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Surveys

Resilience through Transaction Cost Economic Evaluation: Recognizing the Cost-Effectiveness of Sustainable Development

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Abstract

In a step toward more economic and environmentally sustainable decision-making, this paper introduces transaction cost economics as a promising paradigm for revealing the cost-effectiveness of resilient infrastructure investments. Transaction cost economics is a theory and methodology for comparatively evaluating the cost-effectiveness of institutional arrangements governing transactions. Transaction cost theory was formulated to explain the economics of concessions and other forms of organization for delivering infrastructure goods and services. Research designs in transaction cost analysis are comparative, emphasizing the accumulated costs over time of one approach compared to another. Organizing research around comparative production and transaction costs, instead of price, creates an opportunity to internalize externalities, such as ecosystem services, into ex post evaluations of historical investment and ex ante analyses of alternative future development plans.

Resilience theory provides a framework for applying analytical techniques to anticipate the effects of disturbances. Notions of resilience express the idea that the natural world is dynamic, highly specific, and ever-changing. In contrast, we build things that are static, standardized, and unable to adapt to either forces of nature or deliberate acts of destruction. Buildings and infrastructure are designed to tolerate a limited set of disturbances; when stressed beyond those limits, structures are subject to degradation and collapse. Evaluations of infrastructure investments today should take account of the cost of repeated cycles of investment and collapse over the long term. If applied to measure and remedy the costs of disturbances over time, transaction cost economic methodologies may form the basis for evaluating infrastructure projects for resilience, opening the possibility of recognizing economic and environmental co-benefits in infrastructure investments.

KEYWORDS: Resilience, Economics, Infrastructure, Transaction Cost, Governance, Adaptive Management, Evaluation, Collective Choice, Sustainable Development, Cost-Benefit Analysis, Ecosystem Services, Urbanization, Externalities

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1. INTRODUCTION

Our systems of infrastructure exist as vast networks of investment that underpin the urbanization of the landscape. These systems, for energy, water, transport, communication, waste, and myriad other collective goods, sit at the interface of ecosystems and human settlements, and their design and operation are thus central to the path-dependent relationship humans have with the natural environment. For better or worse, our infrastructure commands the stores and flows of elements in nature we find most vital and most toxic, and give both our economic systems of production and consumption a platform for performance. If our cities and their urbanizing edges are to be sustainable, it will be in large part due to the environmental performance of our infrastructure systems.

Despite considerable sunk cost over the past 150 years in environmentally damaging investments, from the combustion engine and its fuels to our concrete ribbons of highways, flooded valleys behind earthen dams, hardened water conveyances, spiderwebs of overhead wiring, overflowing sewers, and piling of waste on land and at sea, the notion that our infrastructure is critical to environmental performance should provide us with reason for optimism. Unlike the decentralized governance of markets for most commodities, infrastructure systems are often centrally managed, standardized in design, and governed with relatively broad concern for the public interest. As such, seemingly minor institutional changes to standards for infrastructure design and operation can have significant effect on environmental performance. Douglass North (1990) suggests that changes to the "rules of the game" offer the hope of massively increasing returns. Changes to the path of infrastructure production can offer hope of massively increasing returns to environmental sustainability.

The multiple models and arguments for sustainable development in this journal are testament to the need for an analytical framework that can support the hard pragmatic and scientific work to be done to discern the attributes of infrastructure systems on a sustainable path from those that are not. Changes to the institutional arrangements that govern infrastructure systems demand empirical evidence of both environmental and economic outcomes if decision-makers are to be persuaded to adopt or replicate environmentally positive attributes. In our opinion, the scientific approaches conceptualized by Oliver Williamson (1975, 1985) and Ronald Coase (1937, 1960) in transaction cost economics, if applied to evaluate infrastructure within the framework of C.S. Holling's (1973, 1996) notion of resilience, can account for the trade-offs in a meaningful way.

Transaction cost economics is a theory and methodology used to evaluate the cost-effectiveness of institutional arrangements. This theory emerged from Coase's explanation of the origin of the firm, and found purchase in Williamson's articulation of the idea that organizational forms exist to economize on transaction costs (Coase, 1937; Williamson, 1975, 1985). The theory made significant headway through debates amongst economists on the merits of franchise bidding for natural monopoly (Williamson, 1976; Demsetz, 1968; Goldberg, 1976; Coase, 1959). Unlike neoclassical models of price and quantity, transaction cost economic models presume that most economic action resides in adaptation to change over time, and come with research methods that offer opportunities to internalize externalities in analyses of costs. Resilience theory, on the other hand, provides a framework for applying analytical techniques to anticipate the long-term effects of disturbances on ecosystems. Resilience is increasingly salient to the design of infrastructure systems, especially systems thought to protect human settlements from disaster and climate change. We argue that together, these micro-analytical methods can be harnessed to evaluate alternative urban infrastructure investments and their institutional arrangements, with both economic and environmental sustainability in mind.

For example, if transaction cost economic analyses were to include the long-term historical *ex post* cost of infrastructure systems, especially those subject to repeated cycles of disaster and reconstruction, the long-term cost savings available through alternative institutional arrangements would become evident. Rail corridors subject to repeated landslides, highway sections subject to repeated inundation from floods, and levees and other embankments that undergo repeated repair and renovation, for example, may be viewed as more cost-effective in an alternative form, mode, or location. Infrastructure investments also induce land use change. In the case of sea level rise threatening coastal assets, or the increasing severity of natural or man-made disasters, the cost effects of alternatives intended to protect property should take into account the cost of disasters at risk of occurring within the designed life of the facility. To do so may open discussions over changes in property markets and property rights that may be less palatable in the short-term, but of long-term economic interest.

If such analyses were to fold in the *ex post* costs and third party impacts associated with environmental assets, feedback loops between infrastructure and ecosystem services would be given economic value, and the long-term savings available through alternative institutional arrangements for the governance of environmental assets would become evident. When planners and ecologists contemplate the long-term implications of restoring wetlands as overflows and buffers to avoid levee breaches and associated damage from floods, this is the type of data that has the potential to demonstrate the economic, as well as environmental appeal of this alternative, more sustainable form of infrastructure investment.

In this article, we suggest that transaction cost economic analysis and resilience are compatible theories for evaluating infrastructure decision-making, and present a generalized procedural model for integrating their micro-analytic approaches.

