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Economic Infrastructure: building prosperity

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ECONOMIC INFRASTRUCTURE – BUILDING PROSPERITY

ABSTRACT

This research uses the Let's Rebuild America Index (U.S. Chamber 2011b) to measure the performance of infrastructure (energy, transportation and water) in a model of economic growth (suggested by Sala-i-Martin 2002). The results indicate a statistically significant positive relationship between infrastructure and growth when controlling for the initial size of the economy, the health of the population and government policy. Of the performance criteria contributing to the Let's Rebuild America Index, quality of service has the strongest impact on economic growth. When government policy is modeled as federal regulations over infrastructure, the result is a statistically significant negative effect on economic growth that is large enough to offset the benefits of improved performance in the year that federal regulatory action is taken. Finally, a simple cash flow analysis using the results from the economic growth model demonstrates that investments that improve infrastructure performance have a payback period of 17.2 years – substantially less than the useful life of most infrastructures.

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INTRODUCTION

In our earlier analysis of the relationship between the economy and the performance of infrastructure, we worked only with transportation (U.S. Chamber 2010b and Trimbath 2011). This new work takes a broader look to include energy and water. Building on the earlier work, we continue to examine the overall contribution of well-performing infrastructure to economic prosperity – not the effect of spending on infrastructure or investment-related construction jobs but the sustainable impact of having good quality infrastructure that fulfills its purpose as the foundation which supports all economic activity. The immediate purpose of this analysis is to demonstrate the usefulness of the Let's Rebuild America (LRA) Index for studying the economic impact of infrastructure.

IMPORTANCE OF TOPIC

Infrastructure is not the end result of economic activity; rather it is the framework that makes economic activity possible.[1] Every developed nation in the world plus those still classified as "developing" are working to improve the fundamental tools of modern economic activity: infrastructure.

TABLE 1 *ECONOMIC IMPORTANCE OF INFRASTRUCTURE COMPONENTS*

COMPONENT	ECONOMIC IMPORTANCE:
Energy	Powers production, moves labor in urban areas, supports healthy population (heat, light, medical, refrigeration, etc.).
Transportation	Delivers inputs (goods, services and labor) to the places of production, delivers output to market and brings consumers and customers to the marketplace.
Water	Quality drinking water supports healthy population; managed water supply used to generate electricity. Wastewater infrastructure protects populations from disease. Stormwater infrastructure helps keep drinking water clean.
Interactions (example)*	Substitution (teleconferencing for travel to meetings); complementarity (satellite telecoms for metering water consumption); "leg-up" (transport

[1] This idea is put more broadly in the OECD (2007) report *Infrastructure to 2030*: "Rather, [infrastructures] are a means for ensuring the delivery of goods and services that promote prosperity and growth and contribute to quality of life …. The longer-term performance of OECD economies, and indeed of the global economy, will depend to an important extent on the availability of adequate infrastructures to sustain growth and social development."

	infrastructure right-of-way for communication networks); dependency (cascading disruptions in natural disasters due to role of energy in water supply and use of water in energy sector); interaction (road constructions crosses communication trenches and drainage systems).

*Examples derived from U.S. Chamber 2010a (see especially Appendix A: Business Community Meeting Notes) and OECD 2006 (see especially Table 1.2 for a more elaborate illustration of interdependencies among specific infrastructures). For a detailed study of just the "the electricity-water nexus", see Sovacool (2009).

When ranked by businesses – some of the heaviest users – infrastructure in the United States declined steadily[2] since 2005 (see IMD various and 2010; and Schwab 2011; plus summaries and commentary provided in U.S. Chamber 2010b). As governments fought to reduce deficit spending in the 2000's – when the U.S. Treasury began paying down outstanding public debt – a new deficit emerged as the gap widened between the investments needed to achieve high-functioning infrastructure and the actual investment in infrastructure. That deficit began slowly narrowing after governments around the world began "buying jobs" (Tal 2009) through short-term stimulus spending on infrastructure.[3] Although the stimulus effect of tax cuts may "leak" into spending on imported goods or savings, the effect of infrastructure spending is more direct and more immediate. Our goal in this analysis is to demonstrate that the economic effect may be more long-lasting than "buying jobs" (during the construction phase of investment).

There is a synergy among the various parts of infrastructure that may not be captured when energy, transportation and water are studied separately. Drinking water and hydro-electric energy are produced from the same river/reservoir system; rain storms that overpower water infrastructure can flood roads and railways, disrupting transportation; roads and railways bring coal and oil to power plants; an accident on a poorly maintained street can damage power and communication lines; many municipalities have backup diesel generators which require roads for fuel deliveries, etc., etc. (see "interactions" in Table 1 above for more).

