referenced Arrow-Lind (1970) theorem proves that the benefits of public projects should be discounted at the risk-free rate when the benefits of each project are independent of one another and of overall macroeconomic risk and when the number of projects is large. In this case, the overall portfolio of projects becomes risk-free, and the risk-free rate is appropriate.

The Arrow-Lind conditions seem unlikely to hold in most cases. Many projects, including roads and bridges, yield benefits that increase with the overall level of economic activity. Many projects, including roads, have benefits that are correlated across projects. Improvements in the quality of cars will cause the benefits of all roads to rise together. Increasing costs of fossil fuel emissions will cause the benefits of all roads, and many other forms of infrastructure as well, to decline together. The issue of risk adjustment for discounting the benefits of infrastructure projects is far from settled.

There is similar controversy about the connection between the level of unemployment and optimal infrastructure investment. Keynes argued that the employment-related benefits of public works spending were greater when employment was low, and macroeconomic advocates of countercyclical infrastructure spending echo his line. Ramey's chapter casts doubt on this view, noting that both empirical work and theory suggest that infrastructure is a weak tool for fighting unemployment. The changing nature of infrastructure investment lends support to her perspective. When Keynes wrote, public works were labor-intensive. New Deal projects often featured large numbers of unskilled laborers. Today, infrastructure is far more capital-intensive and far more likely to use skilled laborers who would be employed in any case. If infrastructure requires machines more than less-skilled people, then the scope for infrastructure policy to exert short-run effects on employment will be limited.

Pricing, Provision, and Maintenance

We now turn from a discussion of the optimal level of infrastructure capital to questions about the management of this capital. We begin with optimal pricing, and then turn to whether it should be provided by the public or private sector, a topic addressed in the chapters by Engel, Fischer, and Galetovic and by Lucas and Montecinos. We also consider the optimal allocation of infrastructure responsibilities between the federal and local governments. We conclude by discussing maintenance and repair, highlighting cases in which the answers about optimal funding and provision may differ between maintenance and new construction.

Efficient Infrastructure Pricing and Funding

Pricing determines the level of infrastructure usage conditional upon the infrastructure's level of maintenance. Pricing can also play a role in determining infrastructure investment decisions, shape incentives for maintenance, and affect the distribution of net benefits from infrastructure. Higher prices for some infrastructure services, such as bus trips, can particularly impact the poor.

The starting point for pricing any service is the principle that efficient use results if price equals marginal cost. On a road, that cost includes the depreciation, congestion, and lost safety to other drivers created by an extra driver. Historically, these costs have often been treated as minimal; consequently, free roads seemed like a reasonable benchmark. Indeed, the Interstate Highway System was originally intended to be without tolls, partly because tolls were seen as largely as a way to raise revenues rather than to ration use. Traditionally, the perceived marginal cost of public transit use was also thought to be quite low, at least up to the point where additional buses or cars need to be run. The gap between marginal and average cost was also invoked in support of tax subsidies for infrastructure construction, such as exempting the interest on bonds issued to finance such projects from income taxation.

In dense metropolitan regions today, the marginal costs of both transit use and driving can be high. Subways, buses, and roads can be quite crowded. For roads, optimal congestion pricing could lead to charges that significant exceed the average cost of provision, especially if the opportunity cost of the land under the road is ignored. Efficient pricing in this setting would mean that road systems break even or generate surpluses instead of requiring subsidies. Small, Winston, and Evans (1991) present calculations in which a system of congestion charges for both cars and trucks, coupled with pavement damage charges for trucks, roughly covers the road system's operating costs.

We have considered externalities within the transit system together with other costs, but if there are other externalities associated with infrastructure use then they should also be included in pricing. If carbon use generates negative environmental externalities, then the price of fuel-intensive infrastructure should be increased to reflect this. If water use in dry states exacerbates fire risks, then the price charged to users of water-intensive infrastructure should include the cost of remediating or insuring those risks.

The optimal pricing for one transport mode, using one type of infrastructure, depends on the pricing or mispricing of other modes. If driving creates negative externalities that are not priced, then reducing the cost of public transit provides one tool for mitigation. This second-best solution will always be less efficient, absent administration costs, than directly taxing the negative externality.

The consequences of pricing decisions can extend beyond rationing use. In public-private partnerships, Engel, Fischer, and Galetovic (2014) point out, charging users for infrastructure access creates incentives for better maintenance, because the private provider does not get paid unless the roads are used, and the roads are not used if they are in bad shape. Ashraf and colleagues (2017) find that water pipes in Zambia are repaired more rapidly when consumers pay by the liter of water consumed rather than by the month. Public providers may be less sensitive to revenues than private providers, but public providers may also deliver better maintenance if they are concerned about losing users. User-fee financing can also be quite helpful when selecting infrastructure projects. If projects are funded primarily through subsidies, then there is little financial reason to choose better projects. If infrastructure is expected to pay for itself, then there is more discipline in the project selection process. Projects will be more likely to be selected when they are expected to generate revenues; this likelihood helps make sure that the projects will actually be used. Typically, equity concerns are used to argue for prices that are lower than marginal cost for services like buses, but equity concerns can also push for higher prices. Airport users are, on average, better off than nonusers. If airports are funded by general tax revenues, and the revenue burden is spread more broadly than airport utilization, then this represents a transfer from the poor to the rich. Setting user fees to cover the cost of an airport project eliminates the possibility of redistribution via pricing.

When there is a gap between the user fee and average cost, then infrastructure requires other forms of financing. In rare cases, infrastructure is priced through a classic two-part tariff, which causes users to pay a flat fee for accessing the infrastructure and then face a low cost of using the infrastructure on a daily basis. Commuter trains sometimes offer monthly passes that have this structure. In other cases, local property taxes serve as form of two-part tariff. If the beneficiaries of infrastructure live in a particular locale, then a combination of low user fees and property-tax financing can still charge those who use the infrastructure but not distort usage decisions.

