INTRODUCTION:

Infrastructure Meets Business: Building New Bridges, Mending Old Ones

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The need for new physical infrastructure has grown dramatically around the world in the last decades. In a recent report from the Organization for Economic Cooperation and Development, the spending required to update infrastructure in developed countries and to develop appropriate infrastructure in emerging economies is estimated at a staggering $53 trillion between 2007 and 2030; OECD also exhorts developed nations to invest at least 2.5% of their GDP in infrastructure.[1] These needs have triggered a galloping involvement of private-sector capital in infrastructure renewal, development, and operations. Just from 2000 to 2006, infrastructure transactions rose from $52 billion to about $145 billion, and demand for new deals rose faster than supply.[2] The massive pressure for new infrastructure stems from a conflation of interrelated factors: population increase, migration flows towards cities, deterioration and obsolescence of existing assets, and the globalization of supply chains.

Large-scale infrastructure includes transportation assets (e.g., airports, roads, railways, and ports), utility networks (e.g., gas, water, and electricity), resource extraction facilities (e.g., mines, offshore platforms, and pipelines), and social assets (e.g., hospitals, prisons, and schools).[3] These assets are key components of the large socio-technical systems (e.g., railway and air travel; energy and water supply; and healthcare and education) that support a wide range of production activities.[4] These systems also support the delivery of services that are central to the continuance and growth of every community and state. Ensuring that everyone has access to these services at affordable costs is necessary to protect equity and public welfare. Sporadically, deadly events such as the collapse of Bridge 9340 over the Mississippi River in Minnesota, Hurricane Katrina striking the city of New Orleans in Louisiana, or the recent attacks on the Chhatrapati Shivaji Terminus railway station and the Cama and Albless Hospital in Mumbai offer stark reminders of the dangers of damaged or failing infrastructure, and of the essential role that infrastructure plays in keeping people and businesses safe and protected against the forces of nature or terrorism.

In the last decades, public infrastructure has undoubtedly become attractive for businesses and investors. Admittedly, their total investment—almost $1 trillion of assets have been sold around the world since the 1980s[5]—represents a tiny fraction of the projected needs. Still, the involvement of the private-sector capital in public infrastructure remains delicate to orchestrate from the political, social, and economic perspectives. The example of the expired bid for the Pennsylvania Turnpike is telling. A private consortium (Abertis Infraestructuras, Citi Infrastructure Investors, and Criteria Caixa) submitted a $12.8 billion winning bid to run the 68-year-old, 537-mile Pennsylvania Turnpike, beating a rival $12.1 billion offer from another private consortium (Goldman Sachs and Australia's Transurban Group, a toll road operator). Opponents of the privatization argued that with the new tolls, the public Turnpike Commission could raise more in future revenues than a privatization deal. Late in 2008, the winning consortium pulled its bid off the table after the Pennsylvanian legislators failed to ratify the proposed toll-road lease. Had the deal gone through, the Pennsylvania Turnpike would have become the world's largest privatized toll road.[6]

This transformation of infrastructure renewal, development, and operations into a business gained popularity in the modern age after the UK initiated a sweeping program to privatize its utilities, airports, ports, and railways in 1979. Many countries followed suit. Two key forces triggered the trend. On the one hand, there is the neo-liberal ideology that the private enterprise—motivated by profit seeking—is inherently more efficient, cost-conscious, and customer-focused and can deliver more quickly than public bureaucracies can. On the other hand, there is the pragmatic necessity to supplement constrained state budgets burdened with growing expenditures on health care and the retired population. Simply put, privatization and private finance have enabled governments to get things done without having to raise taxes or issue bonds. As a result, the activities to design, develop, operate, and manage infrastructure have become a large segment of private sector business, including both suppliers of engineering, manufacturing, and construction services as well as investors, developers, and owners of the assets.

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Given these developments, this special issue of the *California Management Review* aims to build new bridges—as well as mend old ones—between infrastructure and the business and management communities. Surely the renewal, development, and operations of infrastructure demand an understanding of the application of management thinking—particularly so as governments worldwide recourse to privatization and private finance. Surprisingly, however, infrastructure has still received limited attention from management studies even if research on the interplay among the regulation, politics, and economics of infrastructure has a long empirical and analytical tradition.[7] As an empirical research setting, the infrastructure sector exhibits a number of peculiarities: it deals with durable and immobile assets; it sources from the highly fragmented engineering and construction supply chains; it entails heavy public sector involvement; and it repeatedly makes capital investments with long gestation and payback periods, which are vulnerable to changes in policy, technology, and customer requirements. These peculiarities suggest that studies grounded in infrastructure settings offer a rich field for scholarly inquiry and new managerial insights, as well as for testing the validity of extant theories and conceptual framing in different settings and under different conditions. These studies can also shed light on best practices suitable to manage the infrastructure sector. Knowledge of best practices for the infrastructure sector, we conjecture, is likely to apply to other production activities, particularly those that involve complex institutional contexts.

This special issue couldn't be timelier. The infrastructure sector has very recently gained policymaker attention and moved under the media spotlight worldwide with the global economic downturn, and in the U.S. in particular. However, in the face of so many competing needs, the public funds announced for infrastructure represent a tiny fraction of the investment required. Ideological issues aside, bridging this infrastructure gap seems inexorably to call for involving private-sector capital until other alternatives emerge. We next summarize and illustrate the investment that is actually required. We also discuss the challenges in obtaining and managing the investment required, and then turn to the content of this special issue.[8]

The Investment Required

In the U.S. alone, the American Society of Civil Engineers (ASCE) values the cost of restoring the U.S. infrastructure to good condition at $1.6 trillion in the next five years. For California, which ranks amongst the ten largest economies in the world, ASCE's 2005 California Infrastructure Report Card identifies 71% of major roads as being in poor or mediocre condition, 28% of bridges as structurally deficient or functionally obsolete, 44 dams as deficient, and a loss of 222 million gallons of drinking water per day due to leaky pipes. The magnitude of these problems vis-à-vis the scarcity of capital investments in U.S. infrastructure in the last decades led Martin Wachs, RAND policy expert for transportation, to note that "a crisis in transportation finance has quietly emerged…it is now clear that during the coming decade policymakers at all levels of government will be forced to rethink the fundamentals of American transportation finance."[9]

European figures are equally mind-boggling. A Van Miert Group report estimates that the investment required to realize the trans-European transport network (approved by the European Council and the Parliament in 2004) comes to more than €600 billion between now and 2020 for the totality of the projects of common interest, of which €235 billion (circa 1.6% of the European Union's

GDP) is required for the priority projects. The private sector is expected to contribute up to 20% of the total cost of the transport network.[10] In the UK alone, the government spent an estimated $46 billion on infrastructure in 2006. It has also signed over 900 Private Finance Initiative (PFI) projects with a capital value of $79 billion, and it is committed to just under $335 billion in operational payments on those contracts over their 20- to 30-year lives.[11]

Globally, significant investments in water and sewer systems are also urgently needed. UNESCO estimates that 1.1 billion people worldwide lack access to improved water supply and 2.4 billion to improved sanitation, and that 2 billion people will be water scarce by 2050.[12] The World Water Council reckons that developing and transitional countries alone will require $80 billion annually to produce water security in the next 25 years.[13] The African Development Bank (which membership includes 53 African countries) declared that "public resources are not enough, and they'll never be enough" for Africa, where 72 percent of urban residents live in slums.[14] In the U.S., the Environmental Protection Agency projects that sewers in need of urgent repair will increase to 45% by 2020, while the Clean Water Act plans for expenditures of about $11 billion a year for record levels of trenchless construction.[15] Surprisingly, even in Switzerland where the municipalities are largely responsible for sewer systems, 23 percent of the systems are in poor or critical condition.[16]

