Economic Analysis and Infrastructure Investment

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In 2017, according to the Congressional Budget Office (2018), the federal government spent $98 billion on transportation and water infrastructure, and state and local governments spent another $342 billion – a total of $440 billion, or about 2.3 percent of GDP. Although this is a substantial outlay, as a share of GDP it is lower than at any time since President Eisenhower launched the interstate highway program in 1956. Diverse voices clamor for spending far more. President Trump's infrastructure plan aimed to increase infrastructure spending by $1.5 trillion, in substantial part using private funding, and the Green New Deal, which includes a plan to overhaul the transportation system, aims to spend $10.7 trillion over multiple years.

In contrast to these calls, transportation economists are more apt to call for better use of existing infrastructure than for greater spending overall. Vickrey (1952) first argued for congestion pricing which could potentially enable our roads to move more swiftly during peak periods. Meyer, Kain and Wohl (1965) emphasized the economic advantages of the bus over urban rail for passenger travel.   Winston (2010, 2020) has argued that road privatization in the U.S. would lead to significant efficiency gains.

This essay frames the economic issues associated with infrastructure investment, and introduces a collection of studies that offer a broad range of economic insights on infrastructure spending. It begins with a summary of three reasons – limited private capital markets, externalities, and potential natural monopolies – that have drawn the public sector into infrastructure projects. While some of the historic rationales for public investment in infrastructure have disappeared, many remain, including the presence of externalities related to public health and macroeconomic conditions, and the fear of monopoly power.

After our historical review, we turn to the forces that determine optimal spending on infrastructure, recognizing that there are both macroeconomic and microeconomic approaches to determining the right level of spending.   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 counter-recessionary benefits of infrastructure spending and the role that infrastructure may play in fomenting economic growth. While Ramey's contribution to this volume casts doubt on the efficacy of infrastructure as a stimulus for growth, we recognize the need for a unified approach that better integrates the microeconomic and macroeconomic approaches to optimal infrastructure spending.   The natural way forward is to formally quantify the macroeconomic externalities that come from various forms of infrastructure and to embed those external gains into standard microeconomic cost-benefit analysis.

Following this discussion of optimality conditions, we turn to the institutions and funding of infrastructure.   The two issues are linked because, as Engel, Fischer and Galetovic's chapter emphasizes, some of the incentive problems that arise in private public partnerships can be attenuated when infrastructure is significantly funded by user fees. Funding infrastructure with user fees avoids debates over redistribution and helps anchor project selection. There is less risk of "white elephants" when infrastructure projects are only funded when they are expected to generate revenues that can cover costs.   User fee funding creates inefficiencies though if the average cost of the infrastructure is far below its marginal cost.   In that case, funding mechanisms that take advantage of increases in the local property values, such as so-called "tax

increment financing" or even traditional local property taxes, provide a means of getting closer to a more efficient two-part tariff.

While the privatization of infrastructure can seem bold and innovative, for the United States, the intergovernmental allocation of responsibility for infrastructure is at least as important. Since the 1950s, the federal government has taken on responsibility 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 towards 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.

We discuss four areas in which infrastructure spending could become more efficient: procurement, management, mitigation spending and innovation. A growing literature, exemplified by Bajari, Houghton, and Tadelis (2014) and Bolotny and Vasserman (2019), uses data on infrastructure procurement to estimate models of auctions. It may eventually provide lessons on how infrastructure procurement can be made substantially more cost effective.

Many of the most expensive infrastructure investments in the U.S., including Boston's Big Dig and New York's Second Avenue Subway, ended up costing many times the original estimates because new events led to renegotiations with contractors during the construction process. While the original bid process is a competitive auction, renegotiation is often a one-on-one bargaining process that may put governments at a disadvantage. Given that renegotiation is likely to be a constant in future large infrastructure projects as well, we discuss ideas about how to make renegotiation less expensive.

The Brooks and Liscow essay in this volume suggests that mitigation spending, which includes both sound walls and the curving of roads, accounts for a significant part of the increase in the cost of highways between the 1950s and 1980s. Whether a more stringent cost-benefit analysis should be applied to these outlays is an open question. Given the range of innovations such as self-driving cars that are enlarging the possibilities for transportation in America, we summarize potential strategies for adapting government policy to enhance and utilize these innovations.

This chapter concludes by summarizing each paper and explaining the interconnections that knit these eight distinct papers cohere into a single volume.

1. Why Have Governments Invested in Infrastructure? Perspectives from US History

This section reviews the basic arguments for public involvement with infrastructure, and illustrates each argument with an episode from U.S. history. Broadly speaking, the public sector has built and managed infrastructure for three main reasons: the scale of investment was thought to be too high for private investors, the infrastructure generated positive externalities including

health benefits, an enhancement externalities, nation-building and counter-recessionary spending, and infrastructure created the potential for monopolistic abuse. 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 public engagement with infrastructure reflects a large gap between average cost and marginal cost, which will occur when infrastructure is a natural monopoly, then user fee financing is less appropriate.

1.1 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 the 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 19th century canals, such 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, it was vetoed by President Madison.