Tax-increment financing envisions using the increases in property values associated with new infrastructure to help pay for that infrastructure. Hong Kong's Mass Transit Railway uses a particularly creative means of financing in this spirit. The company finances its railways with dense building around new subway stops. The real estate value created by the rail system is therefore captured by the rail builder.

Much US highway financing occurs through the federal Highway Trust Fund, which has historically been financed largely by gasoline taxes. These taxes are a form of user fee, since drivers who use the roads buy gasoline. Over the past 15 years, as gasoline consumption per mile driven has declined and vehicles that do not require gasoline have emerged, a greater share of the trust fund has come from general tax revenues, which means that ordinary taxpayers are subsidizing highway drivers. The highway trust fund also redistributes from high-density states to low-density states that have a large number of highways per capita. In some cases, goods bought in high-density states travel through low-density states, and therefore high-density states benefit from highways in low-density states. Standard economic analysis suggests that directly charging shippers for their highway use is likely to be a more efficient funding mechanism than the current use of Highway Trust Fund subsidies. Beyond shipping and occasional recreational use, it is unclear how higher-density parts of the US benefit from highways in more open areas.

Public versus Private Provision of Infrastructure

Privatization of infrastructure may seem to some to be a recent innovation, but in fact, debates over private versus public infrastructure are centuries old. Private canals and turnpikes were a common feature of the eighteenth century; private transit systems were ubiquitous in the nineteenth century.

The classic analysis of Hart, Shleifer, and Vishny (1997) presents the choice between private and public ownership as a choice between good and bad incentives. Private managers have stronger incentives to cut costs, which can both reduce waste and reduce quality, especially when quality reductions do not lead to losses in revenues. Consequently, there may be some services, such as providing airport safety or prisons, for which the welfare losses from lost quality exceed the benefits from lower expenses.

Engel, Fischer, and Galetovic (2014) turn this logic on its head for public-private partnerships (PPPs) by arguing that private providers have stronger incentives to deliver quality, especially for roads, when the number of riders depends on the maintenance of the road. Singh (2018) shows that private road providers in India deliver smoother roads. The primary difference between public and private road providers appears to be that private ones share responsibility both for initial construction and later maintenance. Because private providers do not cut corners at the initial construction phase, they provide better road services later on.

For many PPPs, the problem is not cutting quality but subverting the government. Glaeser (2004) presents a model in which private companies that supply public services bribe the government to overpay the companies for their effort. In weak institutional environments, the combination of highly incentivized private companies and public officials facing weak oversight can lead to a drain on public funds. Engel, Fischer, and Galetovic (2014) discuss the many problems of this nature created by PPPs in the developing world. While explicit bribery is less common in the US than in emerging markets, private companies still have the capacity to influence the politicians and bureaucrats who determine contract terms.

Several factors bear on whether private or public provision is optimal. If the service is to be funded by user fees and quality is observable to users, then private ownership creates incentives for maintenance. If quality is unobservable, or if there is no link between the number of users of the facility and the private owner's financial return, this effect is not operative. In such cases, private management can lead to lower quality. Roads may be more natural candidates for privatization than prisons, because their output is more observable and the advantage of private rather than public management may therefore be greater. If the procurement process is well designed and relatively immune to subversion or collusion, then private ownership should reduce financial costs. If the number of bidders is small or the institutional environment is weak, then public ownership may be a more attractive option. If public management must be combined with private construction, then private ownership may be a better option since it may be difficult to monitor the quality of initial construction.

Another consideration is the relative quality of lawyers and engineers in the public sector. Public management is engineering intensive. Private management is contract intensive, at least for the public sector. If the legal capacity of government is strong, then contracting with a private provider is relatively more attractive than otherwise. If the engineering capacity of the government is strong, then public management may be relatively more appealing.

A final consideration in the choice between public and private provision is resilience to economic downturns and other adverse demand shocks. In some settings, such as railroads in the US in the 1950s and 1960s and urban bus service providers in earlier decades, private infrastructure providers were unable to weather periods of adversity and the public sector stepped in to ensure continuing service. Enhancing the resilience of private providers, perhaps with new insurance schemes that involve government support but not takeover during periods of adversity, could improve the long-run viability of the private sector in the infrastructure sphere.

This discussion has focused on public versus private provision, but two other distinctions are worth making. First, private provision can be done by nonprofit firms or for-profit entities. The former have weaker incentives to make quality reductions that reduce costs and weaker incentives to subvert the government. Turnpike trusts were essentially local nonprofits that managed roads in eighteenth-century England. Unfortunately, many infrastructure projects today require outlays that are too large for most nonprofits to handle.

Second, there is a question about the choice of public management. When is it optimal for public control of infrastructure to be embedded in the executive branch of government rather than and when is it optimal for that control to be in the hands of a public authority? In the nineteenth-century US, independent authorities were thought to provide freedom from widespread corruption. Yet in many developing countries today, independent authorities or parastatal enterprises are seen as being even more corrupt and unaccountable than the elected executive branch of government. A key question is whether the independent authority will be led by someone whose future depends more on support by local politicians or on the individual's reputation for excellence. If the leader of the authority is beholden to local politicians, then independent authorities only provide an excuse for poor quality. If the leader cares about his or her reputation, then the authority is more likely to deliver quality and cost improvements.

Infrastructure in a Federal System

In the US, infrastructure is provided by national, state, and local governments. Water and sewer infrastructure have primarily been handled at the local level. In some cases, the city government directly owns the waterworks. Local roads similarly are handled by towns and municipalities. Major roads and large public transit systems are overseen by state governments, even when the funding is provided by the federal government. The federal government is extensively involved in most forms of transportation, especially air. Most of these divisions are natural outcomes of network size. Air travel often crosses state boundaries, and so national management is appropriate.

Local streets have fewer externalities across place boundaries. The most basic model of local public finance would allocate control of infrastructure to the lowest level of government that includes all or most of the network. The benefit of local control would come, as Tiebout (1956) suggested, from better local information and stronger incentives to cater to local voters.