Regrettably, the underlying story is similar for energy. The International Energy Agency, in its 2006 World Energy Outlook report, expects global electricity consumption to double by 2030. It also estimates that $20.7 trillion would be required today if all governments simultaneously decided to enact over 1,400 policies to secure energy supplies due to decades of underinvestment in energy infrastructure: 56% of that investment would go to electricity transmission, distribution and generation; 40% to oil and gas exploration and refining; 3% to mining and shipping coal; and 1% to biofuels.[17] A conflation of factors—including the growth in energy demand, shrinking reserves in accessible oil and gas, and government interest in meeting the emission targets set out in the Kyoto protocol—has also spurred (controversial) resurgence in interest in nuclear energy. According to the World Nuclear Association, 25 nuclear power stations were under construction in 2005, and 112 more were being planned or proposed. The market for cleaning up and decommissioning obsolete nuclear assets is also growing. In the UK alone, there is an estimated $89 billion of decommissioning work to be done over the next 100 years, according to the UK Atomic Energy Authority.

High demand for infrastructure also affects the BRIC economies and developing countries in general. Here, the lack of adequate infrastructure makes it impossible to guarantee the provision of even the most basic public services to everyone. The UN predicts in its State of the World's Cities report that urban growth "will become virtually synonymous with slum formation in some regions."[18] Tragically, the obsolete infrastructure of these countries causes transportation difficulties, limiting the cargo flows that globalization could potentially generate, and thus further holding back the prosperity of these populations.[19]

In short, there is massive global demand for investment in both infrastructure renewal and new infrastructure development.

The Challenges in Obtaining and Managing the Investment Required

Infrastructure privatization involves the divestment of government-owned enterprises, transferring the ownership rights of the assets from the public to the private sector. The other public procurement schemes that involve the private sector in infrastructure include: private financing for developing and/or operating assets for a limited period (known in some countries as Concessions or Private Finance Initiatives (PFIs)); and outsourcing or contracting out the provision of conventional public tasks.[20] These two schemes involve long- and short-term management contracts through which the government awards to the private enterprise the responsibility for providing services for a limited period at an agreed level of performance. The public retains ownership of the assets, while the enterprise is paid for making capital investments and operating the assets, either through user-charges or government payments.

Privatization and private finance schemes raise concerns, manifestly, that commercial acumen will prevail over public interest in the decision-making process for capital investment and asset management. The capital-intensive nature of infrastructure married to the longevity and immobility of the assets means that privatization often generates non-competitive markets or natural monopolies.[21] Natural monopolies can benefit from strong economies of scale and networks and can be difficult to contest, i.e., the incumbent has significant market power as it does not perceive the new entrants as a threat due to the high risks involved.[22] In these circumstances, governments may opt to regulate or draft long-term management contracts to ensure that the private enterprise does not opportunistically stop investing or raise fees or tariffs. The private enterprise, in turn, will require safeguards so as to guarantee that deals stay robust to changes in government regulation in the future, and that the long-term contracts allocate the risks fairly between the parties. Recent collapses of privatized enterprises—such as of the British private owner of rail infrastructure, Railtrack, in 2001, and of the London Underground concessionaire, Metronet, in 2006—demonstrate that both running an infrastructure enterprise and writing fair, long-term contracts are challenging undertakings.

More recently, infrastructure investment has become highly attractive to investment firms, pension funds, and family offices.[23] Other major investors include import-export banks of the BRIC economies and the Government of China.[24] Infrastructure assets allegedly provide secure, steady inflation-proof income and market-beating returns due to their monopoly-like position. They can also be a useful source of diversification with their low correlation to equity markets and the economy more generally. In 2006, there were over 70 infrastructure funds aiming to raise more than $122 billion, focused primarily on U.S. and European brownfield infrastructure, with 8 to 15 planned investments and average deal size of around $150-300 million in equity contribution.[25] In the U.S., for example, four investment firms bought a group of 60 Texan power plants for $900 million in 2004; by 2005, only 63% of the electricity generating capacity in the U.S. was owned by utilities.[26] In 2008, a private consortium (composed of Citi Infrastructure Investors, Vancouver Airport Services, and John Hancock Life Insurance Co.) won a $2.5 billion, 99-year lease contract to operate and develop Chicago's Midway Airport, the first privatized major airport in the United States. Elsewhere, the British Airports Authority (BAA), owner of the three major London airports, left the market after being taken over for $20 billion by a private consortium (Spanish Grupo Ferrovial, Quebec Teachers Pension Fund, and GIC)[27] in 2006;[28] and Spain's Abertis Infraestructuras bought Autostrade, the Italian toll roads group, for $28 billion in 2006. Some analysts observe that returns generated by the acquisition of infrastructure may have peaked, and that they are not always pure asset returns; instead, they often emanate from re-leveraging the finances in a debt market.[29] Still, with prospective average returns of 10 per cent (and often as high as 12 percent), infrastructure appears to have become an asset class in its own right.[30]

With this background on the need for infrastructure investment, on the difficulties in obtaining and managing private investments in infrastructure, and on the need for more attention to infrastructure development and operations in the management literature, we turn to the content of this special issue. We introduce five perspectives that the papers in this issue have adopted, and occasionally combined, to derive managerial insights from the infrastructure context: policy and strategy, investment planning, design and innovation, project management, and sustainability. These five perspectives complement one another in the ways they look at new infrastructure development. They illustrate the significance of the issues and opportunities, and highlight some valuable insights derived from studies grounded in infrastructure.

Five Perspectives on New Infrastructure Development

Infrastructure Privatization and Private Finance: Policy and Strategy

Of all streams of research looking into private sector involvement in infrastructure, regulatory economics and political science are arguably the most mature. A range of studies has analyzed the problems of setting out the basic options, the trade-offs, and the implementation issues. Infrastructure privatization has been particularly intense in Europe because a significant proportion of the production capacity was in the hands of the governments. Soon after the UK started privatizing, the trend swiftly spread into other European countries and Latin America. In the U.S., the ideological roots of privatization can be traced back to the works of J. Bennett and M. Johnson (*Better Government at Half the Price*) and E. Savas (*Privatizing the Public Sector*). By the end of the eighties, the U.S. government had sold the freight railroad system, and had started increasingly to use private firms to perform tasks previously left to civil servants.

Ideological issues aside, seminal studies conclude that the pragmatic issues associated with making privatization and private finance schemes work and fulfill their intent (in the sense that efficiencies are gained but not at the expense of the public interest) are complex.[31] These schemes may not lead to efficiency if a contestable monopoly or a competitive market cannot be ensured. Implementing these schemes can also be problematic when long-term management contracts are vague and non-enforceable because performance cannot be easily specified and measured. The more uncertainty there is about value, and the more debatable the requirements are, the more opportunities exist for interested parties to manipulate perceptions of need. In conclusion, this literature advises governments against framing privatization and private finance as a panacea for public sector problems, while acknowledging the opportunities they can create to improve efficiency and the quality of services.