The Erie Canal was enormously successful and user fees quickly funded the Canal's costs. The Canal remains synonymous with infrastructure spending at its best, and it 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 19th century. America's cities and towns were spending as much on water at the start of the 20th century as the federal government was spending on everything except for 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 narrow Mersey and Irwell navigation linking Manchester and the Irish sea was created privately in 1734. When Great Britain dug the much larger Caledonian Canal in 1804, public funding was also used, but by the end of the 19th century, financial markets were sufficiently well developed so that the Manchester Ship Canal could be a private enterprise.

Some recent calls for infrastructure spending – for example, the plan advanced by President Trump – have envisioned a small public subsidy that could encourage a much larger volume of private investment. That vision reflects a sense that global financial markets are robust enough to fund almost any feasible piece of infrastructure that can be reasonably expected to pay for

itself.   Consequently, the primary rationale for public funding of the Erie Canal, which is still invoked to motivate public infrastructure spending, seems to be largely irrelevant today.

1.2 Local Externalities and Public Ownership: Water

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 throughout America's eastern seaboard. Yellow fever returned to Philadelphia in 1797, 1798 and 1799.

While 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 water works.   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 water works, the city established the Manhattan Water Company to provide clean water for its residents. It was subsidized with a franchise to run a bank, a rare privilege at the time.   It transpired that the company could earn far higher returns by banking than by pumping water, and it eventually evolved into J.P. Morgan Chase, along the way passing through the Chase Manhattan Bank which descended from the Bank of the Manhattan Water Company. The company was not nearly as prolific or long-lived a producer of water.

There were two key market failures related to water production during the 19th century.   First, an individual who consumed of dirty water did not internalize the health consequences to his neighbors of becoming infected. Second, consumers could not directly observe whether privately sold water was clean or dirty.   Both limited demand for the Manhattan Company's water.

After New York City's 1832 cholera epidemic, the city embraced investing in clean public water. The city's leaders chose to trust an independent public authority which would hopefully 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. Unfortunately, many poorer New Yorkers still 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.   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 pre-Pigou Pigouvian tax seems to have had an impact, because after 1866 death tolls in New York City began to decline.

If anything, public sewerage has an even higher ratio of public benefits to private benefits.   If sewage is dumped on a neighbor's property, then it is the neighbor that pays most of the cost.

Consequently, the need for public subsidies or Pigouvian taxes with sewerage is even more extreme than with water. Alsan and Goldin (2019) find that early 20th 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. Troesken's (2004) work on later 19th century water systems finds that the death rates of African-Americans declined substantially when cities switched from private to public water provision, which is compatible with the view that private companies skewed their service towards wealthier customers who could pay more. Despite this skew, even the rich were at risk from a cholera epidemic that began in the poorest parts of town.

Local externalities are still a potent justification for public investment in American 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 Legionnaire's Disease.

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 vs. public water provision, but these controversies concern costs more than cleanliness, since private water quality can be easily monitored in the 21st century. The more important local externality debates concern transportation infrastructure and the congestion externalities associated with road overcrowding.

One common justification for public subsidies to metro 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 America's newer metro systems have had limited impact on commuting patterns.

If congestion pricing is politically infeasible, then the case for subsidizing public transit becomes an empirical question. The appropriate subsidy for each public transit trip equals the reduction in driving caused by this 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 should be easy to estimate, since experiments with bus service can be used to estimate the impact on rides, traffic and accidents, and then number of buses can be scaled up or down depending on the appropriate subsidy. If public transit means a fixed rail system, then pricing can still be altered ex post, but there is little ability to change the quantity of subway lines after building finishes..

Congestion externalities are also potentially a justification for building more highways, but any new construction must recognize that more highways often generate more driving. Indeed, what Duranton and Turner (2011) call the fundamental law of highway traffic suggests that the level of traffic may be independent of the number of roads, since vehicle miles travelled seems to scale up roughly one-for-one with highway miles built. If that law holds, then new highway construction generates welfare by allowing more trips, but it will not materially reduce congestion on existing highways.

1.3 Nation-Building and Macroeconomic Externalities

In the 19th century, Henry Clay and the Whig Party advanced a program called the "American System" which was meant to strengthen the nation by imposing tariff on imports and subsidizing internal improvements such as transportation infrastructure. The Cumberland or National Road was the most visible example of these national investments. 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 that would travel from sea to sea, also with the hope of binding the nation together.

Nation-building has at least three coherent economic interpretations. First, nation-building may refer to general equilibrium impacts of transportation that are not internalized by railroad builders themselves. Land values may increase. Firms may benefit from cheaper inputs. Donaldson and Hornbeck (2016) do indeed document that the American railroad system yielded significant and far-flung benefits, a claim that can be reconciled with Robert Fogel's (1962) argument that American economic development could have proceeded without the railroads.

Second, the U.S. disputed its borders in the 19th century with Mexico, Great Britain and native Americans. A more developed transportation network, and the migration that would follow that network, would help buttress the nation's political hold over the central North American land mass. In this case, nation-building denotes political benefits for the U.S. that come at a cost paid by other nations and peoples.