2. TRANSACTION COST ECONOMICS: NOT YOUR TYPICAL NEOCLASSICAL THEORY

To transact is to do business, as in the completion of a trade (Oxford English Dictionary, 1989). Transaction cost economics takes the transaction to be the basic unit of analysis, and asks how transactions are governed. As Williamson says,

> Transaction cost economics poses the problem of economic organization as a problem of contracting. A particular task is to be accomplished. It can be organized in any of several alternative ways. Explicit or implicit contract and support apparatus are associated with each. What are the costs? (1985: 20)

Coase (1937) realized that parties involved in trade experience costs that are not captured in the prices or production costs of goods. Previous economic literature asked how prices were determined, attributing problematic outcomes to the nature of the goods or markets in which they were traded (*e.g.* Smith, 1937; Pigou, 1920). When attention is turned away from price and toward transactions, research recognizes that costs are generated in the formation of contracts, are ongoing with the execution of contracts, and exist in addition to expenditures made with an economically functioning price mechanism (Coase, 1993). Williamson explains,

> Transaction costs of *ex ante* and *ex post* types are usefully distinguished. The first are the costs of drafting, negotiating, and safeguarding an agreement. This can be done with a great deal of care, in which case a complex document is drafted in which numerous contingencies are recognized, and appropriate adaptations by the parties are stipulated and agreed to in advance. Or the document can be very incomplete, the gaps to be filled in by the parties as the contingencies arise. (1985: 2)

For many commodities, transactions are easy to enter and exit and the parties may be either satisfied that their expectations were met or comfortable looking for the next best alternative (Macneil, 1974; Williamson, 2000). However, in transactions between consumers and producers of networked infrastructure (*e.g.* transport, water, waste, and communications) experience and research lead us to be concerned about what happens over time, before and after a contract is signed (*e.g.* Troesken, 2001, 2006). Contracts for infrastructure services, whether between public and private agents on behalf of consumers or directly between consumers and producers, tend to be complex and relatively long-lasting agreements, coupled with significant investments by consumers and producers in durable goods. We also recognize these as essential goods and services and, in the fashion of natural monopoly, their geographic distribution or market concentration can leave consumers without reasonable alternatives or substitutes.

Transaction cost economics is well-suited to the economics of infrastructure goods and services, especially when research is focused on the factors that cause the cost of transactions to rise *ex post*. Parties may enter agreements that appear to align with their interests, but economic issues can arise at any time, from forces exogenous and endogenous to the transaction. Costs rise as the parties find themselves unable to adapt to these changing circumstances. As Williamson says,

> *Ex post* costs of contracting take several forms. These include (1) the maladaptation costs incurred when transactions drift out of alignment . . . (2) the haggling costs incurred if bilateral efforts are made to correct *ex post* misalignments, (3) the setup and running costs associated with the governance structures (often not the courts) to which disputes are referred, and (4) the bonding costs of effecting secure commitments. (1985: 21)

Alignment refers to the balancing of interests and incentives that the parties operate with as they craft and carry out their agreements. Misalignment is the failure of either the parties or the institutional arrangements governing the transaction to strike a proper balance of interests and incentives between the parties (Aoki, 1983). Inefficiency results, reflected in elevated bargaining costs, disputes, or other factors that impede the cost-efficient execution of the transaction (Williamson, 1985). Thus, misalignment suggests that the contracts parties use to govern their exchange are more expensive to execute than they should be or that the contracts or other institutional structures governing the transaction do not adequately safeguard the parties' interests (Macneil, 1974). Collectively, these are examples of contractual hazards that can emerge *ex post*, after a contract has been signed and any economizing effects from competition have faded away.

Williamson's idea that institutional arrangements economize by allowing the parties to avoid or recover efficiently from misalignment and maladaptation is based on a game-theoretic conception of economic action and, in this sense, it mirrors Elinor Ostrom's (1990; Ostrom *et al.*, 1994) understanding of the potential economizing effects of institutional arrangements governing common pool resources. Like Cournot (1838) and Nash (1951, 1953), however, Williamson attends to the human behaviors that lead people away from the economizing effects of cooperation, while Ostrom attends to the behaviors that foster cooperation.

The temporal nature of the game is central to transaction cost economic reasoning. Williamson assumes that people are rational, but they cannot anticipate everything that will happen (Simon, 1986). Contracts for complex transactions cannot be expected to cover all events that occur as the transaction proceeds. Williamson (2002) also assumes that people are opportunistic in that they may, but do not always take advantage of one another. Thus strategic behavior can also lead to costly contractual breakdowns. These assumptions render all complex contracts unavoidably incomplete. Furthermore, although performance is expected to be tied to incentives, such as payoffs and punishments (North, 2005: 18), people are challenged to learn and verify performance *ex post*, under conditions that may be fraught with information asymmetry (Coase, 1960).

Empirical analysis in transaction cost economics compares actual *ex post* costs and consequences for the parties to exchange during transactions over time, with the hypothesis that efficiency results from the discriminating alignment of transactions with alternative, more efficient structures of governance (Williamson, 2002). The theory gains predictive content by naming the key ways in which transactions differ, describing the economic properties of alternative structures of governance, and measuring the costs parties experienced as they carried out comparable transactions under alternative structures of governance (Tadelis & Williamson, 2012). Originally applied to the "make or buy" decision in infrastructure and commodity markets (Shelanski & Klein, 1995; LaFontaine & Slade, 2007), the theory and its practical implications extend to the public sector (Williamson, 1999; Spiller, 2008), or virtually any situation in which two or more different arrangements may be used to govern the same transaction.

While already used to measure the economic consequences of infrastructure investments, we believe a transaction cost approach can also be used to measure environmental consequences. We are only limited in our ability to derive useful transaction cost accounts of investments by our ability to see the extent to which the environmental effects of those investments, whether damaging or sustainable, occur as transactions.

3. A THEORY USEFUL WHEN ASSETS ARE SPECIFIC TO THE TRANSACTION AT HAND

Williamson takes particular interest in costs that accrue when parties become locked in to a bilateral dependent relationship. One key factor he identifies is "asset specificity", a term for assets specific to the transaction at hand, defined as

> specialized physical assets (such as a die for stamping out distinctive metal shapes), specialized human assets (that arise from firm-specific training or learning by doing), site specificity (specialization by proximity), dedicated assets (large discrete investments made in expectation of continuing business, the premature termination of which business would result in product being sold at distress prices) or brand-name capital. (2002: 176)

Asset specificity gives rise to bilateral dependency because when assets are specific to the transaction, buyers find it cost-prohibitive to turn to alternative sources of supply, and sellers cannot redeploy the same assets to alternative uses or users without incurring a loss in value (Klein *et al.,* 1978). Bilateral dependency suggests that parties to an exchange may not find it easy to exit their agreement. Locked in, the parties may be situated for intensive bargaining against one another for maximum gain over incremental *ex post* change.

Infrastructure and ecosystems are generally site-specific. As mentioned above, infrastructure systems consist of site-specific durable assets, often complemented by site-specific or durable investments on the part of consumers in order to gain the benefits of the infrastructure service. Environmental assets also tend to be site-specific. For instance, many species evolve according to geographic conditions, resulting in specialization by location (Darwin, 1859). Indeed, the collective features of ecosystems may be unique to their location; not all expectations of what may be found at a given site can be predicted from general accounts of the features and functions provided in typologies of ecosystems.[1] As habitats grow scarce and become increasingly isolated, islands of biodiversity in a transformed landscape, the chances that an environmental asset will be site-specific to a transaction will grow. Endangered species, for instance, have site-specific habitats, and the odds of population viability are expected to decline with the erosion of the environmental integrity of their habitat.