The case of the privatization of piped water distribution illustrates the issues.[32] Building a network of underground pipes requires a massive capital investment. It is also a challenging market for new entrants because of the economies of scale associated with water distribution, the durability (50 years or more) and immobility of the assets, and the lack of substitutes (new rights of way are hard to get). Taken together, these factors make it difficult to enter and exit the market rapidly without making significant losses. To limit the market power of the incumbent, governments have to regulate, insist on cross-subsidies, and exercise the power of eminent domain to create new rights of way.

Empirical studies of a number of transport privatization and private finance schemes shed light on other issues.[33] First, the savings to society that stem from these schemes are not automatic but rather a function of the ways in which the private firm realizes efficiency and cost savings. They can often be accompanied with increases in user fees as the private sector needs to pay taxes and higher interest on capital. Thus, while citizens as taxpayers can benefit from privatization and private finance, as users they can often be worse off unless service quality goes up or efficiency savings generate a net reduction in user fees. Long-term management contracts under uncertainty are also costly and difficult to write. Thus, privatization and private finance work when competition can be ensured and no government subsidies are needed to make the schemes viable. However, these schemes can be difficult to implement effectively when they involve large redistributions of benefits, losses of subsidized services and massive lay offs, or when regulation is needed to control market power.

Other empirical studies corroborate the notion that privatization and private finance of infrastructure do not automatically bring efficiencies.[34] Efficiency can potentially occur, but the terms of the privatization or private finance must encourage it. This finding emanates, for example, from studies on the UK experience with PFIs involving highways, prisons, the London underground, and schools.[35] Likewise, studies about unbundling (or vertically disintegrating utilities so as to open parts of the sector to the market) reveal instances where the transmission tariffs were reduced, but the number of blackouts increased. Studies on the private development of urban rail transit systems paint an even more complex picture. They show that these schemes can rarely be run profitably without subsidies due to the high operating costs and relatively lower ridership. Somewhat ironically, except for highway-related interests, these schemes appeal to most interest groups across the political spectrum (e.g., downtown and construction-related businesses, labor unions, environmentalists, and preservationists) who perceive rail transit as a way of reconciling development, equity, and amenity goals.[36]

Another insight from this literature elucidates the unstable nature of privatization and private finance schemes. Contract adjustments and renegotiations are often required as the world changes and technology advances, or when pioneering experiments (such as the unbundling of infrastructure and operations, privatizing one or both) fail to work.[37] This point is illustrated by the recommendation of the Competition Commission in 2008 to break up the monopoly on the London airports conceded to BAA—a controversial decision taken in the eighties.[38] Likewise, U.S. railroads started operation under a regime of private contracts, later moved to a concession system, then to discretionary regulation, and more recently moved back to private contracts again. Many foreign investments have also collapsed under the weight of successive economic crises and high-profile disputes between host governments and investors. This pattern, referred to as the "obsolescence bargain," stresses the need to provide institutional protections for investors, which can deter host government opportunism and help the investors cope with change.[39]

In conclusion, assuming that some form of private sector involvement in infrastructure is desirable, market-oriented schemes with private contracts are likely to work better than concessions as the incentives for improved cost efficiency and performance are higher. Concessions, in turn, are likely to work better than discretionary regulation.[40] Regulation aims to protect the public from the detrimental consequences of inadequacies in competition, but it is hard to regulate well. Regulatory agencies are vulnerable to the powerful, wealthy, information-rich, and technically sophisticated private firms, which more often than not capture the regulators over time.[41]

Two papers in this special issue offer relevant contributions in this area of policy and strategy. Young Kwak et al.'s article builds upon a comprehensive literature review to provide a set of recommendations to the public sector and private enterprise interested in forming public-private partnerships for new infrastructure development. Their article contrasts with Damian Dominguez et al.'s article in which the authors argue that public utilities that adopt strategic planning methods can close the capability gap, thereby offering a viable alternative to private sector involvement.

Planning a New Infrastructure Development

Moving an investment plan for a new infrastructure development forward is hard work for the private promoter. Yet, the process is well understood from an urban planning perspective. In essence, a new planning application can only be approved after a business-governmental coalition overcomes a broad range of environmental, ethnic, minority, preservationist, neighborhood, and other interests—a pattern termed negative pluralism.[42]

The private development of new highways illustrates the problem. Private finance of new highways typically requires governmental aid, whether to keep the tolls at acceptable social levels, to assemble enough rights of way, or to expropriate through the power of eminent domain. Setting tolls, for example, is not easy. It can be politically unacceptable and face strong opposition by some stakeholders. When California went through a public discussion about toll roads in the nineties, some groups accepted them in the face of budget constraints and congestion; others rejected the idea on the grounds it was inequitable. The latter argued it would privilege the well-to-do capable of paying for high-quality toll roads, while the less-well-off would have to use inferior free roads. Those opposed further argued that high-occupancy vehicle lanes remain free, a point that raised controversy. They also argued that more highways would negatively impact the environment and the welfare of the local residents.[43]

To overcome these hurdles—or points of potential veto[44]—the private promoter needs to disperse the potential benefits of a new development project across multiple parties so as to diffuse opposition and broaden support. This coalition-building process is very complicated. As the promoter assigns benefits to one party, others oppose if they feel they are being left behind. To move forward, the promoter needs to invest in even more complicated, time-consuming, and costly negotiations aimed at structuring partnerships and building public and private sector support. Measures aimed at mitigating the concerns of the different stakeholders are likely to increase construction costs. They will also increase the cost of capital as lenders' perceptions of risk go up. At the limit, the development costs can escalate to the point where they cannot be offset by the potential revenue stream, and the private promoter has no alternative but to abandon the investment plan.[45]

In-depth empirical studies suggest that too much or too little profitability can increase public opposition to investment plans. Too much can become a political liability inducing stalemate between conflicting interests; too little can dissuade the private sector from investing. Empirical findings also suggest that the planning process tends to become particularly difficult to manage at the economic development extremes. At the low end, demand is not there to make a new project financially viable. At the high end, there are a high number of stakeholders likely to oppose the project and the construction costs are high. The "do no harm" paradigm suggests that to succeed, the project promoter must demonstrate that the impacts to neighborhoods and natural environment will be minimal, or can be mitigated if they are unavoidable.[46] To be effective, promoters of new infrastructure development must be capable of neutralizing those opposing their plans, as well as to forge consensus from a base of intense controversy. This process demands that they draw as much on politically adept leadership and management, as well as on innovation and creativity skills.