Third, nation-building can also refer to creating a coherent sense of national unity. By increasing economic interdependence between regions, transportation infrastructure could potentially limit future secession movements and reduce the inter-regional strife that led to the Civil War. There is some evidence, for example, that the strong transportation linkages between New York City and the American 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 Lincoln, saw the cause of preserving the Union as paramount.

The second of these motives is no longer relevant for the U.S. today, as the nation's borders have been essentially fixed for 150 years. The other two motives still matter. Trade economists are increasingly producing complex general equilibrium models that can quantify the national economic gains from better connections. These models have not yet been used explicitly in transportation network design, but they may be in the future. Infrastructure's role in national cohesion has evolved. While 19th century infrastructure advocates argued that simply connecting to dispersed areas would help build the country, 21st century advocates emphasize that infrastructure can help bring economic prosperity to poorer parts of the U.S. That prosperity, in turn, may lead those areas to feel like fuller partners in the American economy. Yet while such arguments are often made, the impact of new infrastructure on poorly performing regional economies is uncertain. Appalachia is still quite poor after 50 years of extra investment through the Appalachian Regional Commission. Moreover, small numbers of incremental jobs may do little to heal the cultural divisions that still separate region from region.

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 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 for goods and services.

Ramey's contribution in this volume makes clear that the efficacy of infrastructure as anti-recessionary spending is open to debate, and could be quite modest. 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.

1.4 Monopoly Power and the Regulation of Railroads

America's inter-city railroads were built by private companies and they were subsidized for nation-building purposes. After construction, those private companies were the subject to strident criticism because of their alleged monopoly power.   When infrastructure is something of a natural monopoly, with average costs greater than marginal costs, then free market pricing will not generally lead to efficient outcomes. The public response to high transportation prices has taken the form of both regulation and public ownership.

In 1887, the Interstate Commerce Commission (ICC) was established to limit the monopoly power of railroads.   The Hepburn Act of 1906 and Mann-Elkins of 1910 were both meant to further empower the ICC.   The 1893 Railroad Safety Compliance Act gave the ICC further control over safety issues; Glaeser and Shleifer (2003) argue that this was because of the belief that traditional tort remedies for damages were insufficient given the railroads' legal muscle.

The ICC was dismantled during the 1970s, partially because fears of railroad monopoly power had been replaced by fears of railroad insolvency that were set off by the bankruptcy of Penn Central in 1970. In 1900, farmers had few alternatives to shipping their wheat by rail. By 1976, the relatively competitive trucking industry provided a viable alternative. Deregulation meant that railroads were free to focus on their more profitable businesses and to focus on moving goods rather than moving people.

Penn Central's bankruptcy was one of the events that led to the consolidation of U.S. passenger rail into Amtrak, which is a quasi-public entity subsidized by tax dollars.   This transition repeats the movement of municipal transit systems from private to public ownership that began before World War II. At the local level, once-profitable transit companies had lost ridership because of the automobile and public ownership was a means of avoiding bankruptcy.

The economic case for Amtrak and local public transit systems is rarely articulated. The standard argument for public subsidy reflects the aforementioned 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. The second argument is that these systems are still natural monopolies with marginal costs of use

that are below average costs, so charging below average cost is efficient and requires subsidies. There are few attempts to quantify whether subsidies are of the appropriate magnitude.

2. What Determines the Optimal Level of Public Infrastructure Spending?

There is a nearly constant clamor among politicians for increased spending on infrastructure. They have occasionally been echoed by macroeconomists, some of whom see counter-cyclical benefits of spending on infrastructure and perhaps also benefits for long term growth. Transportation economists, in contrast, have a microeconomic orientation and are generally more skeptical.

We begin this section by contrasting the microeconomic and macroeconomic approaches to determining optimal transportation spending. While we do not develop a grand synthesis of the two approaches, 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 as in Duranton, Nagpal, and Turner's paper in this volume. We end with a discussion of macroeconomic issues that shape optimal infrastructure spending.

2.1 Macroeconomic vs. 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 increases to local property values or business profits. Costs are largely construction costs. This ground-up approach typically yields only modest returns for most new large-scale infrastructure projects. Returns for maintenance of existing infrastructure are typically much higher.

These arms-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 also radically overstate reasonable projections of future ridership of rail projects.

The relatively low returns to many projects reflect the relatively advanced level of infrastructure in the U.S. today. In 1816, it cost as much to move goods 30 miles overland as it did to cross the Atlantic Ocean and consequently, the Erie Canal provide 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) is an excellent example of this work, and 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 be unusually high as infrastructure projects in dense urban areas have proven to be particularly expensive in recent decades.