The US also presents some interesting hybrid cases. Highways are an example. The federally funded Highway Trust Fund provides resources, but the resources are directed at the state level. The national government has some ability to place requirements on state governments, such as tying funding to raising the drinking age or lowering speed limits. Typically, though, federal funding does not come with any attempt to manage the highway network.

The federal role in highway spending reflects both historical precedent and federal willingness to borrow, especially during a recession. Indeed, if infrastructure spending plays a countercyclical role that spills over state boundaries, then federal funding may be appropriate. States and localities will not fully internalize the impact that their spending has on national aggregate demand and unemployment during a recession and so will underinvest in infrastructure during a downturn. The case for federal funding is weaker if the macroeconomic stimulus associated with infrastructure spending is limited. Whether the current federal funding of highways is optimal, or whether more state and local financial responsibility would lead to more efficient outcomes, is an open question. The redistribution of highway funds to low-density states is done with little cost-benefit analysis. The reliance on general federal tax revenues rather than local taxes and user fees is an interesting topic for future research.

There are also important questions about the division of control between states and localities. In most cases, localities have better incentives than a state regulator does to monitor and maintain local infrastructure, but localities may also be more subject to capture by connected contractors than the state government. The optimal level of local control must weigh the state's superiority at contracting with the local edge in directing that contracting efficiently.

Efficient Maintenance Policy

Economic analysis and data on the condition of infrastructure assets can help to guide investments in maintenance. For example, the international roughness index (IRI) provided by the Department of Transportation is created by measuring the vertical acceleration of official road surveyors who drive at a fixed speed. Big data provided by private companies can supplement this data by providing more up-to-date information on road quality and by estimating the links between road quality and road speeds and accidents. Both Uber and Lyft have real-time data on the vertical acceleration of their drivers during every trip. Data from these sources mimic the IRI data and are available more frequently and more widely. These data sources can be combined with Google Maps data on road speeds to estimate the time losses due to undermaintained roads, and with data from the American Automobile Association (AAA) to link road roughness to breakdowns and flat tires. If merged with police information, these data could be used to test whether road roughness leads to accidents. Such estimates could be improved by using natural experiments—for example, by looking at the temporal discontinuity in road quality before and after road repaving.

Armed with estimates of the costs of poor road quality, researchers could estimate the optimal time, or road quality level, for repaving. This is a standard optimal control exercise, and it has been solved with a variety of different assumptions about the nature of road depreciation and repair costs, as in studies by Worm and Van Harten (1996) and Gao and Zhang (2013). New estimates using big data like cell phone geolocation information can also contribute to our knowledge of the causes and speed of road deterioration. Other maintenance decisions are less amenable to analysis, especially when maintenance is needed to avoid catastrophic risk. At this point, engineering estimates of the risk of bridge collapse seem far more reliable than anything that can be gleaned from cars driving on the bridge. Similarly, the risks of rail disaster are much harder to meaningfully estimate.

Maintenance, New Construction, and Infrastructure Operation

The foregoing discussion of the appropriate ownership of infrastructure did not differentiate between initial construction and maintenance. In many cases, however, the problems are quite different, and it may well be optimal to split these roles between federal and local government or between public and private entities. Splitting the tasks is easier when monitoring initial construction quality is easier, because otherwise the initial builder may cut quality to save costs, thereby placing greater burdens on the actors responsible for maintenance.

Planning the construction of interstate systems, such as highways and air traffic systems, seems to merit significant federal engagement. The choice of where to put the roads involves the greatest amount of interjurisdictional spillovers. By contrast, the maintenance problem may be more likely to benefit from local attention. Local maintenance is more problematic when the costs of poor maintenance are borne mainly by drivers outside of the community. Indeed, a locality may even have incentives to let roads remain rough in some cases to deter crosstown traffic. In the case of rail, ownership of the rails themselves may generate a local monopoly. In that case, the appropriate model may be public ownership of the rail lines along with competitive private access. That model is followed with private roads, which effectively rent out access to their blacktop to private drivers and truckers. Typically, the monopoly problem in that case is moderated by rules that limit the size of tolls. This same model is typically followed by US airports. They are usually publicly owned entities that contract with private airline companies, which then negotiate rights over gates while the public entity manages the common space. Outside the US, private airport ownership is more common and is often combined with some regulation to reduce monopoly rent extraction. This model is worthy of more study.

In many infrastructure projects, distinctions between new construction (capital costs) and ongoing operations (variable costs) are somewhat artificial. Department of Transportation grants often privilege new purchases, when leasing might be more appropriate. There is no obvious reason why public transit authorities should be expected to cover their variable costs but not their capital costs, but that expectation is quite common. If these entities are pricing at marginal cost, then operating deficits may be entirely appropriate. If fiscal discipline is a primary concern, presumably this discipline should focus on overall deficits, not merely operating deficits.

Can US Infrastructure Spending Become More Efficient?

There are three potential areas for improving the efficiency of infrastructure construction and use: procurement, project management, and cost-benefit analysis of expenditures on mitigation of potentially adverse project externalities. A concern that motivates the efficiency discussion is that US infrastructure costs on a per-unit basis are high from an international perspective. Some policies—such as the Davis-Bacon Act, which requires contractors to pay prevailing wages, and Buy American Act contract provisions—are likely to raise input costs, but their net impact is not clear. While existing research does not provide a to-do list for making US infrastructure spending more cost-effective, additional study of the cost of building and maintaining infrastructure may yield conclusions relevant to policy.

Procurement

In the US, procurement rules were established in the shadow of corruption. Nineteenth-century procurement often involved high costs that were compensated by kickbacks to politicians. A strict set of rules about procurement evolved to limit corrupt practices, but in many cases those rules do not seem to deliver low costs. The rules typically require open bidding on projects and provide frameworks for vendor choice that lead to the selection of the low-cost bidder or the choice of higher-cost bidders only with some justification.

Researchers have identified several ways in which existing first-price auctions can fail to deliver low costs. Most obviously, bidders can collude and agree to bid only high prices or agree that some contractors will sit out the auction. When bids involve specifying a cost for each service and a projected number of services, Bolotnyy and Vasserman (2019) show that savvy contractors can deliver low bids on services where predicted use is too high and high bids on services where predicted use is too low. Finally, highly regulated auctions do not perform well when only one bidder shows up.