In the face of the increasingly time-consuming and complex planning application processes, some governments have started to wonder whether the pendulum has swung too far towards public scrutiny. Specifically for the case of infrastructure projects that satisfy urgent regional needs, governments are asking whether it is time for the pendulum to swing back. The development of the new Terminal 5 (T5) at Heathrow airport, for instance, took almost 20 years between initiating the planning application and the opening of the first phase of the new terminal in 2008. Likewise, the estimated £15.9bn Crossrail project for building new east-west railway connections under London—a development whose first public discussions date back from 1974—is expected to be completed in 2017 after the plan was finally approved and received funding in 2008. Analogous delays have affected the Central Artery/Tunnel project in Boston and the high-speed rail for California. Interestingly, the concern with the difficulties in overcoming negative pluralism is not new. Mancur Olson (1982) argued that interest groups can eventually grow in number until they cause their host society to slip into economic demise; earlier, Arrow (1950) showed it is difficult if not impossible to reach global optima when three or more groups are involved in multiparty negotiation.[47]

This exact debate is now taking place in the UK, where a new Planning Bill was given Royal Assent in November 2008. The new Planning Act will streamline consent procedures by rationalizing eight regimes for nationally significant infrastructure into a single consent regime. Further, Ministers will set out National Policy Statements detailing national infrastructure priorities in areas such as energy, aviation, road and rail transport, and water and waste. The decision as to whether a project ought to go ahead will be taken independently by a new Infrastructure Planning Commission, operating within the framework set by ministers. The aim is to fast-track infrastructure schemes of national importance, expecting the time taken from application to decision to fall to under a year in the majority of cases.[48]

Recent literature suggests that an options framework can be useful to strategically steer capital investments through the uncertainties of the new infrastructure development process.[49] An option is "the right but not the obligation" to choose a course of action (such as expanding, acquiring, deferring, or abandoning) and obtain an associated payoff.[50] The real options approach extends financial options theory to "real" assets by incorporating the effects of private risk and externalities into the valuation of capital investments. The flexibility inherent in this way of framing capital investments can, arguably, help decision makers cope with the vicissitudes of the "do no harm" paradigm, as well as with the need to accommodate external change throughout the years it takes to deliver a new asset, and after during the asset's use life. Smit and Trigeorgis' article in this special issue reveals the state-of-the-art thinking on the application of option games—a methodology for valuing investments that integrates real options valuation and game theory principles—to new infrastructure development.

However, even assuming the planning application process for new critical infrastructure is streamlined in the future in democratic regimes, it takes time before it happens. The current systems, involving full and open debate to move a project forward, are imperfect. Still, some scholars argue that they should not be abandoned as they are needed to reject projects with weak public interest justification and to enhance the merits of strong projects.[51] This calls for integrating flexibility in capital investment with innovation in the design and development of new infrastructure.

Innovation and Design in New Infrastructure Development

Few management studies have yet explored how the delicate balance between profit seeking and public interests plays out in the actual execution of infrastructure design and innovation. Unlike most commercial products, infrastructure should be built to last many decades. Bridges and most airport facilities are expected to operate 40-50 years or more; parts of the water distribution and sewerage systems may be designed to last 100 years. During the service life of these assets, the external environment will change: new technologies will emerge, the needs of customers and end-users will evolve, demand might grow or ebb, and the government will write new legislation and regulation. The core building systems of T5 at Heathrow, for instance, are expected to operate for at least 40 years. However, between the conceptualization of T5 in the mid-nineties and its opening in 2008, the airline and airport activities changed dramatically in Europe with the surge of low-cost carriers, self-service and on-line check-in, stringent security procedures, and the introduction of jumbo aircrafts. Many more external changes will presumably occur in the service life of T5. Designing affordable infrastructure that can cope efficiently with external change over time is at the crux of new infrastructure development.

Noteworthy, the notions of developing new infrastructure to throw away (viz., developing assets that would become obsolete prematurely in the face of evolution in the outside world) are unlikely to offer viable alternatives. New infrastructure developments invariably have detrimental impacts on some elements of the natural environment and to the welfare of some local communities. As a result, these developments involve lengthy processes for gaining planning and licensing permission. Infrastructure promoters and societies simply cannot afford the costs that would stem from developing assets with short operating lives unless these costs could be significantly reduced in some, presently unforeseeable, way. So, infrastructure must instead be designed with the flexibility to accommodate change in requirements throughout both its construction and its use life.

When capital was readily available, an approach to ensure that infrastructure could flex to external changes over time consisted of designing in up-front provisions or allowances for foreseeable needs in the future. The Victorian brick-built sewer network in London, for example, comprised 264 km of mains and 1769 km of local sewers, and it still remains largely operational today because it had enough spare capacity up front.[52] One of the largest suspension bridges of the world is in Lisbon, Portugal, and was engineered and built in the sixties with a structural allowance that left two options open for the future: first, add two more lanes to increase capacity from four to six lanes for car traffic; and second, add two railway tracks. Both options were exercised almost thirty years after the bridge opened to the public in 1964 when demand finally materialized. However, when scarcity of capital resources and profit-seeking interests drive design decision making, designers are asked to judiciously balance up-front provisions for the future with affordability in the present. Infrastructure promoters are wary of making investments in provisions that will not pay off because the foreseeable scenarios about the future that need to be made at the project onset may be wrong. This means that designers need to find new ways to design "evolvable" infrastructure in a resource-constrained environment, i.e., design new infrastructure that can economically adapt to change while limiting the capital investment. The British National Health Service (NHS) pioneered the request for "future-proof" designs when it commissioned new hospitals through PFI schemes. Embedding this notion in the contracts themselves, however, was vehemently contested by designers who felt they could not be made liable for "future proofing."[53]

Applying options thinking to infrastructure design can perhaps enable to operationalize design for evolvability.[54] Unlike the advances made using real options for valuing infrastructure investments and managing risk, research on applying options thinking to infrastructure design is still in its infancy. A recent study of airport design practices suggests that designers may occasionally apply options thinking in an intuitive fashion as they search for modular design solutions. These designs exhibit built-in options that make them inherently flexible to accommodate change.[55] Modularity requires physically decoupling functional modules, agreeing the interface rules, and establishing tests for validating whether the interfaces work.[56] Modular principles, for example, underpin the development of trenchless technologies to lay down pipes inside conduits already buried in the ground. These technologies have allowed modern urban societies to avoid the disruption of major open-cut construction.[57] The same principles help make sense of the award-winning design of the new Upton-upon-Severn viaduct in the UK. Floodwaters typically inundate the Severn floodplain and rise above the road once every five years. Urgency to replace the deteriorated 1939 viaduct did not leave enough time for a wholesale elevation of the roadway. The 170-meter deck was designed for inundation conditions, as well as to be jacked up in the future.[58] The same principles also inform recent efforts to engineer adaptive structures that can move in response to outside forces, such as bridges whose load-bearing capability might literally follow a large truck driving across. Interestingly, these approaches appear to echo how manufacturers of commercial products have long searched for new architectures that can evolve, or allow for "generational variety," i.e., architectures that minimize the design effort for future products and make selected structures common across generations.[59]

Design innovation can also be a source of ideas to resolve problems related to non-contestable natural monopolies and thereby eliminate the need for regulation. In the electricity generation industry, technological innovations have enabled the development of small power generation stations. The capital intensity and lead times involved in the provision of services has since then dropped substantially with modularization. This in turn has allowed restructuring of the sector and narrowing the focus of regulation to the areas where competition is not feasible.

James Barlow and Martina Köberle-Gaiser's empirical study in this special issue suggests that PFI schemes in their current form, somewhat disappointingly, have limited success in encouraging private investors to put forward innovative infrastructure designs. Building upon multiple cases of new hospitals commissioned by the British National Heath Service, the study reveals that the terms of the procurement process and of the long-term management contracts have discouraged promoters from innovating and taking risks in design. On a more positive note, the article from Andrew Davies, David Gann, and Tony Douglas in this special issue investigates whether the notion of systems integrators—organizations responsible for establishing a project governance structure, collating customer requirements, managing risks, and coordinating the supply chain—can be appropriated by both infrastructure promoters and constructors to successfully create product and process innovations in megaprojects.[60]

However, even when designers generate ideas for built-in options, they incur the risk of these being scoped out in value engineering exercises later on if the project budget becomes tight.[61] Plausibly, the same can happen to other innovations advocated by designers. Surely, budget concerns are fair since so many megaprojects overshoot their estimates.