By contrast, the macroeconomic approach to infrastructure starts with far larger objectives linked to either stabilization or growth. Keynes (1936) wrote that "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" (p. 164).   Keynes feared both excessive speculation and "crises of confidence," which would lead private markets to either over or under invest in capital. He distrusted the ability of private markets to get the overall level of investment right or to target that investment towards 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' general skepticism about private investment has had less impact that 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 where adding 100,000 people on public works leads total employment to rise from 5.2 million to 6.4 million because of the multiplier. While Herbert Hoover's enthusiasm for counter-cyclical spending predates Keynes', the latter's writing inspired later generations of economists and policy-makers to consider "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 U.S. economic time series. Aschauer (1989b) showed the connection between public infrastructure and growth across the "Group-of-Seven" nations between 1965 and 1985. While Gramlich's (1994) skeptical response to Aschauer's work is widely cited by microeconomists, Aschauer's views retain considerable currency among many policy-oriented macroeconomists.

While the microeconomic approach yields clear policy tools for selecting infrastructure projects, the macroeconomic approach yields only a general impetus to spend more on infrastructure during a downturn. A much-needed reconciliation of the two approaches might start with a clear quantification of the macroeconomic externalities associated with providing different forms of infrastructure. The counter-cyclical case for infrastructure should be amenable to empirical analysis.

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 and the tax payments. In Keynes' own example, the cost of the 100,000 public works employees would be mitigated by the increasing tax payments and decreasing benefits received by the 1.2 million extra employees in the economy as a whole.

The fiscal benefit from each employed worker is easier to estimate than the employment impact of infrastructure spending. The tax payment and benefit levels can be plausibly estimated and so it is relatively easy to multiply the change in employment by that number. Unfortunately, as Ramey's contribution in this volume makes clear, the empirical literature on the employment effects of infrastructure has not reached a consensus. Many researchers doubt that most forms of infrastructure spending would lead to any significant change in 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 its employment benefits will no longer be as valuable. Counter-recessionary maintenance is easier to manage than new projects, but even then there

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may be some social losses from basing maintenance schedules on the state of aggregate employment rather than the condition of the 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 only began in 2015 and 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 that capital. Leaving aside a number of empirical issues surrounding the estimation of the return to government capital, 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 general equilibrium spatial model, then the model can be expected to match any observed relationship between the level of public infrastructure and overall economic activity. This could generate an empirically grounded estimate of the productive benefits of different road segments that incorporates the larger growth estimates, and to make welfare statements about different forms of infrastructure investment.

Keynes' skepticism about private investment may be the most difficult macroeconomic concern to include within infrastructure planning. If the overall interest rate is seen as being too high or too low for some reason, then public spending could still be discounted using the correct rate. Private spending can either be stimulated or taxed through the tax code. Yet while Keynes' fears about private sector errors may have merit, it is not clear that public planners can outguess the private sector and to correctly "calculate the marginal efficiency of capital-goods on long views and on the basis of general social advantage."

In considering the framework for assessing optimal spending, we first discuss micro, and then macro, approaches to estimating the benefits of infrastructure spending. The could often be large gaps between the results of the two approaches; the research challenge is to reconcile them.

2.2 Microeconomic Determinants of Optimal Infrastructure Spending

The microeconomic approach to infrastructure generally proceeds on a project by project basis, and does not focus much on the aggregate level of infrastructure. Yet there are at least two major aggregate scorecards that appear relevant even for the microeconomic approach: the American Society of Civil Engineers' (ASCE) *Infrastructure Report Card* and the World Economic Forum's *Global Competitiveness Report*.   The ASCE Report Card is the work of 28 civil engineers who assign grades based on their assessment of the current state of American infrastructure. The Global Competitiveness Report is based on surveys of business leaders.

America's overall grade on the 2017 infrastructure report card is a D+, which implies that our infrastructure is "poor" and "at risk." Our roads received a straight D, bridges a C+, which implies that they are "mediocre" and "need attention," And our drinking water received a D.

Taken at face value, these grades suggest that America needs to spend more on its infrastructure, although readers can be excused for thinking that civil engineers might have a financial interest in making the case for more spending on civil engineering projects. Moreover, it is hard to accept a grade of D for our drinking water given that outbreaks of water-borne diseases are quite

rare. The Flint catastrophe was correctly seen as terrible catastrophe not the routine state of affairs. Duranton, Nagpal, and Turner's paper in this volume shows that our roads are much smoother than they have been in the past, which makes the grade of D for roads difficult to understand especially since the report card gave our highways a grade of C+ in 1988 when they were much rougher.

Yet the engineers are most likely to know if our bridges are in danger of imminent collapse. The heterogeneous grades by sector and state do seem to offer the hope of incorporating more engineering into public infrastructure decisions.   To make these estimates usable, they need to be turned into estimates of actual harm from failing to maintain particular assets, and then the state of the infrastructure needs to be multiplied by the social costs of an infrastructure failure. For example, America's bridges may be in better shape than our roads, but if they fail the loss of life may be far more terrible.

The World Competitiveness Report does not claim to utilize the civil engineering expertise embedded in the report card, but it does have the virtue of global compatibility. The report contains a significant section on infrastructure and it splits the infrastructure scores into transportation and utilities.   Overall, the U.S. score on infrastructure in 2019 was 87.9, which placed America thirteenth in the world. While this score (a seemingly high B) is considerably less troubling than the civil engineer's D+, many are still troubled that our infrastructure is no longer rates as among the best in the world.