The first major procurement choice involves the decision between the use of auctions or negotiation. Bulow and Klemperer (1996) argue that any advantages provided by negotiation are small relative to the benefits that come from adding more bidders to an auction. While correct, this argument ignores the fact that a highly regulated auction may end up with only one bidder. A smart negotiator can keep on calling until he or she gets a reasonable bid.

The downside of flexible negotiation is that it is more prone to corruption than an arms'-length sealed-bid auction. While some countries, such as Singapore and Denmark, appear to give their procuring entities substantial independence, it is unclear whether that approach would produce efficiency or corruption in the US setting. Flexible procurement will work only if procuring entities have strong incentives to keep costs down; US bureaucracy is not known for strong incentives.

The contribution to this volume by Dejan Makovšek and Adrian Bridge considers the choice between strong incentive systems, such as fixed-price contracts, and weak incentive systems. The authors point out that strong incentive systems generally come at a higher cost, which can be explained if contractors are risk averse. In many cases, Byzantine regulations serve to restrict entry into an auction rather than to promote competition. These restrictions may ensure high quality levels but warrant further analysis. One reliable message of both theory and empirical work on procurement auctions is that attracting more bidders is important for keeping costs low.

Project Management

The initial bidding phase of procurement typically features competition among contractors, but inevitably, once work has begun, renegotiation becomes bilateral. Consequently, midstream renegotiation during the course of a contract is a chance for costs to rise enormously. The perils of renegotiation provide one reason so many megaprojects end up costing far more than initially planned or bid. For smaller well-defined projects, the renegotiation process can be regulated ex ante. For example, the auction process described by Bolotnyy and Vasserman (2019), in which bidders specify costs for specific services, is meant to accommodate changes in services over time. The procurer has the right to change the services needed as the work develops, and the contractor must provide those services at the auction-specified price. If the contractor has some predictive power beyond the estimates provided by the procurer, then the system can be gamed, but at least it is less subject to wholesale abuse ex post. In a large megaproject, this renegotiation process is far more complex. When tunneling hits an unexpected barrier, resolving the problem is not simply a matter of adding an extra ton of concrete. The costs must be renegotiated, and there is no competition to keep costs down.

There is a robust literature, illustrated by Hart and Moore (1988), on contracts and renegotiation. The models, typically formulated with private sector settings in mind, can be used to analyze the renegotiation of infrastructure projects. The complexity of these projects nevertheless limits the application of any simple model. Unless the work can be partitioned so that any new requirement for renegotiation can be handled competitively, the difficulties of bilateral bargaining reappear. Renegotiation appears to be a much greater generator of cost overruns for infrastructure in the US than elsewhere. Further research on this issue is needed. It could take the form of more qualitative comparisons of the US with other countries in which renegotiation is less difficult, or of a detailed study of renegotiation across many US contracts. While painstaking, such work seems necessary if we are to make any progress on understanding how to limit the extra costs that are added to projects after they are awarded.

Externality Mitigation and Infrastructure Costs

In the 1950s, Altshuler and Luberoff (2003) explain, infrastructure projects often ignored the concerns of local residents. The projects were cheaper, but many of those who were harmed went largely uncompensated. After the neighborhood organization and freeway revolts of the 1960s, projects were far more carefully selected and planned. They were also far more expensive, as Brooks and Liscow (2019) document. Glaeser and Ponzetto (2018) present a simple model in which rising education levels lead to more mitigation expenditures, especially if the federal government is paying for much of the cost.

This combination of well-organized community residents and federal funding lies behind the planning and expense of Boston's Central Artery/Tunnel Project, the Big Dig. Although the enormous cost of the project was largely paid for ex post by Massachusetts, ex ante voters were told that the costs would be covered by federal funding. The project was planned so that not a single house would have to be moved. A key question is how much could have been saved if a somewhat less sensitive planning procedure had been followed.

Other countries that pay less attention to community concerns have much lower infrastructure costs. China is an extreme example; infrastructure is built with a focus on low cost and speed, not compliance with local desires. It would be helpful to better understand the sources of cost differences between China and the US. France, Japan, and Spain might provide more natural comparisons. Gordon and Schleicher (2015) report that the per-mile cost of building the Second Avenue Subway line in New York City was eight times higher than a recent subway project in Japan and 36 times more expensive than one in Madrid. Even Paris's Metro Line 7, a particularly tricky building project, was much less costly than recent US projects.

Gordon and Schleicher suggest that potential litigation, standard in common-law countries, may explain some of the difference. The threat of litigation is one reason US infrastructure builders spend so much on mitigation. The Big Dig, for example, made numerous concessions because of environmental lawsuits. Concern for local harm is appropriate, and mitigation expenses can be well justified. Yet if mitigation explains a sizable fraction of the relatively high infrastructure construction costs in the US, some assessment of the efficiency of mitigation spending may be warranted.

Two types of research seem necessary. First, there must be more testing of whether mitigation expenses are responsible for high costs. This research could compare environments in which mitigation is more or less necessary. Alternatively, mitigation effects can be directly estimated for particularly projects, with engineering cost estimates used to determine the impact. Second, there is a need for better cost-benefit tools for examining mitigation actions. How should we value the losses to neighbors who are harmed by an infrastructure project? Do those neighbors value the expensive forms of mitigation that now exist? Are there less costly tools for compensating those neighbors? The call to improve US infrastructure currently collides with the very high cost of building that infrastructure. Strategies for reducing costs while still sheltering impacted communities could lead to welfare improvements for all.

A Road Map of This Book

The essays in this volume collectively survey much of the economic research on infrastructure. While this volume is not comprehensive—some important issues that have been actively studied have been omitted, and a number of key issues warrant future research—the book nevertheless introduces several core streams of investigation.