Managing Mega Infrastructure Projects

Large-scale infrastructure developments are delivered though megaprojects. They involve putting together a "coalition of organizations" for designing and constructing the massive structures, plus manufacturing and installing engineered-to-order equipment and other high-tech components.[62] These projects invariably require some public involvement to secure the right of way. They are also expensive, and budgets continue to go up due to inflation in construction costs, stringent health and safety procedures, and mitigation measures.[63]

Megaprojects are also highly likely to suffer significant overruns relative to their original budget and schedule. A RAND Corporation study of 52 major public and private civilian projects found an average cost overrun of 88%, with only half performing as expected, and many leading to disputes between developers and contractors. Similarly, a global investigation of 258 large road and rail projects revealed that costs were underestimated in 90 percent of the cases, routinely by 40+ percent and often by much more.[64] The list of megaprojects exhibiting overruns is notorious: the estimated price tag for Boston's artery/tunnel project nearly tripled in real terms from 1987, when Congress approved funding for it, to 2002; the Channel Fixed Link, Hong Kong airport, Scandinavian Great Belt road/rail bridge/tunnel, and Royal Dutch Shell's Sakhalin 2 gas project off Russia's Pacific Coast also incurred significant cost overruns.

Of course, the large number of stakeholders, often with conflicting interests, makes megaprojects complicated to coordinate and manage.[65] However, other factors also contribute to the challenge. The scope of new projects has become more and more ambitious from the technological and engineering perspectives. Think, for example, of the Central Artery/Tunnel project that rerouted the chief highway through the heart of Boston into a 3.5 mile (5.6 km) tunnel under the city—a project (which also included bridges and sophisticated embedded IT) estimated to have cost over $16 billion adjusted for 2006 prices; or the recently approved Crossrail project, which will include a railway tunnel about 13.75 miles (22 km) long across central London. Managerial challenges also stem from changes in design requirements to accommodate externalities and from tight delivery timescales to suit political and financial commitments. In addition, many infrastructure projects have to cope with hostile local stakeholders, geographic remoteness, and extreme climates.

Research on managing megaprojects is vast even if the theoretical base was scant until a few years ago.[66] Early literature is quite prescriptive. It builds on Knight's (1921) work to define risks as future occurrences that can be modeled into probability distributions, whereas uncertainty exists where knowledge is insufficient to do so.[67] Accordingly, this literature recommends investments in front-end strategizing to reduce uncertainty, including risk management, scope and task definition, and contingency planning.[68] This literature also advises against the perils of overlapping design and construction as rework can be too costly and irremediably delay delivery after cascades of interdependent moves are made to move the project forward. Other studies encourage project managers to: formulate lists of "critical success factors" for guiding decision-making; and use scenario planning for assessing the likelihood of foreseeable events and developing contingent actions to counter impacts.[69] Critical to this work is contingency planning for the variety of uncertainties that may beset the project.

Subsequent developments in research have asked why traditional project management methods—such as activity-based networks, PERT/CPM, contingency planning, and risk and opportunity registers—seem inadequate to manage megaprojects and their stakeholders. Recent contributions assume that design-construction overlaps and design changes are inevitable when projects take more than a decade to deliver. They also advocate supplementing prescriptive approaches with flexible strategies that can respond to novel situations, namely, postponing design decisions so as to gather more information before locking a project in a specific configuration.[70] Trial-and-error learning refers to the capacity to re-plan, and can be preferred when problems are novel, designs can only be imperfectly tested (e.g., through simulations, mock ups, and prototypes), and rework costs are low. Set-based exploration involves the pursuit of multiple alternatives that gradually converges to a single-point solution.[71] Realizations of the latter approach in infrastructure projects often take the form of "optioneering" exercises through which designers compare alternatives and choose one option based upon knowledge that is available.[72]

Another stream of literature has focused on the organizational aspects of managing projects under uncertainty.[73] The escalation literature draws from organizational behavior theory to explain what went wrong on large projects and which actions compounded losses. It recommends that administrators make more explicit the costs of changes and decouple the project from its constituencies.[74] Sociological studies encourage project organizations to promote frequent cross-stakeholder meetings for discussing how to accomplish a *future perfect* when "planning is almost impossible."[75] Other studies have started to overlay the power(lessness) dimension in studies on project performance, revealing how power inequalities can negatively influence project strategic implementation notwithstanding stakeholders' efforts to build trust.[76]

One final stream of work has started to look into how to formulate contractual arrangements that can drive the parties to behave in ways that contribute towards project success.[77] Recent studies, for instance, indicate that PFI contract forms will sooner or later become available, allowing public agencies (e.g., a hospital trust, a highways agency) to request bidders to price strategic design options in their proposals for new infrastructure developments. If the public agency chooses to pay for the option fees, it will acquire the right to ask the project promoter to exercise the options at a cost (also agreed to up front), if and when the uncertainties resolve favorably.[78] Given the long timescales to deliver megaprojects, this flexibility can end up positively affecting project performance.

The use of innovative forms of contracting in projects—a topic mentioned in passing in Davies et al.'s article in this special issue—is at the heart of Nuno Gil's contribution in this special issue. Building upon an embedded case study of the £4.2 billion T5 project, the article discusses the extent to which relational contracts between the client and suppliers can enable cooperative relationships and the implementation of lean management practices in megaprojects.

From the planning literature, we know that the staggering complexity of managing megaprojects can be compounded by perverse incentives built into public and public-private financing schemes. Based on case study research of transportation schemes in the U.S., Wachs notes that forecasts were frequently cooked to produce numbers that were enough to gain federal support regardless of whether the project could be fully justified on technical grounds or not.[79] Likewise, an analysis of cost overruns in urban transportation schemes worldwide has suggested that project promoters often use aggressive low-cost estimates so as to tactically get a new project approved and gain public support.[80] Interestingly, seminal literature on the "principle of the hiding hand" argues that for specific situations in developing countries "[because we tend to underestimate our creativity,] it is desirable we underestimate to a roughly similar extent the difficulties of the tasks we face, otherwise, we would not dare undertake tasks that we actually can accomplish."[81] However, if a project is strategically misrepresented, overruns are then almost inevitable and will have nothing to do with the effectiveness of the management of the project that was set up to fail. In this special issue, Bent Flyvbjerg, Massimo Garbuio, and Dan Lovallo shed light on how delusion and deception need to be taken into account when examining megaproject overruns. They also discuss how accountability, transparency, and best practices such as reference class forecasting can overcome strategic misrepresentation.