America's two worst infrastructure scores in the Competitiveness Report appear in the railroad sector. We receive a 41.3 in railroad density, which makes us 48th in the world, and a 69.2 in the efficiency of rail services. These low scores reflect the reality that since the 1970s deregulation of rail services, America 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, the general pattern is that America's connectivity is superb, but maintenance is less perfect. We are the global leaders in road and airport connectivity.   One hundred percent of the US population has access to electricity and the US ranks eighth in "liner shipping connectivity." The quality of road infrastructure, however, is rated only 74.5 making the US 17th in the world and the efficiency of our airport and port services is ranked tenth in the world.   The Competitiveness Report gives the U.S. a 100 for water safety, somewhat belying the Report Card's D, but only an 86.1 for water reliability.

The report appears to lend support to Gramlich (1994) who argued that the time series data and common sense both suggested that the US had 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 constructing new forms of infrastructure. This has been a mantra for microeconomic transportation economists ever since.

Economic analysis and data on the condition of infrastructure assets can help to guide some investments in maintenance. For example, the International Roughness Index (IRI) provided by the Department of Transportation, and used by Duranton, Nagpal, and Turner in their chapter in this volume, 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 the 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. This data mimics the IRI data, and is 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. With data from the Automobile Association of America (AAA), it is even possible 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 car crashes. Such estimates could be improved by using natural experiments like the temporal discontinuity in road quality before and after road repaving.

Armed with estimates of these costs of poor road quality, researchers can estimate the optimal time, or road quality level, for repaving. This problem is standard optimal control exercise and it has been solved with a variety of different assumptions about the nature of road depreciation and repair costs, for example by Worm and Van Harten (1996) and Gao and Zhang (2013). New estimates based on "big data" like the cellphone 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.

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 approach to the optimal decision to invest 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, then this implies that public spending per mile travelled should be equalized across modes. While their 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 that marginal benefit of spending on buses and more than twice the marginal benefit of spending on rails. While they do not incorporate any redistributive benefits of favoring transit for lower income individuals, their work highlights an important fact: the US currently spends far more per passenger mile on rail and buses than we on highways.

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

2.3 Macroeconomic Determinants of Optimal Infrastructure Investment

The macroeconomic approach to infrastructure emphasizes two measurable variables: the interest rate and joblessness. If we better understood the broader effects of infrastructure on economic growth, they should also be included. The benefits of infrastructure investment occur over time and 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, and that implies that the optimal level of infrastructure investment should rise. Equivalently, if the repayment of infrastructure debt is time to coincide with future usage, then lower long-term 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 low interest rate environment.   Their basic logic is unassailable, but even a zero real interest rate does not make the case for investing in mediocre projects. Moreover, many forms of infrastructure come with costs that are born in the future and these costs will not fall with lower interest rates.

The chapter by Lucas and Montecinos addresses the issue of risk-adjustment for interest rates of public infrastructure projects. The widely-referenced Arrow-Lind (1970) theorem provides conditions under which the benefits of public projects are discounted at the risk-free rate, especially that the benefits of each project are independent of one another and of overall macroeconomic risk and the number of projects is large. In this case, the overall portfolio of projects becomes risk-free and the risk-free rate is appropriate.

Yet 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, so their returns are not uncorrelated with macroeconomic conditions. Many projects, including roads, have benefits that are correlated across project.   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 optimal connection between the level of unemployment and optimal infrastructure investment. Keynes argued that the employment-related benefits of public works spending were higher when employment was low, and macroeconomic advocates of counter-cyclical infrastructure spending echo his line.   The critical question is whether infrastructure spending boosts aggregate employment, and whether that effect is larger when aggregate employment is lower.

Ramey's chapter casts doubt on this view.   She notes 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 toiling by the side of a road. 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 and employment policy will be limited.

3. Funding and Provision

We now turn from a discussion of the optimal level of infrastructure to questions about its management. We begin with optimal pricing of infrastructure, and then turn to its privatization, a topic which is addressed in two chapters, those 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 end by discussing cases in which the answers about optimal funding and provision may differ between maintenance and new construction.

3.1 Efficient Infrastructure Pricing and Funding

Infrastructure pricing determines the level of usage of the infrastructure conditional upon its level of maintenance. It can also play a role in determining infrastructure investment decisions, can shape incentives for maintenance, and affects equity, since higher prices for some infrastructure services, such as bus trips, will 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 being minimal and consequently, free roads seemed like a reasonable benchmark. Indeed, the US interstate highway system was originally intended to be without tolls, partially because any tolls were seen as largely serving 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 added buses or cars need to be run. The gap between marginal cost and average cost historically then justified the case for tax subsidies.

In dense metropolitan regions today, the marginal costs of both transit and driving can be quite high. Subways, buses and roads can be quite crowded. In the case of roads, it is quite possible that optimal congestion pricing leads to charges that significant exceeds the average cost of providing the roads, at least if the opportunity cost of the land involved is ignored. Consequently, efficient pricing would mean that road systems generate surpluses instead of requiring subsidies.