If mindful of the site-specificity of environmental assets, a transaction cost economic approach could factor in costs from damage to these assets as a result of the transaction. Ecosystem service valuation offers one means to measure, in economic terms, the environmental assets at stake. A transaction cost approach could also draw attention to the possible misalignment of the interest parties have in the environmental assets affected by or valued in transactions, and provide the means to systematically account for *ex post* maladaptation when damage occurs or positive spillovers result

1 This is not to say that ecosystem functions cannot or should not be generalized and given economic value; it just says that the features of ecosystems are likely more rich, varied, and irreplaceable than the functions we can measure and account for in the valuation of ecosystem services at any given site. As Holling (1996) suggests, the spatial attributes of ecosystems are patchy and discontinuous, and abiotic and biotic processes and variables control the patchiness of ecosystems, but do so across a range of scales, and in cycles that function at a number of scales. In our opinion, these features complicate but do not detract from the need to ascribe value to ecosystem services, and thus render these assets on par with the local assets decision-makers routinely value through investments in the built environment.

from infrastructure goods and services. Environmental or not, assets specific to transactions pose hazards that can raise costs for one or more parties to the exchange and, Williamson (1985) cautions, governance structures should safeguard the parties against opportunistic behavior and bounded rationality.[2] If current arrangements do not adequately safeguard the interests of the parties, alternative institutional arrangements may be warranted.

The research questions guiding transaction cost economic analysis have often centered on the question of which form of contract to use to govern a given transaction. Williamson (2002: 183) uses a schema (Figure 1) to explain that, when economic exchange involves an asset specific to the transaction (k), this can pose a hazard to the contracting parties which, unless relieved through a safeguard (s) offered in the form of a credible commitment in the contract or a hierarchical arrangement – an employment agreement, with the firm as a hierarchical organization – the parties will be exposed to the hazards that drive up *ex post* costs. Empirical analyses usually sit within this theoretical framework for economic organization, which distinguishes governance structures, from the simple, spot market exchange, to long-term contracts, to the private firm, to the public bureau, for the ways in which they safeguard the parties in transactions (*e.g.* Williamson 1975, 1985). To economize, more complex governance structures are reserved for more hazardous transactions. By the same token, institutional arrangements that fail to safeguard the interests of the parties, or that are excessive in their effort to govern, should be found to be uneconomical, especially if alternative arrangements exists that can remedy the situation.

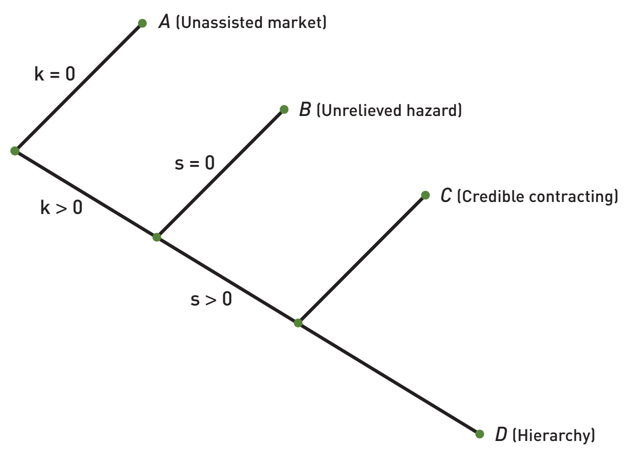

Figure 1: Simple contracting schema.
Source: Williamson (2002: 183)

Figure 1 depicts forms of contract for safeguarding the interests of producers and consumers as they carry out economic exchange, differentiating exchanges that may include transaction-specific assets, such as infrastructure investments, from those that do not. The schema can be extended to include the role of the public sector (Williamson, 1999) and the various contractual arrangements public organizations use to manage or regulate markets, including markets for land (Alexander, 2001). The same schema can be extended to describe hazards to ecosystem functions, and the various institutional arrangements that firms, non-profit organizations, planners, and public managers use to govern them.[3]

4. INTERNALIZING ENVIRONMENTAL EXTERNALITIES WITH TRANSACTION COSTS

The idea that exchange between two parties, irrespective of price, can raise costs for people external to the exchange is one of the founding principles of transaction cost economics. As Coase (1937, 1960) reasoned, costs above and beyond the price mechanism can explain the origin of the firm, and although pollution and other environmental costs to society are costs above and beyond the price mechanism, they are also the product of market exchange. Williamson suggests that empirical tests examine the "comparative costs of planning, adapting, and monitoring task completion under alternative governance structures" (1985: 2). By this logic, research designs can and should be arranged to account for environmental as well as economic costs. Costs experienced by third parties deserve just as much examination as costs experienced by the two parties engaged in market exchange.

Consider the Coasian (1960) problem of transactions in the marketplace, governed by institutions, that create undesirable – indeed, uneconomical – external effects. Coase provided several examples, from the case of cattle grazing on a neighbor's crops, to the case of machinery at a confectionary disturbing the work of a neighboring doctor, to the case of a factory polluting the air or water of a community. By his line of reasoning, these external effects are transactions, and may be subject to the same sort of transaction cost analysis we apply to transactions that are internal to markets (*i.e.* "internal" simply because they are priced and presumably voluntary exchanges).[4]

The simplest of transaction cost empirical tests is the

2 Opportunistic behavior and bounded rationality are the human behavioral assumptions of transaction cost economic theory (Williamson, 1975, 1985). The idea that humans behave opportunistically with regard to ecological systems and processes has been widely acknowledged by writers in disciplines across the natural and social sciences; this tension could be said to be driving research in urban ecology toward an interdisciplinary synthesis (Alberti, 2008). Bounded rationality is the generally accepted assumption from Herbert Simon (1986) that humans have several limitations that prevent us from achieving the optimal states of decision-making previously assumed in neoclassical economics and more applied disciplines, such as urban planning. Bounds to rationality are especially evident in game-theoretic settings with environmental consequences, such as the tragedy of the commons (Hardin, 1968).

3 This theoretical framework could focus entirely on ecosystem functions, such that the prototypical exchange is nothing more than the collection of abiotic and biotic processes and variables understood as a functioning ecosystem, and the safeguards are comprised of the various practices and regulatory instruments used to protect ecosystems. Alternatively, we are suggesting that the prototypical exchange could consist of coupled human-natural systems, and array governance structures for the means and relative extent to which they safeguard the long-term viability of coupled human-natural systems.

4 One could argue that such externalities, which we recognize as "nuisances", provide justification for zoning, and similar urban planning tools. Infrastructure investments have similar rationales and effects. We invest in them to promote economic development, but we also invest in them to reduce exposure to numerous natural and human hazards, and they are critical components of long-range plans for urban development.

comparative measure of the real costs of completing one type of transaction under two different institutional arrangements (*e.g.* Williamson, 1976; Whittington, 2012). Holding constant the attributes of the transaction, such as the nature or design of the good or service to be delivered, allows research to search for the economic effects of alternative forms of contract, or other institutional arrangements. Institutional arrangements consist of informal norms, formal rules, and enforcement characteristics, understood to varying degrees for the economic, political and social order they provide (North, 2005: 48). In comparing the sum of production and transaction costs for transactions under alternative governance structures, research can reveal the relative economic effects of these instruments.[5]

To learn how any given transaction generates costs, one would disaggregate the tasks involved in executing the transaction and account for the costs as they accrue with each task. In the market for infrastructure development, the same general tasks can be found from sector to sector: planning, finance, land acquisition, design, construction, operations, maintenance, and rehabilitation or improvement.[6] Alternative institutional arrangements exist for governing these tasks; which call for more or less involvement from various public organizations, private firms, and non-profit organizations. Empirical transaction cost analysis usually takes a keen interest in the relative cost-effectiveness of these governance structures for any given transaction.