The volume begins with a chapter by Jennifer Bennett, Robert Kornfeld, Daniel Sichel, and David Wasshausen that describes the measurement of infrastructure in the Bureau of Economic Analysis's National Income and Product Accounts. Two difficult issues are determining the rate of depreciation for infrastructure and computing a price index for new infrastructure projects. The empirical work used to establish infrastructure depreciation rates is dated and might benefit from updating. The chapter provides basic facts about the stocks of infrastructure and the flow of infrastructure spending over time, including an experimental new data series on highway investment at the state level. One finding is that real net infrastructure investment per capita has fallen since the Great Recession (2007–2009) and that it is currently at its lowest level since 1983. The only significant infrastructure growth since the 1990s has been in digital infrastructure. The stock of basic infrastructure has grown by only 0.6 percent per year over the past 20 years. State-level variation in highway infrastructure investment per capita is particularly illuminating. Throughout the period from 1992 to 2017, states such as the Dakotas and Wyoming have led the nation in per capita highway investment. Between 1992 and 2017, spending on infrastructure investment in northeastern states, such as Pennsylvania and New York, rose dramatically relative to other states, which may reflect the extremely high cost of building in those areas. Southern states have seen their highway investment decline relative to northern states.

The second chapter, by Brooks and Liscow, focuses on the cost of building highways in the US. This paper and their related work (Brooks and Liscow 2019) suggest that the per-mile cost of building highways rose dramatically between the 1950s and the 1980s. This fact does not appear to reflect changing highway locations, such as a switch to more urban environments, or rising input costs. Rather, the cost of mitigating environmental or other local externalities appears to be an important factor. The rise in highway costs occurred largely after environmental concerns associated with highways began appearing in the media in the late 1960s. The rise is associated with increasingly wiggly roads, which may arise from attempts to avoid disturbing existing residents.

The chapter also documents large differences across states in construction costs. Connecticut and New Jersey spend much more per mile than the national average, even controlling for geography, while Wyoming and the Dakotas spend much less. Once the researchers control for geography, Delaware and Rhode Island appear to be areas with particularly low construction costs. Differences in construction costs after 1970 appear to be correlated with other measures of local spending. For example, while highway costs are correlated with average construction costs, there is also a strong correlation between highway costs and both Medicare spending per enrollee and per capita local government spending. These correlations suggest that some states may exercise less restraint than others with their budgets. The correlation with construction costs may mean that states that regulate housing supply more, and therefore drive up building costs, also impose more mitigation requirements on highway construction.

The third chapter, by Duranton, Nagpal, and Turner, presents evidence on the output of the infrastructure capital stock, rather than the flow of new investment. The chapter shows that according to Department of Transportation IRI measures, US roads are in much better shape today than in the past. This fact challenges the prevailing view of national infrastructure decline, primarily by dispelling the view that in some distant past the nation had pristine roads. Bridge quality also shows no clear downward trend. The US subway fleet did get older between the 1980s and the early 2000s, but average subway car age has remained constant since that point.

Duranton, Nagpal, and Turner, like Brooks and Liscow, find rising highway construction costs. One consequence of rising costs is a lower optimal level of highway capital and construction. Chapter 3 does not dispute the decline of investment levels, but rather suggests that this decline represents diminishing returns to expanding traditional transportation infrastructure. These facts suggest the value of grounding infrastructure investment decisions in data on performance and quantified risks rather than opaque letter grades.

The chapter also includes an interesting theoretical contribution on how to assess the optimal level of infrastructure investment across different modes. The logic of the model is that the incremental cost, including public and private spending, of providing a given level of mobility—think "move a person a mile"—should be equalized across modes. Duranton, Nagpal, and Turner apply this framework to highways, buses, and subways and find that current spending patterns generate less transportation services per dollar from spending on subways and buses than from spending on highways.

The fourth chapter, Ramey's analysis of the macroeconomic effects of infrastructure spending, begins with a standard neoclassical macroeconomic model that generates multipliers from government investment and consumption. The multiplier for government investment is typically higher than the multiplier from consumption. While Ramey's baseline model generates a multiplier between 2.2 and 4.4, she also presents results from a number of more complicated models that generate lower multipliers, some even below 1. This chapter summarizes the large empirical literature on infrastructure multipliers and presents estimates of the impact of American Recovery and Reinvestment Act (ARRA) spending. ARRA seems to have generated a modest increase in highway spending but little rise in long-term highway-related employment. The findings of Garin (2019), and Ramey's summary of related empirical work, suggest relatively low multipliers from ARRA-related spending, casting doubt on the use of infrastructure spending as a countercyclical policy tool.

The next chapter, by Makovšek and Bridge, addresses infrastructure procurement. The chapter adopts a global perspective and describes differences in the structure of procurement contracts that are used in different nations. Some contracts bundle the design and build phases together, while others proceed linearly, going from design to bid to build. Contracts also differ in whether they have high-powered incentives, such as a fixed price, or more flexible cost-plus structures. Prior research is not clear about whether bundling designing and building together is optimal, but chapter 5 suggests that fixed-price contracts generally lead to higher costs, perhaps because risk-averse builders require high payments to bear the risk of unknown cost shocks. The chapter presents a typology of procurement contracts, which is interpreted through the theoretical lens developed by Laffont and Tirole (1993) and others. The essay ends with a summary of the empirical work on the efficiency of different procurement contracts and a case study that illustrates many of the points about procurement that are developed in the chapter.

Chapter 6, an assessment of public-private partnerships (PPPs) by Engel, Fischer, and Galetovic, builds on the authors' previous criticism of many standard arguments for PPPs. The public case for PPPs often claims that private provision reduces the need for public outlays. The authors note that this argument often is only a reflection of artificial accounting practices. If the project will cost more than it earns, in net present value terms, then the government will need to pay for that difference, whether the provision is private or public. The PPP may enable the government to pay the costs in the future, but the same benefit could be achieved by borrowing.

Instead, these authors argue, the potential gains from PPPs must arise from better incentives in some part of the infrastructure procurement or management process. For example, while public managers may not be interested in revenues from tolls, for a PPP those tolls determine profits and losses. Tolls give the PPP strong incentives to maintain roads or other infrastructure and to generate future revenues. The PPP may also have stronger incentives to cut construction costs.