We have included "externalities" that are within the transit system together with other costs, but if there are other externalities associated with infrastructure use then they should also be included into the price. If carbon use generates negative environmental externalities then the price of fuel-intensive infrastructure should be increased. If water use in dry states exacerbates fire risks, then this also merits inclusion in the price.

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

The consequences of pricing policy go beyond rationing use. With public-private partnerships, Engel, Fischer, and Galetovic (2014) point out, pricing generates incentives for better maintenance since the private provider doesn't get paid unless the roads are used and the roads won't get used if they are in bad shape.. Ashraf, Glaeser, Holland and Steinberg (2017) find that water pipes in Zambia are repaired more rapidly when consumers pay by the liter instead of by the month. Public providers may be less sensitive to revenues than private providers, but they may also provide better maintenance if they are frightened of losing users.

User-fee financing can also be quite helpful when selecting infrastructure projects. If infrastructure is 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 and that helps make sure that they 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. Fliers are typically richer than the average American. Consequently, if airports are funded by general tax revenues then this represents a transfer from the poor to the rich. User fee financing eliminates takes the possibility of redistribution via pricing off the table, which has both and bad consequences.

When there is a gap between the user fee and average cost, then infrastructure requires other forms of financing. In rare cases, this is done through a classic two-part tariff where users 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 the people who use the infrastructure but not distort regular usage.

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 of U.S. highway financing occurs through the federal highway trust fund, which was historically 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 implicitly means that ordinary taxpayers are subsidizing driving on America's highways.

The highway trust fund also redistributes across states, particularly 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. Beyond shipping, it is unclear how higher density parts of the US benefit from highways in more open areas.

3.2 Public vs. Private Provision

Privatization of infrastructure may seem to some like a post-Reagan innovation but as the earlier history makes clear, debates over private vs. public infrastructure are centuries old. Private canals and turnpikes were a common feature of the 18th century; private transit systems were ubiquitous in the 19th.

The classic analysis of Hart, Shleifer and Vishny (1997) presents the case 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, Galetovic and Fischer (2014) turn this logic on its head for 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) provides evidence showing that private road providers in India do actually deliver smoother roads. The primary difference appears to be that private road providers share responsibility both for initial construction and later maintenance, and consequently, they don't cut corners at the initial construction phase which leads to better roads later on.

In the case of 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 them for their effort. In weak institutional environments, the combination of highly incentivized private companies and unincentivized public officials can lead to a steady disappearance of public funds. Engel, Galetovic and Fischer (2014) discuss the many problems of this nature created by PPPs in the developing world. While explicit bribery is less common in the U.S., private companies still have the capacity to influence the politicians and bureaucrats who determine the terms of their contracts.

This discussion implies several factors that would help determine 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 delivers incentives for maintenance. If quality is unobservable or management fees are not tied to usership then private providers have no quality-related incentive advantage, and as Hart, Shleifer and Vishny (1997) argue, private management may in that case lead to lower quality. Roads may be more natural candidates for privatization than prisons.

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 road construction, then this may make private ownership is a better option since it may be difficult to monitor the quality of initial construction.

A final 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 more appealing.

This discussion has focused on the decision of public vs. private provision, but two other distinctions are worth making. First, private provision can be done by non-profit 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 non-profits that managed roads in 18th century England. Unfortunately, many infrastructure projects today require outlays that are too large for most non-profits 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 19th century America, 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.

One key question is whether the independent authority will be led by someone whose future depends more on support by local politicians or on his or her 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 reputation, then the authority is more likely to deliver quality and cost improvements.

3.3 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, and has a particularly large role in air transportation.

Most of these divisions are natural outcomes of the size of the relevant network. 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 more interesting aspects of the US system occur when there is a hybrid system, as in the case of highways. The federally-funded highway trust fund provides resources that are directed at the local level. This provides the national government with some ability to place requirements on state governments, such as tying funding to raising the drinking age or lowering speed limits. Typically, though this federal funding does not seem to come with any attempt to actually manage the highway network.

The federal role in highway spending, instead, seems to reflect both historical precedent and federal willingness to borrow, especially during a recession. Indeed, if infrastructure spending plays a counter-cyclical role that spills over state boundaries, then federal funding may be appropriate. 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 stimulation associated with infrastructure spending is limited.

It is worth asking whether the current federal funding of highways is optimal, or whether more state and local financial responsibility would lead to more efficient outcomes. 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 to monitor and maintain their infrastructure, but they may also be more subject to capture by connected contractors than the state government. In that case, the optimal level of local control weighs the state's superiority at contracting with the local edge in directly that contracting efficiently.

3.4 Maintenance, New Construction and Operations

The previous discussion did not differentiate between initial construction and maintenance. Yet in many cases, 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 as discussed by Singh (2018).

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 has the highest level 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 born mainly by drivers outside of the community. Indeed, there are cases when a locality can even have incentives to let roads remain rough to deter cross-town 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. The 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 airports in the US; 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. Private airport ownership is more common outside of the U.S. and that model is worthy of more study. With private ownership some regulation may be needed to reduce monopoly rent extraction.