For example, in her comparative analysis of two modes of governance for constructing highway intersections, Whittington (2012) explains transaction cost empirical investigation by disaggregating construction into tasks, and comparing the *ex post* costs that accrued to the public agency for the tasks performed by private firms over time, on two completed projects, each delivered with a different form of contract (Figure 2). The projects were selected to control for design, quality, and scale, and this research design allowed the elevated construction cost for one of the projects to be attributed to the form of contract selected to govern that project.

Whittington's study focused on the exchange between the public agency and the producer of the infrastructure project. To learn how transactions bring about external environmental costs – costs that economists ascribe to third parties – one would account for those costs as they accrue as well. Line items, akin to those generated in *ex post* analyses of costs and benefits, could be generated that specify the ecosystem service values lost, spared, or restored.[7] Thus research could internalize environmental externalities by recognizing and valuing the interests parties have in environmental assets, accounting for *ex post* costs associated with environmental assets, and recognizing the burden each party bears in the form of *ex post* costs.

By this process, transaction cost analysis could be used to comparatively analyze the environmental, as well as economic, consequences of historic investments in infrastructure goods and services. Infrastructure and ecosystem assets are, however, assets with very long designed and natural lifespans. We run the risk of truncating research, missing what may be valuable environmental effects, by trying to account for costs while limiting analysis to the time of construction, or a given period for a concession agreement to govern an infrastructure investment. The theory of resilience offers a frame of reference that may help alleviate temporal distortions in cost accounting.

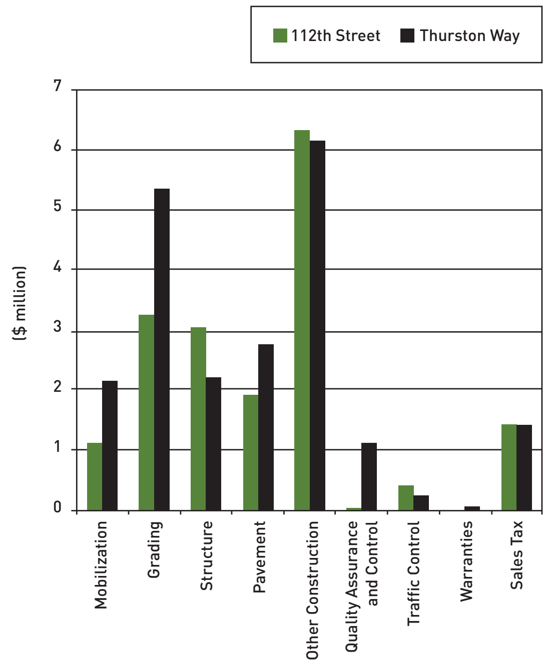

Figure 2: Construction cost accounts for transaction cost analysis of the 112th Street (bid-build) and the Thurston Way (design-build) projects. Source: Whittington (2012: 278)

5 If, in research, one has reason to believe that the cost of producing the good equates to the price of the good, then research can focus on transaction costs. If, as in most infrastructure goods and services, researchers are challenged to discover the relationship between production cost and price, then the values that matter are the sum total of production and transaction costs (Williamson, 1991).

6 The same is true for the development of land; land use change usually involves a series of routine transactions, each comprised of a set of tasks carried out by various parties (Alexander, 2001).

7 As the science of transaction cost economics progresses, researchers aggregate and compare costs in larger samples, coupled with multiple variations in institutional arrangements. The promise of this line of research is that patterns of cost may emerge that make it possible for economic theorists to develop formal mathematical models, and test predictions made with those models (Williamson, 2007).

5. RESILIENCE AS A THEORY OF COUPLED HUMAN-NATURAL SYSTEMS

The term 'resilience' was first developed by physicists to describe objects that rebound, recoil, or spring back (Oxford English Dictionary, 2013). The term also describes objects that can resume their original shape after they are bent or subjected to some type of strain.

Ecologists have since developed a coherent theory around the concept of resilience (Gunderson *et al.,* 2009). In ecology, resilience is one of several possible properties that a group of organisms can have in an environment when all elements are thought of together, as a system (Holling, 1973). When ecologists study interactions between predators and prey, they ask themselves why species go extinct. When speaking of resilience, they ask why species persist – what are the conditions that allow groups of organisms to persist, despite exposure to destabilizing forces? This line of reasoning leads ecologists toward the study of all the plausible types and magnitudes of disturbances for any given population in an ecosystem, and to conduct empirical research that suggests how that population has responded or may respond, over time, to any given disturbance.

Urban ecologists, noting the degree of and quickening pace with which urbanization has altered the world's ecosystems, as well as the absolute dependence humans have on the function of ecosystems, describe cities as complex ecological systems dominated by humans (Alberti, 2008; Alberti & Marzluff, 2004). Viewed as part and parcel of complex, adaptive, and therefore self-organizing systems, humans are one of many species simultaneously interacting and adapting to change over time. Consistent with ecological principles, resilience in the examination of coupled human-natural systems asks how much alteration urban ecosystems can tolerate, before they are reorganized around new structures and new processes (Holling, 1973, 1996). As Alberti and Marzluff (2004) explain,

> ...in urbanizing regions complex interactions between human and ecosystem functions over multiple scales affect resilience. These complex interactions need to be included in studying such systems. Simply considering human and ecosystem functions separately may not be adequate to understand system resilience because integrated socio-economic and ecological systems can behave differently than their separate parts. Furthermore, since urban development patterns affect the amount and pattern of built and natural land cover, as well as human use of ecosystem services in urban ecosystems, we argue that alternative urban patterns (i.e. urban form, land use distribution, and connectivity) have differential effects on resilience. (2004: 242)

Thus, infrastructure investments and land use policies are – along with population, economic growth, topography, and climate – driving forces in the creation of patterns of land use and land cover change (Alberti, 2008). The patterns that emerge across the landscape can be described as precipitating events, with resulting impacts on biophysical and socio-economic processes and measurable effects or changes to human and biotic communities, that cycle back to effect driving forces.

En route to a theory amenable to formal testing of the relationships between urban patterns and ecological resilience, Alberti and Marzluff hypothesize that, as urbanization increases, natural vegetation decreases "until a point is reached where natural vegetation is too degraded and fragmented to perform vital ecological functions and the system becomes unstable" (2004: 244). As ecosystem functions decline, urbanization flips into a "sprawl state" where, for lack of information about the full costs to ecological systems from providing low-density development, a "forced" equilibrium, low in resilience, emerges. If allowed to continue in this state, urbanization may degrade ecosystem function to the point of collapse, unable to support the human population. That said, multiple equilibria are possible; resilience would suggest a steady state of co-existence, where human and ecological functions remain intact.