The downside of PPPs is that they must be monitored by the government. Failures to monitor may mean that the PPP delivers lower-quality infrastructure or extracts too much in payments from the public, either through excessive prices or excessive contributions from the public sector. The downsides can be particularly large when the public sector can be easily corrupted.

The next chapter, by Lucas and Montesinos, addresses the role of risk in assessing the fair value of infrastructure investments. This is often a particularly important consideration in valuing PPPs. The authors question the claim that the benefits of public projects should be discounted at the risk-free rate because project risks are largely idiosyncratic, suggesting instead that both public and private investments should be evaluated using a market rate that will differ from the risk-free rate based on the covariance between the project's future benefits and aggregate consumption, which is its "beta." A high-beta public project should be discounted just as much as a high-beta private project. Using the risk-free rate or the rate on government bonds to discount the benefits of infrastructure will generally lead to inefficient overinvestment.

A novel aspect of this study is its proposed approach to analyzing minimum revenue guarantees that are often promised by the public sector to PPPs. These guarantees are options that are transferred to the PPP; their cost to the government can be evaluated using a variant of the Black-Scholes options pricing formula. The authors point out that when options change the incentives of the PPP—for example, when guarantees reduce the incentive to maintain infrastructure—these options may have other costs that also need to be considered.

The volume concludes with Shane Greenstein's analysis of digital infrastructure, which is the category of infrastructure investment that has grown most significantly over the last 25 years. The discussion in this chapter is divided into three parts. The first addresses the expansion of digital access for both consumers and businesses. The adoption of broadband followed an S-shaped curve: richer consumers adopted first. Later in the adoption cycle, it was not lower prices but rising broadband speeds and the proliferation of broadband-intensive content that attracted initially reluctant adopters. This part of the chapter reviews measures of the productivity gains that broadband produced for businesses.

The second part focuses on the growth of network-related services that did not exist in the 1990s. For example, content delivery networks (CDNs) that deliver video and gaming experiences online have proliferated since 2000. The rise of data centers in the "cloud" is another example of new businesses that are made possible because of improved digital infrastructure. In a sense, this process is repeating the business transformations that followed the earlier transportation revolutions around sea shipping, railroads, and highways. The mass production of cotton in the nineteenth century, for example, was far more attractive because recent advances in transportation made it possible to ship cotton worldwide at relatively low cost.

The third section focuses on governance of the digital world. Protocols that shape the efficiency of digital connections were largely developed by public and nonprofit entities. This part of the chapter raises questions about whether current institutions are designed to maximize the efficiency of future protocol innovation and about the appropriate governance institutions for software, mapping, and entities such as Wikipedia.

COVID-19 and the Economic Analysis of Infrastructure

Four months after the symposium at which the research papers in this volume were presented, the US was struck by the COVID-19 pandemic. The pandemic has affected virtually every aspect of the economy, and it is likely to have long-term effects as well as short-term consequences. Many of the most notable short-run effects, such as the collapse of public transit use in large metropolitan areas and the drop in air travel, are related to infrastructure. This section offers a postscript to the chapters in this volume by describing some of the ways the pandemic has affected the demand for some types of infrastructure. This section also identifies key questions about the future role of infrastructure that have been raised by the pandemic.

Mobility declined radically over the course of a single week in March 2020. As the pandemic raged, international air travel was often impossible. Roads that had been clogged were empty. Many saw public transportation as a source of potential contagion, and millions avoided subway cars and buses. By May 2020, 49 million Americans were telecommuting, placing extraordinary demands on the country's digital infrastructure. How the demand for public transportation infrastructure will evolve after a vaccine or other public health measures make it possible to return to most prepandemic activities is an important but open question, and it is too soon to offer long-run predictions.

Nonetheless, it seems sure that existing public transit systems will face enduring challenges and that the impact of future pandemic risk will need to be considered as future investments in public transit are made. Public transit is particularly vulnerable to the effects of contagion, both because travel in this mode entails human proximity and because the costs of public transit scale down less readily when use declines. Drivers do not pay for gas when they do not drive, but public transit systems continued to run throughout 2020 with only a small fraction of their pre-COVID ridership. These systems are incurring large operating costs even with very low levels of use.

Reduced ridership levels seem likely to persist until there is widespread access to a COVID-19 vaccine and even perhaps beyond that time. All mobility declined substantially because of COVID-19, but transit particularly suffered because of fear that shared travel can lead to infection. In one May 2020 poll, 57 percent of all Massachusetts residents said that they would avoid taking public transit even if COVID-19 could be effectively treated. Rules about wearing masks have proved difficult to enforce on buses, and this difficulty may further reduce public confidence in shared vehicular transit.

Reduction in ridership leaves a fiscal hole in the system that will persist for many years without a state or federal bailout. If systems are left to cover their COVID-related fiscal shortfalls, then they will reduce their service further even after the disease has disappeared. The fiscal problems will create pressure to increase fares, which will reduce ridership further.

The extreme vulnerability of public transit to pandemics has rarely been incorporated into past cost-benefit analyses of system extensions, yet the COVID-19 pandemic is a reminder that public health shocks are a nontrivial risk. Similar disease outbreaks could have potentially occurred with SARS, MERS, and H1N1 during just the past two decades. Going forward, there is value in research that examines how to make systems more resilient during disease outbreaks and how to incorporate the risks of future pandemics in transit planning.

The US Bureau of Labor Statistics (2020) reports that nearly 50 million US workers stopped commuting and switched to working from home in spring 2020. If this massive shift from physical transportation to digital mobility persists, it would require an associated shift of investment in digital infrastructure. The rise of videoconferencing has led many to suspect that decades-old predictions that a vast fraction of the American economy would no longer meet face-to-face might come to pass, creating a massive decrease in demand for cities and urban space. Bartik et al. (2020) find that more than 40 percent of small businesses predict that more than one-third of their workers who switched to remote work during the pandemic will remain at home after the pandemic. That prognosis does not mean that office towers will be vacant in the future; rents may decline. Some commercial space may convert into residential usage. Still, if predictions for increased telecommuting prove accurate, the demand for urban real estate will decline along with demand for access to the highways that facilitate commuting.