Sustainable Development of New Infrastructure

Sustainable development builds upon the far-reaching and most often-quoted notion of meeting the needs of the present without compromising the ability of future generations to meet their own needs.[82] This notion props up two core principles in the Aalborg Charter that inexorably affect new infrastructure development: the rate at which renewable resources are consumed should not exceed the rate at which the natural systems can replenish them; and the rate of emitted pollutants should not exceed the capacity of the air, water, and soil to absorb and process them. Various studies have examined how reductions in the ecological footprint of new infrastructure, as well as in the emissions and waste that infrastructure produces, matter for sustainable development. Energy emissions as a whole are estimated to be responsible for 65% of the global greenhouse gas emissions, of which 14% come from the transportation sector, 24% from power generation, and 8% from the use of buildings.[83]

More specifically, the impact of transportation infrastructure projects on the environment is substantial.[84] For instance, expanding and maintaining the pavement network in the U.S. annually requires nearly $150 billion and 350 million tons of raw materials for the construction, rehabilitation, and maintenance of a system of over 8 million lane-miles that support 3 trillion vehicle-miles each year.[85] These requirements and strain on the pavement network will increase as the infrastructure ages and new projects to grow capacity attempt to satiate an ever-growing demand. The challenge, of course, is to meet the demand using environmentally sustainable engineering practices. Unfortunately, the environmental burdens associated with pavements are largely unknown. This makes it difficult to ascertain how to best resolve the challenge. Early life-cycle cost analyses suggest nonetheless that there are opportunities in this regard.[86]

For the building sector, recent studies reveal that the activities to construct, maintain, and operate buildings in the U.S. consume about 40% of the country's raw materials and energy, and are responsible for 33% of the CO_2 emissions, 40% of the SO_2 and NO_2 pollution, 16% of the water use, and 25% of the wood use.[87] More broadly, 70% of the 2.5 million metric tons of nonfuel materials that moved through the U.S. economy in 1990 were estimated to be used in construction.[88] According to the Greater London Authority plan to meet Kyoto levels (*Action Today to Protect Tomorrow*), the needed 80% carbon emissions reduction, using existing technologies, can come from a 50% improvement in the physical infrastructure of buildings; a 20% improvement in the physical infrastructure of plants; a 25% behavioral change, and 5% building more energy-efficient facilities.

Incontestably, technical literature on "green" design has long provided guidance on how to address sustainability issues, namely, through methods to evaluate the environmental friendliness of new assets; to assess energy life-cycle costs of alternative supply systems; and to assess the external costs of the air emissions from the transportation systems.[89] Colleges and universities around the world are actively leading by example and are agreeing to drastically limit greenhouse gas emissions from new major real estate projects.[90] However, a major barrier to moving green design forward more rapidly has been decision-maker bias towards first-cost assessments. As put by David Orr, a pioneer on this matter, "the technical challenge of designing a high-performance building, complicated as that can be, proved to be much easier to solve than the human and institutional aspects of the design process."[91] Green designs at the high end can come with an up-front cost (an average of 5 percent in buildings according to the U.S. Green Building Council, 2002) that inevitably requires trade-offs up front when capital is scarce and limited. This is true despite the fact that from the viewpoint of life-cycle costing, the operational benefits that stem from integrating "sustainable" features can pay off in a relatively short period of time. In effect, the studies of 121 energy-efficient buildings designed and built to Leadership in Energy and Environmental Design (LEED) standards developed by the U.S. Green Building Council suggest that initial increases in costs can be offset by substantial energy performance improvements.[92] A recent study on green buildings designed per the LEED rating system notes that the estimated payback period due to reduced operational costs is approximately five years.[93] These results corroborate the findings spelled out in the 2007 McKinsey report on the abatement of CO_2 emissions, which shows negative life-cycle costs of abatement for "green" air conditioning, lighting, and insulation systems.[94] It is worth putting energy costs into perspective: for office buildings, salaries are 72 times higher than energy costs on average, and account for 92% of the life-cycle cost of a building.[95]

The concern that infrastructure promoters will skimp on environmental responsibilities—a critique that has been made traditionally for the public agencies' bias towards capital costs at the expense of life-cycle costs—is fair as profit-seekers become involved in new infrastructure development. Many parts in the process of developing and operating new infrastructure can easily fall outside the market, such as air emissions associated with the physical execution of the new asset. The blunt words of the BAA CEO addressing the Heathrow Consultative Committee (in December 2006) illustrate this point: "BAA is not a public, but a responsible private company. Therefore, we should not only subscribe to and support schemes such as environmental trading and emissions trading, we also need commercial incentives to do this." Likewise, British Petroleum has recently deferred a decision on building one of the world's first "zero emissions" power plants because of doubts over the state's willingness to subsidize the technology.[96] European regulation is foreseen to become more stringent regarding environmental impacts, including requirements for new fossil fuel power plant designs to include CO_2 capture systems by 2020 and for new buildings to reduce energy consumption by about 50 percent and CO_2 emissions by about 75%.[97] However, more research is needed as to whether further government intervention may be needed to force businesses to internalize some of the externalities.

Literature in corporate social responsibility also suggests that consumers are increasingly aware of which companies consider environmental issues in decision making, and this awareness can affect their purchasing decisions. Evidence indicates that some businesses are already willing to invest more than it is strictly necessary to meet environmental regulations at the present in order to protect institutional legitimacy and reputation, even if many others appear reluctant to do so.[98] The Climate Change report notes that the wind and solar power industries are increasingly generating more clean energy, as well as double-digit annual growth and jobs. In Germany, wind energy provided 5.7% of the country's electricity in 2006, whereas in the U.S. the investment on renewable capacity approached $3.5 billion. Equally impressive data comes from Japan, where new energy codes for residential and commercial buildings are estimated to save $5.3 billion in energy costs and 34 million tons of CO_2 annually.[99] The notion of how individual decisions and markets can reduce greenhouse gas emissions is developed in Martha Amram and Nalin Kulatilaka's article in this special issue. After summarizing the opposing views in the debate on climate change, the authors cogently argue that, first, grassroots lobbying efforts can be effective to make firms change their policies in regards to sustainability; and second, that firms that listen can seize profitable business opportunities.

However, despite all the progress made worldwide, the concentration of pollutants in China's air has increased by 50% in the last decade, and the country is already home to 16 of the world's 20 most air-polluted cities. Hence, we close off this introduction with a note on yet unmentioned issues affecting new infrastructure development around the globe.

Outlook

The articles that are part of this special issue offer conceptual framing and tools derived from research grounded in the infrastructure context. They look at infrastructure through the five lenses introduced above—policy and strategy, capital investment planning, design and innovation, project management, and sustainability. This is not an exhaustive set, admittedly. In particular, strategic management of cognitive-cultural and political risks is highly relevant for the infrastructure projects that take place in the developing countries.[100] These risks can be challenging to manage. Rapid economic growth in some developing countries and the diffusion of market-oriented ideas has generated huge demand for new infrastructure. Just for 2008, emerging economies were estimated to spend $1.2 trillion on infrastructure projects, equivalent to 6% of their combined GDPs, and twice the average infrastructure-investment ratio in developed economies.[101] However, the unforeseen transaction costs can be huge for the private entrant if it fails to comprehend the regulatory institutions of the host society and other differences in cultures and social structures.[102]

Rapid growth of developing countries has also dramatically increased energy use and emissions. The United Nations calculates that London's population took 130 years to grow from 1 million to 8 million, whereas Bangkok took 45 years and Seoul just 25. In 2008, half of the world's population lived in urban areas for the first time in history, and the United Nations estimates that the world urban population will nearly double to 6.4 billion by 2050.[103] Developing countries are entirely right in seeking to rapidly achieve the standards of living in Western societies. Hence, another challenge involves structuring new infrastructure development to respond both to sustainability concerns in ways that fit with the regulatory institutions of the host societies, as well as that exploit opportunities to leapfrog the problems of the current high-income world.[104]

In this regard, developments in Africa are worthy of a final note. The African Development Bank points to the mobilization of private-sector capital as one of the "pillars" for the economic revival of infrastructure in Africa. Astonishingly, Chinese contractors already win around 28% of World Bank and 33% of African Development Bank procurement contracts for construction services. Their aggressive price structure is leading other foreign contractors to exit the market.[105] This illuminates the complex nature of global markets for infrastructure. It also shows that exciting opportunities and challenges centered in the infrastructure context lie ahead for the management and business communities. Other conversations are therefore much needed. We hope that this special issue will begin to foster them.