There are two primary obstacles to breaking out the relationship of the economy to the individual components of infrastructure. The first is that businesses make tradeoffs and substitutions among

[2] The exception is information communication technology infrastructure (e.g., broadband access), which is not included in the LRA Index. ICT's impact on economic development may go beyond infrastructure performance to the content of what is transmitted (OECD 2006).

[3] In January 2009, Foreign Affairs and International Trade Canada inventoried more than $2.3 trillion of stimulus spending plans directed toward infrastructure worldwide. (See http://www.international.gc.ca/canadexport).

certain elements of infrastructure. A simple example is when businesses use video conferencing instead of face-to-face meetings – substituting broadband infrastructure for transportation (U.S. Chamber 2010a).[4] It was not possible within the scope of this project to sort out all the potential tradeoffs, although we attempt to control for separate impacts through the use of proxy measures (e.g., controlling for differing regulatory regimes).

Just as the economic impact of one component of infrastructure can't be easily separated from another, it is increasingly difficult to separate the impact of infrastructure geographically. An interstate highway crosses – by definition – state lines. Dammed rivers provide water supply and flood control across broad regional swaths of the nation. Advances in energy transmission and distribution allow shared infrastructure systems. One very recent example illustrates this point. An error made during the replacement of a piece of equipment in Arizona caused outages not just locally, but in New Mexico and California, too.[5] Our study is done at the national level and makes no attempt to break out infrastructure or its economic impact at lower levels. (On this point, see Praxis and Kotkin 2010 for excellent coverage at the state level.)

Finally, not all infrastructures are created equal: "Poorly managed or poorly conceived infrastructure does not necessarily generate the same return" to the economy as high-quality, high-performing infrastructure (OECD, 2006). That's why the LRA Index is critical to the success of this analysis – it gives us an indication of the quality of the *performance* of infrastructure in the United States. For the purpose of this analysis and the creation of the LRA Index, "performance" is defined as meeting the needs of the broad range of actors (business, labor, community) as they go about the daily process of interacting in the United States economy.[6] The criteria used by the LRA Index to measure the performance of infrastructure are supply, quality of service and utilization.[7]

[4] Also, see OECD 2006 and 2007 for some forward looking studies on "technology-induced substitution effects" in infrastructure.

[5] "Power restored for most in Ariz., Calif., Mexico, September 9, 2011, Associated Press; and "Cause of Widespread Outage Under Investigation, APS Works to Restore Service to Customers in Yuma Area", Arizona Power Supply Press Release, September 8, 2011.

[6] The definition specified in U.S. Chamber 2010a is "the degree to which the infrastructure system serves U.S. economic and multi-level business community objectives."

[7] The definitions for infrastructure components (energy, transportation and water) and the performance criteria (quality of service, utilization and supply) used in the development of the LRA Index are provided in an Appendix.

BACKGROUND

(This section repeats the "Background" of the economic analysis in U.S. Chamber (2010b) and is included here for completeness. Readers already familiar with that report may skip this section and proceed to "A Simple Model of Economic Growth" without loss of continuity or substance.)

Prior research on infrastructure and its connection to the economy has achieved mixed results. Development of the analytical framework began thirty years ago with studies of government spending on public capital infrastructure projects (the stock or flow of investment money) to analyze the impact on economic growth and productivity as well as on social welfare (reducing income inequality).

Before the mid-1990s, infrastructure research was conducted separately from studies on economic growth (Holtz-Eakin and Schwartz, 1995). In the early 1990s, the basic model was extended to specifically endogenize economic growth and to include private spending on infrastructure. Starting around 1990-1995, empirical modeling with data appeared as academic and policy researchers contributed both theoretical and empirical studies on the contribution of infrastructure development to growth and productivity (Calderón and Servén, 2008a).

Most of the policy work (e.g., Henderson, Shalizi, and Venables, 2000; Gausch and Kogan 2001) is based on examinations of countries where development may have been delayed by the lack of infrastructure. These studies compared countries to each other, usually including some selection of developed countries, implying that good infrastructure has a positive effect on the economy. Generally, that kind of research makes use of comparative cross-regional perspectives in an international context, and the findings measure the contribution of infrastructure to the level and growth of aggregate output and productivity. World Bank economists Calderón and Servén (2008a) offer the best published account of the literature on the growth and inequality effects of infrastructure.

In the last 20 years, literally hundreds of research papers have been published devoted to assessing the effects of infrastructure on growth, productivity, poverty and development, etc. The variety of data and empirical methodologies is nearly as great as the number of measurements. While there are almost as many ways to measure "economy" (e.g., income, output, productivity, growth, etc.), this discussion's focus will be on the differences in the way that "infrastructure" is treated and in the methodologies applied in the analyses.

CHALLENGES WITH MEASUREMENT

As we began our research, we discovered that past global and national studies on infrastructure and the economy reported contradictory findings because they measured "Infrastructure" as "Spending" (Straub 2007). This approach is flawed for several reasons.