Infrastructure investments and land use policies are both driving forces for urban ecological change, and decisive factors in the anthropogenic flow of carbon into the atmosphere and resultant radiative forcing we now understand as climate change. Climate change is altering the pace, magnitude, and rate of change for multiple variables in biophysical processes, placing stress on ecological as well as urban systems, and bringing a sense of urgency to the quest for resilience. Infrastructure investments are often the subject of short-term decision-making, despite their long-term and durable nature. The need to adapt to and mitigate climate change through infrastructure investment places an explicitly long-term goal on what is, ultimately, a long-term investment.

6. RESILIENCE AS AN OPERATIVE TERM FOR INFRASTRUCTURE INVESTMENTS

Researchers are beginning to use the term "resilience" to characterize the goal planners and decision makers should have when developing urban systems (Vale & Campanella, 2005). Our world is dynamic and ever-changing, yet we build things that are static, unable to adapt to either forces of nature or deliberate acts of destruction. Buildings and infrastructure are designed to tolerate a limited set of changes over a given period of time. When stressed beyond those tolerances the structures that house our communities are subject to degradation and collapse. Resilience provides a framework for applying analytical techniques to anticipate the effects of disturbances under present and future circumstances. Emphasis is on the capacity to persist despite loss of life and property.

Infrastructure goods and services, and the organizations that manage them, likely differ in terms of their response, over time, to any given disturbance. Disturbances may be natural or man-made destabilizing forces, and are often the combination of many factors, including development. Development increases the severity of disasters from sudden change by either contributing to driving forces in a way that accelerates change, or putting more people and property at risk. Development can precipitate sudden change, for instance, by destabilizing ecosystem functions. Gradual changes increase the probability of experiencing disaster from sudden changes, and our knowledge of these effects may give us more time to consider and launch alternative courses of action.

In the course of conducting empirical research, ecologists find that populations of organisms can be resilient, persisting by absorbing or adapting to numerous changes, maintaining the same relationships with other populations or other variables, up to a point (Holling, 1973). There are limits that, when passed, cause dramatic and rapid change through the entire system. What remains is still a system, yet it does not function at the same state or in the same way. In particular, populations with the capacity to absorb or adapt to extreme fluctuations in given variables or parameters are believed to be resilient.[8] When urban communities experience changes that surpass the thresholds that protective infrastructure or buildings can tolerate, they experience the system-wide destruction analogous in ecological research. The urban environment may recover and rebuild, though their elements and urban fabric may appear quite different than before. If measured, resilience would be the amount of disturbance a community can absorb without changing configuration; without moving to a "new" normal (Gunderson *et al.*, 2009: xix).

It is important to note that resilience and stability are not the same goals. Stable systems return as rapidly as possible, with the least fluctuation, to their original state (Holling, 1973). When our goal is stability, we manage against change. When our goal is resilience, we manage for change (Gunderson *et al.*, 1995). Resilient communities persist despite losses, adapting in the sense that they invest time and energy in infrastructure goods and services and other built environments that anticipate the forces that threaten to truly destabilize homes and ways of life.[9]

Infrastructure is often imagined to serve the purpose of adapting to, or protecting against the effects of a changing climate. Yet, global models of climate change bring widespread uncertainty to local decision-makers charged with developing infrastructure. The science of predicting sea level rise, floods, droughts, extreme weather events, or urban heat island effect, operates most effectively over 100 years or more, at a global, or perhaps regional scale. For instance, recognition that the magnitude of these effects over a 100 year period hinge to a large extent on the amount of mitigation yet to be achieved, is leading the World Bank to develop new methodologies for determining the value of proposed infrastructure investments (Hallegate *et al.,* 2012; Bonzanigo & Kalra, 2014). These methodologies diverge from the traditional practice of predicting the future and optimizing for that future. Instead, they examine how investment options might perform under a wide range of plausible future conditions.

Urban planning is central to determinations of what infrastructure to build and where to build it. We suspect that planning efforts could help urban environments gain a toehold in the climb to resilience by envisioning plausible future scenarios, engaging public participation, examining the likely consequences and options available when the tolerances of protective infrastructure are exceeded, and collecting local preferences for investment options in a systematic way. Planning for resilience would incorporate a preference for managing change, beyond typical limits or tolerances, in the design of infrastructure and other components of our built environments.

7. *EX POST* EVALUATION OF HISTORICAL INVESTMENT

As noted above, transaction cost analysis of historical infrastructure investments have focused on the cost-effectiveness of transactions from the buyer's and seller's point of view. Analysis could, however, be expanded to include costs experienced by third parties, such as environmental externalities. Furthermore, while transaction cost analysis of historical infrastructure investments have focused on the cost-effectiveness of the choice of contract, the scope of analysis could be expanded to take into account the cost consequences of the choice of what and where to build.

Transaction cost economics theorizes that institutional arrangements economize by safeguarding against hazards. For any given infrastructure investment one could ask, what are we safeguarding against? Resilience would suggest that we design infrastructure to address potential hazards, such as floods, droughts, or earthquakes, and climate change elevates attention to some hazards more than others. Also, there are multiple infrastructure design and planning options for addressing any given hazard. In the case of floods, for instance, one can contemplate unprotected development, basins or wetlands to absorb flows, barriers of various types and materials, the elevation of structures, or retreat to higher ground. Transaction cost analysis for resilience would compare these investment options for the safeguards they provide for human and ecological functions, amassing an array of alternatives, along Williamson's schema.

Recall that, in Williamson's theory of economic organization (Figure 1), the safeguards provided by forms of organization, from market to hybrid to hierarchy, become more expensive to

8 Or, on the scale of the ecosystem, redundancies in the niches occupied by various species may allow ecosystem functions to persist, at some level or form, after the loss of a species.

9 Nor is resilience synonymous with recovery. Investments in the built environment should be characterized as resilient to the extent that they result in less damage when disaster strikes, and thus raise less demand for investment during recovery.

execute as one walks down the schema. This is a compelling economic theory, because economizing is possible when more elaborate and thus expensive safeguards are reserved for more hazardous transactions. Resilience, however, is an aim achievable only with respect to the highest plausible level of hazard.

Our theory and schema differentiate short-term from long-term economizing. In our theory of economic investment for resilience, investment options provide more resilience, in the form of protection from expensive, irreversible damage, as one walks down the schema. Economizing in the short-term would characterize investments in the upper end of the schema, at risk of total loss. Long-term economizing would occur when designs and accompanying planning policies provide resilience in the face of a plausible extreme hazard.

Measures of cost would, in keeping with the aim of resilience, expand to include a longer timeframe for historical analysis than is customary in transaction cost analysis. The designed life and path dependent nature of infrastructure would suggest that the timeframe of analysis for resilience should be at least the designed lifespan of the infrastructure. If the history of investment allows a 100 year span of *ex post* analysis, this may be a convenient time frame, given the plausibility of much greater magnitudes of hazards from climate change over the long-term (Hallegate *et al.,* 2012).