In many cases, the distinctions between new construction (capital costs) and ongoing operations (variable costs) that currently exist 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 it should focus on overall deficits, not merely operating deficits.

4. How Can U.S. Infrastructure Spending Become More Efficient?

There are three potential areas for improving the efficiency of infrastructure construction and use: procurement, project management and the level of mitigation. The concern that lurks behind this section is the sense that US infrastructure costs are high by international perspective. We do not know how to make U.S. infrastructure more cost effective, but we suspect that sustained economic research on the cost of infrastructure may yield policy-relevant conclusions.

4.1 Can procurement become more efficient?

In the U.S., 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 roles don't seem to deliver low costs.

Researchers have identified several ways existing first price auctions can fail to deliver low costs. Most obviously, bidders can collude and agree to only bid high prices or for some contractors to sit out. When bids involve specifying a cost for each service and a projected number of services, Bolotny 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 ignores the fact that a highly regulated auction may end up with only one bidder. A smart negotiator is likely to 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 if that would produce efficiency or corruption in the U.S. setting. Flexible procurement will only work if procuring entities have strong incentives to keep costs down; U.S. bureaucracy is not known for strong incentives.

The Makesovic and Bridge chapter considers the choice between strong incentive systems, such as fixed price contracts, and weak incentive systems. It points out that strong incentive systems generally come at a higher cost, which can be explained if contractors are highly 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 rules that deter entry are worth more analysis. One reliable message of both theory and empirical work on procurement auctions is that attracting more bidders is important for keeping costs low.

4.2 Can project management become more efficient?

The initial bidding phase of procurement typically features competition among contractors, but inevitably once work has begun, renegotiation becomes bilateral. Consequently, any renegotiation during a contract is a chance for prices to rise enormously. The perils of renegotiation provide one explanation for why so many mega-projects 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 Bolotny 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 mega-project, this renegotiation process is far more complex. When tunneling hits an unexpected barrier, then it 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 U.S. than elsewhere. Further research on this issue is needed. It could take the form of more qualitative comparisons of the U.S. with other countries in which renegotiation is less difficult, or of a detailed study of renegotiation across many U.S. 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 through renegotiation.

4.3 Is mitigation inefficiently increasing 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 by Massachusetts ex post, ex ante voters were told that the costs would be covered by federal funding.   Secretary of Transportation Fred Salvucci planned the project so that no house would have to be moved.   We cannot know how much could have been saved if a somewhat less sensitive planning procedure had been followed.

We do however know that other countries that pay less attention to community concerns have much lower infrastructure costs. China, of course, is an extreme example where infrastructure is built with a focus on low costs and speedy delivery, not compliance with local desires.   It would be good to better understand the sources of cost differences between China and the U.S. France, Japan and Spain, however, 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 is eight times higher than a recent subway project in Japan and 36 times more expensive than one in Madrid. Even Paris' Metro Line 7, a particularly tricky building project, came in at one-tenth of the cost of recent US projects.

Gordon and Schleicher suggest that the litigation that is 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 US' high construction costs, 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 indeed driving high costs. This research can take the form of comparing environments in which mitigation is more or less necessary. Alternatively, mitigation action can be directly estimated for particularly projects, with engineering cost estimates used to determine the impact. Second, we need 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 tools for compensating those neighbors that could cost less? The call to improve US infrastructure currently collides with the very high cost of building infrastructure in the U.S. If we could reduce costs while still sheltering impacted communities, then everyone would be better off.

5. A Roadmap of the Volume

The essays in this volume collectively survey much of the economic research on infrastructure. There are important omitted issues that have been actively studied, and there are additional issues that warrant future attention.

The volume begins with a paper by Bennett, Kornfeld, Sichel and Wasshausen which describes the measurement of infrastructure in the Bureau of Economic Analysis' National Income and Product Accounts. Two of the difficult measurement issues are the assumed depreciation rate and the infrastructure price indices. The empirical work used to establish infrastructure depreciation rates is now quite old and might benefit from updating. The paper provides basic facts about the levels of infrastructure and its changes over time, including an experimental new data series on highway investment at the state level.

One finding is that real net investment per capita has "drifted downward since the financial crisis and stands at its lowest level since the series hit bottom in 1983." The only significant infrastructure growth since the 1990s has been digital infrastructure. The stock of basic infrastructure has grown by only 0.6 percent per year over the past twenty years. Whether these facts suggest that the US is investing too little in in infrastructure depends on both the valuation of new projects and their cost.

State level variation in highway infrastructure investment per capita is particularly illuminating. Throughout the 1992 to 2017 period, states such as the Dakotas and Wyoming have led the nation in per capita highway investment. Between 1992 and 2017, the level of investment in northeastern states, such as Pennsylvania and New York, has risen 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 Duranton, Nagpal and Turner presents a different picture of the level of US infrastructure investment It focuses on outputs from infrastructure capital rather than on investment spending. It 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 from the 1980s to the early 2000s, but average subway car age has remained constant since that point.