The long-run postpandemic changes in economic activity are difficult to predict. Surges in entertainment-related mobility that followed the end of lockdowns in the Sunbelt in June and July 2020 are reminders that the demand for face-to-face contact is likely to be robust, especially for younger consumers. Younger workers and consumers seem likely to still pursue the pleasures of proximity. A switch from older urbanites to younger urbanites, and from established urban businesses to new firms, would have important implications for transportation infrastructure. Some suburban office parks may actually see an increase in demand, especially if firms attempt to provide their workers with more square footage to reduce the risk of disease spread. Some telecommuting professionals may relocate to high-amenity, medium-density locales such as Vail or Boulder. These areas have experienced rapid growth in recent decades and seem likely to continue to present robust demand for future infrastructure investments.

The pandemic should stimulate new research not just on public transit and air travel, but also on digital infrastructure. The switch to remote work occurred disproportionately among better-educated and better-paid workers, who had presumably acquired access to digital connections long ago. The switch to remote schooling, however, was universal and the lack of access to digital infrastructure imposed particular costs on poorer children. While the effects of the switch to digital learning is sure to be extensively studied, one important realization is that if online classes are going to feature more prominently in the education sector going forward, digital infrastructure requires heightened attention. Children without reliable Wi-Fi access will lose out in any such transition, even if they are motivated learners.

The pandemic has renewed calls for the use of infrastructure spending as a tool of macroeconomic stabilization, while also highlighting some of the limitations of such policy levers. The Ramey chapter in this volume discusses the evidence on the capacity of infrastructure spending to improve macroeconomic outcomes. One of the traditional arguments for funding infrastructure investment during a downturn is that there are jobless workers available. Employment in the construction industries dropped substantially during 2020, but it has already begun to rebound, without an infrastructure spending plan, in part because of the robust demand for housing. The brunt of the labor market decline during the pandemic was felt by workers in urban services industries, like leisure and hospitality. It is not clear that expanding spending on infrastructure projects would support a stronger labor market for these workers, particularly if public health concerns still discourage visits to restaurants, bars, and sporting events.

Conclusion

Taken together, the essays in this volume highlight many important economic insights about infrastructure and also show that much is still to be learned. We need to know more about improving procurement, and to better understand why US infrastructure costs are so high. We hope that future research will address these topics and that the economic analysis of infrastructure will receive the attention that its enormous importance merits.

References

Allen, Treb, and Costas Arkolakis. 2019. "The Welfare Effects of Transportation Infrastructure Improvements." NBER Working Paper 25487. Cambridge, MA: National Bureau of Economic Research.

Alsan, Marcella, and Claudia Goldin. 2019. "Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880–1920." *Journal of Political Economy* 127 (2): 586–638.

Altshuler, Alan, and David Luberoff. 2003. *Mega-Projects*. Washington: Brookings Institution.

American Society of Civil Engineers. 2017. *2017 Infrastructure Report Card.* Reston, VA: ASCE. https://www.infrastructurereportcard.org/.

Andonov, Aleksandar, Roman Kräussl, and Joshua Rauh. 2018. "The Subsidy to Infrastructure as an Asset Class." NBER Working Paper 25045. Cambridge, MA: National Bureau of Economic Research.

Arrow, Kenneth J., and R. C. Lind. 1970. "Uncertainty and the Evaluation Decisions of Public Investment." *American Economic Review* 60 (3): 364–78.

Aschauer, David. 1989a. "Is Public Expenditure Productive?" *Journal of Monetary Economics* 23 (2): 177–200.

———. 1989b. "Public Investment and Productivity Growth in the Group of Seven." *Federal Reserve Bank of Chicago Economic Perspectives* 13 (5): 17–25.

———. 1990. "Is Government Spending Stimulative?" *Contemporary Policy Issues* 8 (4): 30–46.

Ashraf, Nava, Edward Glaeser, Abraham Holland, and Bryce Millett Steinberg. 2017. "Water, Health and Wealth." NBER Working Paper 23807. Cambridge, MA: National Bureau of Economic Research.

Bajari, Patrick, S. Houghton, and S. Tadelis. 2014. "Bidding for Incomplete Contracts: An Empirical Analysis." *American Economic Review* 104 (April): 1288–319.

Bartik, Alexander W., Zoe B. Cullen, Edward L. Glaeser, Michael Uca, and Christopher Stanton. 2020. "What Jobs Are Being Done at Home during the COVID-19 Crisis? Evidence from Firm-Level Surveys." NBER Working Paper 27422. Cambridge, MA: National Bureau of Economic Research.

Baum-Snow, Nathaniel, and Matthew E. Kahn. 2000. "The Effects of New Public Projects to Expand Urban Rail Transit." *Journal of Public Economics* 77 (2): 241–63.

Bolotnyy, Valentin, and Shoshana Vasserman. 2019. "Scaling Auctions as Insurance: A Case Study in Infrastructure Procurement." Working paper, Harvard Economics Department.