The unit of analysis, the transaction, would consist of investment in a particular infrastructure project or system, and the governance structure would consist of the bundle of rules governing investment and land use over the long-term. The governance structures would be independent variables, and a long-term cost-based measure of resilience would be the dependent variable. To be comparable, infrastructure investment transactions would have to be selected to control for the form of hazard to which they are exposed, and a few general physical properties of the sites where they are located, such as the steepness of slopes and geologic conditions that drive up the cost of engineered solutions and thus generate extraneous variance.[10]

Organized in this way, empirical *ex post* analysis would reveal resilience in the form of comparative long-term cost-effectiveness of historical infrastructure options. In particular, this approach would highlight the inefficiency of infrastructure investment choices which may have appeared to be cost-effective in the short-term, but have proven to be relatively expensive over the long-term.[11] This would especially be the case for designs that failed prematurely, as in infrastructural investments that became sources of or subject to disaster, resulting in expensive or irreversible costs to human and ecological functions, due to the inability of the investment to adapt to or withstand the given hazard (Figure 3).

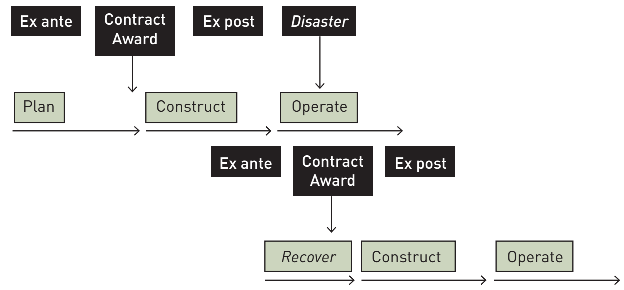

Figure 3: Infrastructure Planning, Disaster and Re-Investment.
Source: Authors

In keeping with Williamson's theory of economic organization, transaction costs would be attributed to *ex post* maladaptation. Production and transaction costs would be counted. The hypothesis of discriminating alignment would remain in place. The unit of analysis is still the transaction, cost-effective in discriminating alignment with a governance structure that safeguards against the hazards of bounded rationality and opportunism in the presence of asset specificity. Williamson's remediableness criterion would still apply, as only institutionally feasible options are applicable.

The incorporation of the theory of resilience shifts the research question from the "make or buy" decision to the "risk or resilience" decision. It also stretches the time horizon of applicable analysis over as long as 100 year timespan, or at least as long as the designed life of the infrastructure investment. Emphasis is on the behavioral assumption of bounded rationality, leaving actors with imperfect foresight and allowing, in a game-theoretic conception of decision-making, for the appearance of gambling with long-term risk in a short-term game of infrastructure investment. Production and transaction costs are both accounted for, with transaction costs that account for the expenses and losses experienced to the infrastructure investment and human and ecological functions over the long-term. Transaction costs are excessive long-term losses, and resilience is thus the relative measure of long-term cost-effectiveness of the choice of infrastructure investment. Discriminating alignment is the choice of governance structure that economizes over the long-term, providing resilience. When searching for a remedy, only institutionally feasible options need apply.

8. *EX ANTE* ANALYSIS OF ALTERNATIVE FUTURE DEVELOPMENT PLANS

Climate change is creating global demand for empirical information that can be used to guide local investment in infrastructure toward outcomes that make effective use of limited resources over the long-term and prove resilient by safeguarding against disruption to human and ecological

10 Similarly, Whittington's (2012) research design involved checking the selection of comparable cases to control for the features in the design of highway projects known to skew costs, such as area of the footprint, mass of structure, surface area of bridge, and area of wall. In that analysis, form of contract was the independent variable and cost outcome was the dependent variable.

11 Through empirical ex post analysis of historical investments, this schema may show how some designs and plans which appear elaborate and expensive in the short-term, are more cost-effective over the long-term than their counterparts, because of the safeguards they provide. Similarly, the theory and schema may show how some designs and plans that seem politically infeasible because of their implications for property rights, prove to protect human and ecological assets more effectively over the long-term.

functions. The aim of empirical analysis of historical investment would be to amass predictive content by naming the key ways in which transactions involving infrastructure investment differ, describing the economic properties of the structures employed to govern investment and land use over the long-term, and measuring the comparative costs parties experienced from these choices. To be of use in the analysis of alternative future development plans, *ex post* analysis would have to provide the types of empirical information that would be of strategic use to local decision-makers as they attempt to reconcile uncertainty about the exogenous forces created by climate change with knowledge of the endogenous limitations of existing physical and financial assets.

The methodology likely to elucidate the value of empirical transaction cost analysis for resilience, and support its use in deciding amongst infrastructure investment options, is a modified method of decision-making for robustness from operations research and modern systems theory. Jonathan Rosenhead (2001) explains that robust methodologies support decision-making when "there is radical uncertainty about the future, and where decisions can or must be staged sequentially"; it aims to resolve the problem of future uncertainty by organizing decisions "in terms of the attractive future options that they keep open" (2001: 181).

Although infrastructure investments are endogenous to local decision-makers, they are also, as noted above, driving forces in urban ecological models of land use and land cover change. They are often the first of multiple sequential investments that collectively serve as precipitating events, with resulting measurable impacts to human and biotic communities. Empirical analysis of historical investments and their long-term consequences can be used to determine parameters for decisions, and populate decision-trees with scenarios of alternative future infrastructure investments. To illustrate, we have populated one such decision-tree from Rosenhead (2001) with hypothetical values (Figure 4).

Moving from left to right, diamond 1 represents the policy objective the infrastructure investment is meant to deliver. Diamonds 2-5 are four alternative infrastructure investment options, which are precursors to the plausible changes in land use differentiated by diamonds 6-14. Together, the patterns of infrastructure and land use investment expressed in diamonds 2-14 can be linked to end states, measurable in terms of the qualities ascribed economic value in human and biotic communities, identified by boxes 15-31. Up to this point, the items identified are treated as endogenous variables, subject to the governance structures and range of institutionally feasible infrastructure and land