Notes

1. Organization for Economic Co-operation and Development (OECD), *Infrastructure to 2030: Mapping Policy for Electricity, Water and Transport.* Vol. 2 (Paris: OECD, 2007).
2. L. Saigol, "Infrastructure Deals Soar to $145 bn," *Financial Times* (October 2006): 13.
3. Infrastructure also includes telecommunications and large IT systems. However, since these have received significant attention in management studies, we chose to focus this special issue on the large-scale *physical* infrastructure
4. For seminal work on this analytical positioning, see T.P. Hughes, "The Evolution of Large Technological Systems," in W. Bijker, T. Hughes, and T. Pinch, eds., *The Social Construction of Technological Systems* (Cambridge, MA: MIT Press, 1987).
5. OECD (2007), op. cit.
6. It remains unclear how the events were affected by the financial crisis that unraveled at the same time around the world.
7. Departments of Civil Engineering and Environment have welcomed, historically, small groups of scholars interested in construction, engineering, and project management, but they and business schools have remained disparate communities apart from notable exceptions. New developments call for more synergy and complementarity, we argue.
8. We acknowledge the support of the Royal Academy of Engineering, which is funding a visiting scholar appointment at the Collaboratory for Research on Global Projects at Stanford University through a Global Research Award (recipient Gil on sabbatical leave). We also thank Graham Winch and Ryan Orr for helpful comments on earlier drafts.
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10. Van Miert Group, *Trans-European Transport Network: The Enlarged EU must Find Adequate Resources*, European Commission, Directorate-General for Energy and Transport, Ref. IP/03/914, 2003.
11. See G. Brown, "Budget 2006: The Speech," *Financial Times*, March 23, 2006; N. Timmins, "One in Five PFI Projects Unprofitable," *Financial Times,* April 25, 2007.
12. UNESCO, *Water for People, Water for Life* (Paris: UNESCO Publishing and Berghan Books, 2003).
13. World Water Council, *The 3rd World Water Forum Final Report* (Marseille: World Water Council, 2003).
14. UN Habitat characterizes slum housing as lack of durable housing, insufficient living area, and lack of access to clean water, inadequate sanitation, and insecure tenure. See D. White, "Uneven Distribution," *Financial Times*, Special Report, African Infrastructure, November 21, 2006.

15. For details, see D. Downey, "Trenchless Technology: A Modern Solution for Clean-Flowing Cities," *Proceedings of ICE Civil Engineering*, 159 (2006): 26-30.
16. M. Maurer and A. Herlyn, *Zustand, Kosten and Investitionbedarf der Schweizerischenn Abwasserentsorgung: Schlussbericht* (Dubendorf: Eawag, 2006).
17. IEA, *World Energy Outlook* (Paris: International Energy Agency, 2006).
18. For a pungent description of life in slums and of the magnitude of the socio-economic phenomenon, see M. Davis, *Planet of Slums* (New York, NY: Verso 2006).
19. R. Wright, "Blocked Up: How Failings in Transport Hold Back Prosperity for Billions," *Financial Times*, March 13, 2007.
20. Seminal studies use "privatization" as an umbrella term, encompassing divestment, private finance, and outsourcing. Lately, the term "public-private partnership" (PPP) has also been used to refer to schemes that involve the private sector.
21. C.V.P. Goldberg, "Regulation and Administered Contract," *Bell Journal of Economics*, 7/2 (Autumn 1976): 431.
22. For more on this discussion, see the international comparative study J.A. Gomez-Ibanez, *Regulating Infrastructure. Monopoly, Contracts, and Discretion* (Boston, MA: Harvard University Press, 2003).
23. A private company that manages investments and trusts for a single wealthy family.
24. For more information see, for example. R. Orr and J.R. Kennedy, "Highlights of Recent Trends in Global Infrastructure: New Players and Revised Game Rules," *Transnational Corporations*, 17/1 (2007): 95-130.
25. S.M. Stodder and R. Orr, "Understanding Renegotiation and Dispute Resolution Experience in International Infrastructure Investment," *Proceedings of the 2nd General Counsel's Roundtable*, Stanford University, Stanford, CA, February 1-3, 2006.
26. D.C. Johnston, "In Deregulation, Power Plants Turn into Blue Chips," *New York Times*, October 23, 2006.
27. The investment management fund responsible for Singapore's foreign reserves.
28. The offer was 49 per cent more than the level BAA's share price was at before Ferrovial's interest became known, beating off competition from a consortium led by U.S. bank Goldman Sachs.
29. C. Thorne, "Infrastructure's Era of Bumper Returns Over," *Financial Times,* July 20, 2008.
30. K. Fitzpatrick, "Infrastructure Starts to Become as Asset Class in its Own Right," *Financial Times*, April 23, 2007.
31. For a comprehensive discussion see J.D. Donahue, *The Privatization Decision: Public Ends, Private Means* (New York, NY: Basic Books, Inc., 1989).
32. The issues with water privatization are described at length in Gomez-Ibanez (2003), op. cit.
33. See, for example, J.A. Gomez-Ibanez and J.R. Meyer, *Going Private: The International Experience with Transport Privatization* (Washington, D.C.: The Brookings Institution, 1993).
34. This point first surfaced in D.W. Caves and L.R. Christensen, "The Relative Efficiency of Public and Private Firms in a Competitive Environment: The Case of Canadian Railroads," *Journal of Political Economy*, 88/5 (October 1980): 958-976.
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36. For more on this discussion, see A.A. Altshuler and D. Luberoff, *Mega-Projects: The Changing Politics of Urban Public Investment* (Washington, D.C.: Brookings Institution Press; Cambridge, MA: Lincoln Institute of Land and Policy, 2003).
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38. Equally controversial, the decision to break-up the monopoly builds upon criticisms that it resulted in poor service standards, complacency about responding to airline needs, and inadequate capital investment. For the controversy in the eighties, see D. Starkie and D. Thompson, "London's Airports: The Privatization Option," in J. Kay, C. Mayer, and D. Thompson, eds., *Privatization and Regulation: The UK Experience* (Oxford: Oxford University Press, 1986), pp. 210-220.
39. E. Woodhouse, "The Obsolescing Bargain Redux? Foreign Investment in the Electric Power Sector in Developing Countries," *New York University Journal of Law and Policy*, 38/121 (2006): 121-219.