Brooks, Leah, and Zachary Liscow. 2019. "Infrastructure Costs." Working paper, Yale Law School.
Bulow, Jeremy, and Paul Klemperer. 1996. "Auctions versus Negotiations." *American Economic Review* 86: 180–94.
Cutler, David, and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States." *Demography* 42 (1): 1–22.
Donaldson, Dave, and Richard Hornbeck. 2016. "Railroads and American Economic Growth: A 'Market Access' Approach." *Quarterly Journal of Economics* 131 (2): 799–858.
Downs, Anthony. 1962. "The Law of Peak-Hour Expressway Congestion." *Traffic Quarterly* 16 (3): 393–409.
Duranton, Gilles, and Matthew A. Turner. 2011. "The Fundamental Law of Road Congestion: Evidence from US Cities." *American Economic Review* 101 (6): 2616–52.
Engel, Eduardo, Ronald Fischer, and Alexander Galetovic. 2014. *The Economics of Public-Private Partnerships: A Basic Guide.* Cambridge: Cambridge University Press.
Fogel, Robert. 1962. "A Quantitative Approach to the Study of Railroads in American Economic Growth: A Report of Some Preliminary Findings." *Journal of Economic History* 22 (2): 163–97.
Furman, Jason, and Lawrence H. Summers. 2019. "Who's Afraid of Budget Deficits?" *Foreign Affairs.* March/April.
Gao, Hui, and Xueqing Zhang. 2013. "A Markov-Based Road Maintenance Optimization Model Considering User Costs." *Computer-Aided Civil and Infrastructure Engineering* 28 (6): 451–64.
Garin, Andrew. 2019. "Putting America to Work, Where? Evidence on the Effectiveness of Infrastructure Construction as a Locally Targeted Employment Policy." *Journal of Urban Economics* 111: 108–31.
Glaeser, Edward. 2004. "Public Ownership in the American City." In *Urban Issues and Public Finance: Essays in Honor of Dick Netzer*, edited by A. E. Schwartz. Northampton, MA: Edward Elgar.
Glaeser, Edward, and Giacomo Ponzetto. 2018. "The Political Economy of Transportation Investment." *Economics of Transportation* 13: 4–26.
Glaeser, Edward, and Andrei Shleifer. 2003. "The Rise of the Regulatory State." *Journal of Economic Literature* 41 (2): 401–25.
Gordon, Tracy, and David Schleicher. 2015. "High Costs May Explain Crumbling Support for U.S. Infrastructure." *Real Clear Policy*. https://www.realclearpolicy.com/blog/2015/03/31/high_costs_may_explain_crumbling_support_for_us_infrastructure_1249.html.
Gramlich, Edward. 1994. "Infrastructure Investment: A Review Essay." *Journal of Economic Literature* XXXII (September): 1176–96.
Gupta, Arpit, Stijn Van Nieuwerburgh, and Constantine Kontokosta. 2020. "Take the Q Train: Value Capture of Public Infrastructure Projects." NBER Working Paper 26789. Cambridge, MA: National Bureau of Economic Research.
Hart, Oliver, and John Moore. 1988. "Incomplete Contracts and Renegotiation." *Econometrica* 56 (4): 755–85.
Hart, Oliver, Andrei Shleifer, and Robert W. Vishny. 1997. "The Proper Scope of Government: Theory and an Application to Prisons." *Quarterly Journal of Economics* 112 (4): 1127–61.
Hornbeck, Richard, and Martin Rotemberg. 2019. "Railroads, Reallocation, and the Rise of American Manufacturing." NBER Working Paper 26594. Cambridge, MA: National Bureau of Economic Research.

Jaworski, Taylor, and Carl T. Kitchens. 2019. "National Policy for Regional Development: Historical Evidence from Appalachian Highways." *Review of Economics and Statistics* 101 (5): 777–90.

Kain, John. 1990. "Deception in Dallas: Strategic Misrepresentation in Rail Transit Promotion and Evaluation." *Journal of the American Planning Association* 56 (2): 184–96.

Keynes, John Maynard. 1936. *The General Theory of Employment, Interest, and Money*. New York: Harcourt Brace.

Kline, Patrick, and Enrico Moretti. 2014. "Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority." *Quarterly Journal of Economics* 129 (1): 275–331.

Laffont, Jean-Jacques, and Jean Tirole. 1993. *A Theory of Incentives in Procurement and Regulation*. Cambridge, MA: MIT Press.

Meyer, John, John Kain, and Martin Wohl. 1965. *The Urban Transportation Problem*. Cambridge, MA: Harvard University Press.

Pigou, Arthur C. 1920. *The Economics of Welfare*. London: Macmillan.

Singh, Ram. 2018. "Does Choice of Procurement Contract Matter for Cost and Quality of Infrastructure?" International Growth Center Working Paper S-89209-INC2.

Small, Kenneth A., Clifford Winston, and Carol A. Evans. 1991. *Road Work: A New Highway Pricing and Investment Policy.* Washington, DC: Brookings Institution.

Smith, Adam. 1776. *The Wealth of Nations.* https://www.adamsmithworks.org/documents/chapter-i-of-the-expences-of-the-sovereign-or-commonwealth.

Tiebout, Charles M. 1956. "A Pure Theory of Local Expenditures." *Journal of Political Economy* 64 (5): 416–24.

Troesken, Walter. 2004. *Water, Race, and Disease.* Cambridge, MA: MIT Press.

US Bureau of Labor Statistics. 2020. *Labor Force Statistics from the Current Population Survey: Supplemental Data Measuring the Effects of the Coronavirus (COVID-19) Pandemic on the Labor Market.* Accessed November 26, 2020. https://www.bls.gov/cps/effects-of-the-coronavirus-covid-19-pandemic.htm#data.

US Congressional Budget Office (CBO). 2018. *Public Spending on Transportation and Water Infrastructure, 1956 to 2017*. Washington, DC: CBO. https://www.cbo.gov/system/files/2018-10/54539-Infrastructure.pdf.

Vickrey, William. 1952. *The Revision of the Rapid Transit Fare Structure of the City of New York.* Technical Monograph 3, Finance Project, New York City Mayor's Committee for Management Survey.

Winston, Clifford. 2010. *Last Exit: Privatization and Deregulation of the US Transportation System.* Washington, DC: Brookings Institution.

———. 2013. "On the Performance of the U.S. Transportation System: Caution Ahead." *Journal of Economic Literature* 51 (3): 773–824.

———. 2020. *Autonomous Vehicles: The Road to Economic Growth?* Washington, DC: Brookings Institution.

World Economic Forum. 2019. *The Global Competitiveness Report.* Geneva: World Economic Forum.

Worm, J. M., and A. Van Harten. 1996. "Model Based Decision Support for Planning of Road Maintenance." *Reliability Engineering & System Safety* 51 (3): 305–16.