This paper also shows that highway construction costs are rising, which also suggests that lower levels of construction may be optimal. This paper doesn't contradict the fact that investment levels have declined, but rather suggests that this decline represents diminishing returns to building new traditional transportation infrastructure. To us, these facts suggest that infrastructure investment decisions need to be grounded in data on performance and quantified risks rather than opaque letter grades.

The paper also includes an interesting theoretical contribution on how to assess the optimal level of infrastructure investment across mode. The logic of the model is that total public and private spending costs to move a mile over space should be equalized across modes. They apply this framework to highways, buses and subways and find that we are getting far less transportation services for our spending on subways and buses than for our spending on highways.

The chapter by Brooks and Liscow follows and focuses directly on the increasing cost of building highways in the U.S. In this contribution and in their related work, Brooks and Liscow (2019), the authors find that the 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. Their research suggests that the cost of providing mitigation against environmental or other local externalities may be an important factor in rising costs. The rise in prices 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 are presumably meant to avoid disturbing existing residents.

There are large differences across states in construction costs. Connecticut and New Jersey spend much more 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 particularly low construction cost areas.

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 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 her 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 one.

This paper then 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. Ramey's analysis casts doubt on the use of infrastructure spending as a counter-cyclical policy tool.

The next paper is Greenstein's analysis of digital infrastructure, which is the category of infrastructure investment that has grown most significantly over the last 25 years. This paper divides its discussion into three parts. The first addresses the expansion of digital access for both consumers and businesses. The adoption of broadband appears to follow an S-shaped curve where 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 the initially-reluctant adopters. This chapter reviews the significant literature that attempts to measure 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 (CDN) 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, rail and highway. The mass production of cotton in the 19th 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 non-profit entities. There are important 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 Wikipedia.

The next paper, by Makovšek and Bridge, confronts the central issue of infrastructure procurement. It adopts a global perspective, and notes that procurement contracts can differ in their structure. Some contracts bundle the design and build phase together, while others proceed linearly going from design to bid to build. Contracts also differ in whether they have high powered incentives, such as fixed price, or more flexible cost-plus structures. Prior research is not clear about whether bundling designing and building together is optimal, but the paper suggests that fixed price contracts generally lead to higher costs. One explanation for this is that risk averse builders require high payments to bear the risk of unknown cost shocks.

The paper presents a typology of procurement contracts which is interpreted through the theoretical lens developed by Laffont and Tirole (1993) and others. The essay ends by summarizing the empirical work on the efficiency of different procurement contracts, and with a case study that illustrates many of the points about procurement that are developed in the study.

The penultimate chapter, 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 only reflects 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, any potential gains from PPPs must arise from better incentives. While public management may not be interested in revenues from tolls, for a PPP those tolls determine profits and losses. Consequently, the PPP has strong incentives to maintain roads or other infrastructure that generates future revenues. It 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 sector. The downsides of PPPs can be particularly large when the public sector can be easily corrupted by large private infrastructure companies.

The volume concludes with Lucas and Montesinos' essay on risk and the fair value of infrastructure investments. This paper questions 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 future benefits and aggregate consumption or "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 overinvestment in infrastructure.

A novel aspect of this study is the proposed approach to analyzing the minimum revenue that is often guaranteed to PPPs. These guarantees are essentially 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, they may have other costs that also need to be considered. This chapter includes an application of these finance-theoretic tools to a hypothetical toll road.

Taken together, the essays in this volume highlight many important economic insights about infrastructure, but they also show that there is still much to be learned.   We need to know more about improving procurement, and to better understand why U.S. infrastructure costs are so high. We hope that future research will address these topics, and the infrastructure will receive the full measure of attention from the economics profession that is merited by its enormous importance.

References

Allen, Treb and Costas Arkolakis. 2019. "The Welfare Effects of Transportation Infrastructure Improvements." NBER working paper 25487, Cambridge, MA.

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, Virginia: ASCE. https://www.infrastructurereportcard.org/

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.

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

Aschauer, David. 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. 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): 1288-1319.

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): 241-263.

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: 180-194.

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.

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): 163-197.

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): 451-464.

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: 108-131.

Glaeser, Edward. 2004. "Public Ownership in the American City." In A. E. Schwartz, ed., *Urban Issues and Public Finance: Essays in Honor of Dick Netzer*. Northampton, MA: Edward Elgar Publishing.

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): 401-425.

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): 1176-1196.

Hart, Oliver, and John Moore. 1988. "Incomplete contracts and renegotiation." *Econometrica* 56 (4): 755-785.

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): 1127-1161.

Kain, John. 1990. "Deception in Dallas: Strategic Misrepresentation in Rail Transit Promotion and Evaluation." *Journal of the American Planning Association* 56 (2) : 184-196.

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

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

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

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

Tiebout, Charles M. 1956. "A pure theory of local expenditures." *Journal of Political Economy* 64 (5): 416-424.

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

U.S. Congressional Budget Office. 2018. *Public Spending on Transportation and Water Infrastructure, 1956 to 2017*. Washington: 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 Number 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.

Winston, Clifford. 2020. Autonomous Vehicles: The Road to Economic Growth? Washington, DC: Brookings.

World Economic Forum. 2019. *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): 305-316.