40. For a comprehensive discussion, see Gomez-Ibanez (2003), op. cit.
41. See W. Baumol, “Modified Regulation of Telecommunications and the Public Interest Standard,” in M. Bishop, J. Kay, and C. Mayer, eds., *The Regulatory Challenge* (Oxford: Oxford University Press, 1995), pp. 254-282.
42. Altshuler and Luberoff (2003), op. cit.
43. Gomez-Ibanez and Meyer (1993), op. cit.
44. See A.A. Altshuler and R. Curry, “The Changing Environment of Urban Development Policy: Shared Power or Shared Impotence?” *Urban Law Annual*, 10/3 (1975): 3-41, at p.45.
45. For more on this discussion, see Gomez-Ibanez (2003), op. cit.
46. Altshuler and Luberoff (2003), op. cit., p. 220. See also G. Winch, “Managing Project Stakeholders,” in P.W.G. Morris and J.K. Pinto, eds., *The Wiley Guide to Managing Projects* (Hoboken, NJ: John Wiley & Sons, 2004), pp. 321-339.
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48. The process was controversial, not surprisingly. Some groups argued that the new Planning Bill needed to include a Strategic Infrastructure Planning Body capable of working across government departments to ensure a more joined up approach, and draw up a “National Infrastructure Framework.” Others were concerned that the definition of national significance was too loose, and that planning approval would be taken out of the hands of the local authorities.
49. L. Trigeorgis, *Real Options: Managerial Flexibility and Strategy in Resource Allocation* (Cambridge, MA: MIT Press, 1996).
50. A.K. Dixit and R.S. Pindyck, *Investment under Uncertainty* (Princeton, NJ: Princeton University Press, 1994).
51. Altshuler and Luberoff (2003), op. cit.
52. This case also illustrates the power of infrastructure to improve public welfare. The Victorian network of sewers was spurred by the last of three cholera epidemics affecting London between 1831 and 1854. The network of sewers facilitated the restoration of the highly polluted Thames River. Such was its success that by 1872 London had a lower death rate than any other major city (despite being the most populous city in the world at the time).
53. The term “future-proofing” has been labeled an oxymoron. The point, however, is not to design an infrastructure assuming that predictions about future scenarios are 100% reliable. Rather, the aim is to have a process in place that ensures serious thinking about foreseeable scenarios informs design decision making. See, for example, R. Kitching, “Future Proof” Hospital Design Impossible, Say Consultants,” *New Civil Engineer*, December 2, 2004.
54. Wang and de Neufville call it building options “in” projects; see T. Wang and R. de Neufville, “Real Options “in” Projects,” *9th Annual International Conference Real Options*, Paris, France, 2005.
55. Some infrastructure architectures can be, however, difficult to modularize; and the lack of competitive intensity and low heterogeneity of demand also do not create a sense of urgency to modularize. When the architectures remain integral, designers can incorporate safeguards to purposely leave an option open. For more, see N. Gil, “On the Value of Project Safeguards: Embedding Real Options in Complex Products and Systems,” *Research Policy*, 36/7 (September 2007): 980-999.
56. See C.Y. Baldwin and K.B. Clark, “Modularity in the Design of Complex Engineering Systems,” in A. Minai, D. Braha, and Y. B. Yam, eds., *Complex Engineered Systems: Science Meets Technology* (New York, NY: Springer-Verlag, 2006).
57. For details, see Downey, op. cit.
58. This case is detailed in J. Sreeves, “Future-proof: Upton upon Severn viaduct, UK,” *Civil Engineering*, 160/1 (February 2007): 33-38.
59. See, for example, M.V. Martin and K. Ishii, “Design for Variety: Developing Standardized and Modularized Product Platform Architectures,” *Research in Engineering Design*, 13/4 (November 2002): 213-235; C.Y. Baldwin and C.J. Woodard, “The Architecture of Platforms: A Unified View,” Harvard Business School Working Paper, No. 09-034, September 2008.
60. For how this notion was originally derived from studies in manufacturing and service firms, see A. Davies, T. Brady, and M. Hobday, “Charting a Path toward Integrated Solutions,” *Sloan Management Review*, 47/3 (Spring 2006): 39-48.

61. For more on this practice, see N. Gil, "Project Safeguards: Operationalizing Optionlike Strategic Thinking in Infrastructure Development*," IEEE Transactions on Engineering Management*, (in press).
62. The "coalition" term first appeared in G. Winch, *Managing Construction Projects: An Information Processing Approach* (Malden, MA: Blackwell Publishing, 2002). [New edition scheduled to appear in 2009.]
63. At least $250 million in inflation-adjusted year 2002 dollars in Altshuler and Luberoff terms [(2003), op. cit.]. See also R. Miller and D. Lessard, *The Strategic Management of Large Engineering Projects* (Cambridge, MA: MIT Press, 2000).
64. For more information, see E.W. Merrow, *Understanding the Outcomes of Megaprojects: A Quantitative Analysis of Very Large Civilian Projects* (Santa Monica, CA: Rand Corporation, 1988); B. Flyvbjerg, N. Bruzelius, and W. Rothengatter, *Megaprojects and Risk: An anatomy of Ambition* (Cambridge: Cambridge University Press, 2003).
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66. See, for example, Z. Shapira and D.J. Berndt, "Managing Grand-Scale Construction Projects: A Risk-taking Perspective," *Research in Organizational Behavior,* 19 (1997): 303-360.
67. F.H. Knight, *Risk, Uncertainty, and Profit* (Boston, MA: Houghton Mifflin, 1921).
68. See, for example, D.I. Cleland and W.R. King, *Systems Analysis and Project Management*, 3rd edition (New York, NY: McGraw-Hill, 1983); D.F. Cooper and C.B. Chapman, *Risk Analysis for Large Projects: Models, Methods, and Cases*. (New York, NY: John Wiley & Sons, 1987); P.W.G. Morris and G.H. Hough, *The Anatomy of Major Projects: A Study of the Reality of Project Management* (Chichester: Wiley, 1987).
69. See J.K. Pinto, and D.P. Slevin, "Critical Factors in Successful Project Implementation," *IEEE Transactions on Engineering Management,* 4/1 (1987): 22-27. See also Miller and Lessard (2000), op. cit.
70. See, for example, A.J. Shenhar, "One Size Does Not Fit All Projects: Exploring Classical Contingency Domains," *Management Science*, 47/3 (March 2001): 394-414; M.T. Pich, C.H. Loch, and A. De Meyer, "On Uncertainty, Ambiguity, and Complexity in Project Management," *Management Science*, 48/8 (August 2002): 1008-1023; D. Dvir and T. Lechler, "Plans Are Nothing, Changing Plans Is Everything: The Impact of Changes on Project Success," *Research Policy*, 33 (2004): 1-15; N. Gil, I.D. Tommelein, and L.W. Schruben, "External Change in Large Engineering Design Projects: The Role of the Client," *IEEE Transactions on Engineering Management,* 53/3 (August 2006): 426-439.
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72. N. Gil, S. Beckman, and I. Tommelein, "Upstream Problem-Solving under Uncertainty and Ambiguity: Evidence from Airport Expansion Projects," *IEEE Transactions on Engineering Management,* 55/3 (August 2008): 508-522.
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77. N. Dayanand and R. Padman, "Project Contracts and Payment Schedules: The Client's Problem," *Management Science*, 47/12 (December 2001): 1654-1667.
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79. M. Wachs, "When Planners Lie with Numbers," *Journal of the American Planning Association*, 55/4 (1989): 476-79.
80. Flyvbjerg et al. (2003), op. cit.
81. See A.O. Hirchman, *Development Projects Observed* (Washington, D.C.: The Brookings Institution, 1967).

82. G.H. Bruntland, ed., Report of the World Commission on Environment and Development, *Our Common Future*, General United Nations Assembly Resolution 42/187, December 11, 1987.
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