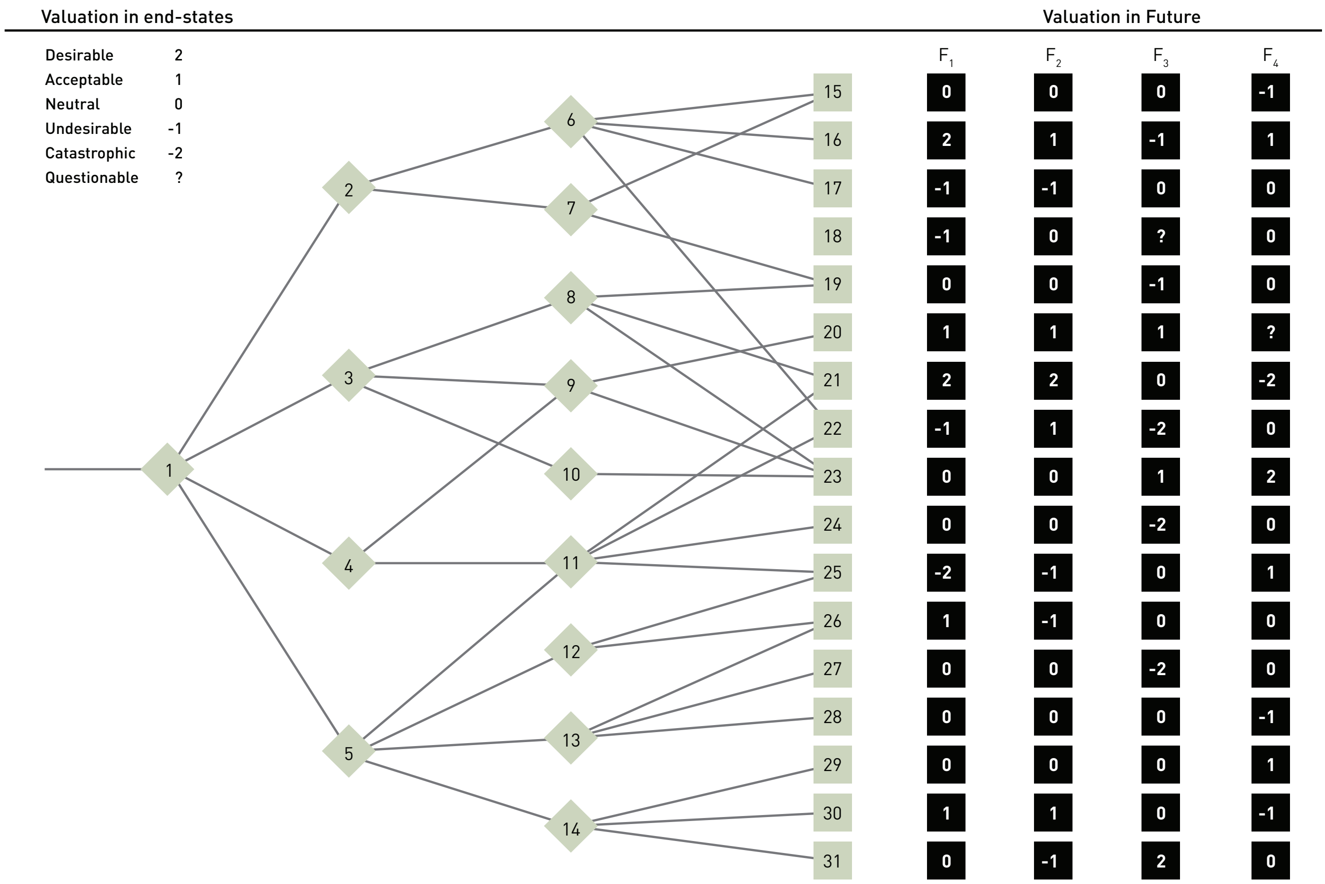

Figure 4: A three-stage planning problem with multiple futures. Source: Adapted from Rosenhead (2001: 196) (copyright © 2001, John Wiley & Sons, Ltd). Symbols of future valuation have been replaced by numerical values.

Future

Initial Decisions	F_1	F_2	F_3	F_4
2	$\frac{1}{5}$	$\frac{2}{5}$	0	$\frac{1}{4}$
3	$\frac{2}{5}$	$\frac{2}{5}$	$\frac{2}{3}$	$\frac{1}{4}$
4	$\frac{2}{5}$	$\frac{3}{5}$	$\frac{2}{3}$	$\frac{2}{4}$
5	$\frac{3}{5}$	$\frac{3}{5}$	$\frac{1}{3}$	$\frac{2}{4}$

Robustness matrix (on sets D and A)

Future

Initial Decisions	F_1	F_2	F_3	F_4
2	$\frac{2}{4}$	$\frac{1}{4}$	$\frac{3}{5}$	$\frac{1}{4}$
3	0	0	$\frac{1}{5}$	$\frac{1}{4}$
4	$\frac{2}{4}$	$\frac{1}{4}$	$\frac{2}{5}$	$\frac{1}{4}$
5	$\frac{2}{4}$	$\frac{3}{4}$	$\frac{3}{5}$	$\frac{3}{4}$

Debility matrix (on sets U and C)

Figure 6: Option maintenance analysis. Source: Adapted from Rosenhead (2001: 197) (copyright © 2001, John Wiley & Sons, Ltd).

use developments.[12] Exogenous hazards are represented by the columns of boxes (F_i) aligned with each end state. Each column represents a hazard experienced in a future state, and numerical values in the boxes are used to indicate the positive and negative impact to each valued end state from exposure to the hazard.

When urban planning influences infrastructure investment, the range of options for investment is quite wide, limited only by one's capacity to envision the plausible effects of alternative arrangements of local assets and policies in relation to preferences. The parameters for deciding what and where to build (*i.e.* diamonds 2-5) could be quite simple, suggesting alternative locations for infrastructure investments and alternative forms, some conventional and "grey" with others more "green" in their components and intended functions (Figure 5). Historical analysis of the long-term effects of various infrastructure investments under alternative governance structures would provide an empirical basis for delineating the plausible precipitating effects of each infrastructure decision on land use, and measuring the effect of each pattern of urban development in terms of plausible end states. Importantly, empirical analysis would help decision-makers avoid optimism bias by presenting empirical cases, with measured impacts to human and biotic communities, of undesirable as well as desirable outcomes.

Infrastructure

Location		Grey	Green
	A	2	3
	B	4	5

Figure 5: A simple matrix with parameters describing infrastructure investment alternatives. Source: Authors

From Rosenhead's (2001) explanation, we gather that when the decision-tree is complete, the decision options (diamonds 2-5) can be comparatively assessed using robustness scores across each future state. For example, moving from left to right across Figure 4, if one were to select the infrastructure investment represented by diamond 2 (as in Figure 5, a conventional infrastructure project at location "A"), this investment could result in two land use changes (diamonds 6 and 7). Together, these patterns of development across the landscape could result in five measurable end states (boxes 15, 16, 17, 19, and 22). For each initial infrastructure investment, robustness is measured as the proportion of plausible end states with desirable or acceptable impact in each future state, while debility is measured as the proportion of end states with undesirable or catastrophic impact in each future state (Figure 6).

The robustness matrix, with desirable and acceptable scores, shows that these decisions are roughly comparable in terms of their odds of producing positive outcomes. In contrast, measures of unacceptable or catastrophic outcomes in the debility matrix suggest that decision 3 ("green" infrastructure at location "A") would be more likely to avoid unacceptable long-term costs, and thus prove more resilient. Working back through Figure 4, one can even imagine accompanying infrastructure investment option 3 with changes to land use policy designed to avoid catastrophic (box 21) and undesirable (box 19) end states, by regulating against one particular form of land use change (diamond 8).

Transaction cost economic evaluations of historical investments in infrastructure would allow one to populate these matrices with estimates of actual costs from empirical accounts of historical damage resulting from various hazards. The simple ordinal values that describe desirable, acceptable, undesirable, or catastrophic outcomes, in the matrices of Figure 6 would be replaced by economic values, or other more fine-grained ordinal scales of benefit and cost. In this way, one could use empirical transaction cost analyses of historical

12 In the absence of hazards, this methodology can be used to gauge the preferences stakeholders have for alternative infrastructure investments based on plausible scenarios of future urban development patterns and end states. Thus, the stakeholders would be represented by Fi, and their preferences would be indicated by the values shown in the boxes below. Positive values are desirable, negative values are end states the stakeholders would prefer to avoid, and questions suggest that the stakeholder lacks adequate information to form a preference.

infrastructure investments for resilience to populate *ex ante* evaluations of alternative future plans for development.

9. MEASURING DEVELOPMENT FOR SUSTAINABILITY

The organization of science toward the pragmatic and challenging pursuit of sustainable development depends on methodologies and designs for research that unite empirical evidence of the environmental and economic consequences of our investments, support the norms of scientific production, and offer hope of predictive content. Transaction cost economics and resilience offer opportunities to do so through theoretical approaches and research methodologies that make common cause of research designed to reveal, in transaction cost economic terms, the long-term efficiency of investments in systems of infrastructure that complement and incorporate valuable environmental assets. These are well-developed theories, each of which has a history of application to infrastructure systems. If we can expand our concept of transactions in search of long-term value, we may see more than economic rewards.

References

Alberti, M. (2008). *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems.* New York: Springer.

Alberti, M. & J. Marzluff (2004). Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. *Urban Ecosystems* 7: 241-265.

Alexander, E. (2001). Governance and transaction costs in planning systems: a conceptual framework for institutional analysis of land use planning and development control – the case of Israel. *Environment and Planning B: Planning and Design* 28: 755-776.

Aoki, M. (1983). Managerialism revisited in the light of bargaining-game theory. *International Journal of Industrial Organization* 1(1): 5.

Bonzanigo, L. & N. Kalra (2014). *Making informed investment decisions in an uncertain world: a short demonstration.* Policy Research Working Paper 6765. Washington, DC: The World Bank, Sustainable Development Network, Office of the Chief Economist.

Coase, R. (1937). The nature of the firm. *Economica* 4 (16): 386-405.

Coase, R. (1959). The Federal Communications Commission. *The Journal of Law and Economics* 2: 1-40.

Coase, R. (1960). The problem of social cost. The Journal of Law and Economics 3: 1-44.

Coase, R. (1993). 1991 Nobel lecture: the institutional structure of production. In: Williamson, O. & S. Winter (Eds.) *The Nature of the Firm: Origins, Evolution, and Development*, pp. 227-235. New York: Oxford University Press.

Cournot, A. (1838). *Researches into the Mathematical Principles of the Theory of Wealth*. New York: A. M. Kelley, 1897.

Darwin, C. (1859). *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray.

Demsetz, H. (1968). Why regulate utilities? *Journal of Law and Economics* 11: 55-65.

Goldberg, V. (1976). Regulation and administered contracts. *The Bell Journal of Economics* 7(2): 426-448.

Gunderson, L., C. Allen & C. Holling (2009). *Foundations of Ecological Resilience.* Washington, DC: Island Press.

Gunderson, L., C. Holling & S. Light (1995). *Barriers and Bridges to the Renewal of Ecosystems and Institutions.* New York: Columbia University Press.

Hallegate, S., A. Shah, R. Lembert, C. Brown & S. Gill (2012). *Investment decision making under deep uncertainty: application to climate change.* Policy Research Working Paper 6193. Washington, DC: The World Bank, Sustainable Development Network, Office of the Chief Economist.

Hardin, G. (1968). The tragedy of the commons. *Science* 162: 1243-1248.

Holling, C. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4: 1-23.

Holling, C. (1996). Surprise for science, resilience for ecosystems, and incentives for people. *Ecological Applications* 6: 733-735.

Klein, B., R. Crawford & A. Alchian (1978). Vertical integration, appropriable rents and the competitive contracting process. *Journal of Law and Economics* 21(2): 297-326.

LaFontaine, F. & M. Slade (2007). Vertical integration and firm boundaries: the evidence. *Journal of Economic Literature* 45: 629-85.

Macneil, I. (1974). The many futures of contracts. *The Southern California Law Review* 47: 691-816.

Nash, J. (1951). Non-cooperative games. *The Annals of Mathematics 2nd Series* 54(2): 286-95.

Nash, J. (1953). Two-person cooperative games. *Econometrica* 21(1): 128-40.

North, D. (1990). *Institutions, Institutional Change and Economic*

Performance. Cambridge, UK: Cambridge University Press.

North, D. (2005). *Understanding the Process of Economic Change*. Princeton, NJ: Princeton University Press.

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge, UK: Cambridge University Press.

Ostrom, E., R. Gardner & J. Walker (1994). *Rules, Games, & Common-Pool Resources*. Ann Arbor, MI: University of Michigan Press.

Oxford English Dictionary (1989). John Simpson & Edmund Weiner (Eds.), 2nd edition.

Pigou, A. (1920). *The Economics of Welfare*. London, UK: MacMillan and Co., Ltd.

Rosenhead, J. (2001). Robustness analysis: keeping your options open. In: Rosenhead, J. & J. Mingers (Eds) *Rational Analysis for a Problematic World Revisited* pp. 181-208. Chichester, England: John Wiley & Sons, Ltd.

Shelanski, H. & P. Klein (1995). Empirical research in transaction cost economics: a review and assessment. *Journal of Law, Economics, and Organization* 11: 335-61.

Simon, H. (1986). Rationality in psychology and economics. *The Journal of Business* 59(4): S209-S24.

Smith, A. (1937). *An Inquiry into the Nature and Causes of the Wealth of Nations.* Edited by Edwin Cannan. 5th ed. New York, NY: The Modern Library.

Spiller, P. (2008). *An institutional theory of public contracts: regulatory implications*. Cambridge, MA: National Bureau of Economic Research. URL: http://www.nber.org/papers/w14152

Tadelis, S. & O. Williamson (2012). Transaction cost economics. In: Gibbons, R. & J. Roberts (Eds.) *Handbook of Organizational Economics* pp. 159-191. Princeton, NJ: Princeton University Press.

Troesken, W. (2001). Race, disease, and the provision of water in American cities, 1889-1921. *The Journal of Economic History* 61(3): 750-76.

Troesken, W. (2006). *The Great Lead Water Pipe Disaster*. Cambridge, MA: MIT Press.

Vale, L. & T. Campanella (2005). *The Resilient City: How Modern Cities Recover from Disaster*. Oxford, UK: Oxford University Press.

Whittington, J. (2012). When to partner for public infrastructure? *Journal of the American Planning Association* 78(3): 269-285.

Williamson, O. (1975). *Markets and hierarchies: analysis and antitrust implications*. New York, NY: The Free Press.

Williamson, O. (1976). Franchise bidding for natural monopolies – in general and with respect to CATV. *Bell Journal of Economics* 7(1):73-104.

Williamson, O. (1985). *The Economic Institutions of Capitalism*. New York, NY: The Free Press.

Williamson, O. (1991). Comparative economic organization: The analysis of discrete structural alternatives. *Administrative Science Quarterly* 36(2): 269-296.

Williamson, O. (1999). Public and private bureaucracies. *The Journal of Law, Economics & Organization* 15(1): 306-42.

Williamson, O. (2000). The new institutional economics: taking stock, looking ahead. *Journal of Economic Literature* 38: 595-613.

Williamson, O. (2002). The theory of the firm as governance structure: from choice to contract. *The Journal of Economic Perspectives* 16(3): 171-95.

Williamson, O. (2007). *Transaction cost economics: an introduction*. Discussion paper 2007-3, Economics Discussion Papers. URL: http://www.economics-ejournal.org/economics/discussionpapers/2007-3