First, not all money designated for infrastructure is spent the same way for a variety of reasons, from government inefficiencies and political corruption to purchasing power and the size of the economy, so inconsistency in quantity and quality of infrastructure based on money spent makes measurement difficult. Differences in the efficiency of spending on infrastructure explain one-quarter of the growth differential between Africa and East Asia, and more than 40 percent of the growth differential between low- and high-growth countries (Calderón and Servén, 2008a). Another study from Sanchez-Robles (1998) finds no relationship between infrastructure development and the economy when using spending to measure infrastructure. However, when an index is built based on physical infrastructure, the results are not surprising – economies grow with infrastructure development.

Measuring infrastructure in terms of spending has also resulted in "bi-directional results," where infrastructure affects growth and growth affects infrastructure. In other words, that a growing economy can afford more infrastructures is just as likely a cause of positive statistical results as the possibility that more infrastructures help the economy grow. Further, where spending is used to measure infrastructure, the model usually considers only public spending, ignoring the contribution of investments from private companies (e.g., the contribution of private satellites to communications infrastructure). Calderón and Servén (2008a) report that less than half of the empirical studies using expenditure-based infrastructure measures find that developing or maintaining infrastructure has significant positive effects on the economy. In contrast, over three-fourths of the studies using physical indicators find a significant positive contribution from infrastructure to the economy.

Note, however, that even in studies where physical measures were used, most included only one or two indicators. This was done of necessity in studies that included developing nations, where more data is not available. For example, Estache, Speciale and Veredas (2005, cited in Calderón and Servén 2008a) present pooled linear growth regressions based on an augmented Solow model including a variety of infrastructure indicators, one at a time. Their main conclusion is that roads, power and telecommunications infrastructure – but not water and sanitation – contribute significantly to long-run growth in Africa.

Other studies are arriving at the same results: the relationship between infrastructure and its impact on the economy is buried in the dollars with a model that uses spending to measure infrastructure, but that relationship becomes clear using multiple indicators based on physical measures. Calderón and Servén (2008b, unpublished, discussed and cited in Calderón and Servén, 2008a) found significantly positive effects "using a synthetic indicator of infrastructure quality." (Their index used only one measure of quantity and quality for each of three infrastructure components: broadband, energy and transportation.) We rely on the work, too, of Sanchez-Robles who did a comparative empirical analysis with investment and physical assets and found that measures based on physical assets provide superior, more consistent results in a model of economic growth.

A SIMPLE MODEL OF ECONOMIC GROWTH

The history of the study of what causes economic growth was discussed in detail in our contribution of the economic analysis in U.S. Chamber (2010b and see excerpt above), along with a review of the existing knowledge of the specific role of infrastructure in economic growth. Our work here on economic growth differs from much of the work of others because we move outside discussions solely focused on government spending and social policy. Our work on the role of infrastructure also differs significantly by measuring "infrastructure" as performance (versus money spent, count of physical units, etc.). Since no comprehensive index of infrastructure performance was available, the few prior studies that used an index of infrastructure have created and implemented the index as part of the economic study. Sanchez Robles (1998) is one of the few published examples we found that used an index to measure infrastructure, though the focus was on the quantity of infrastructure and not the quality. Our analysis will use an economic modeling technique similar to that in Sanchez-Robles but with the LRA Index to address the question of whether or not better performing infrastructure aids the economy by providing a functioning base for the activities of the business community.

THE SPECIFICATIONS

We specify a pure time-series model following cointegration methods to estimate a long-run relationship between infrastructure and the economy. The individual data represented by the LRA Index (54 indicators, see U.S. Chamber (2011b)) would overwhelm the economic data if we tried to include all of it in one model with annual observations. We rely on the specification and construction of the LRA Index to provide a measure of the ability of infrastructure to meet the performance demands of productive businesses. The general form of the model (based on Sala-i-Martin 2002)[8] is:

Economic Prosperity = f (Infrastructure | size of economy, population health, government policy)

Prosperity is modeled as growth in GDP per capita (see Appendix 4 for a more technical description). The LRA Index is used to model infrastructure performance. The size of the economy is measured as GDP.[9] Population health is measured using average life expectancy at birth in the United States.[10] In the implementation that follows, we use the ratio of debt-to-GDP[11] as a proxy for government policy which is the same variable we used in our study of the Transportation Performance Index (Trimbath 2011). Federal policy toward transportation infrastructure is tied quite closely to funding – making it virtually impossible to separate the economic impact in a study focusing on performance and not spending. In the case of the LRA Index, where energy and water infrastructure are included, there is much less federal funding involved and much more federal regulation. Below, we construct a simple variable to control for these policy effects as separate from the effect of infrastructure performance on the economy.

[8] See Aschauer (1990) for a critique of other models, e.g., the Y=KL productivity model. The positive impact of infrastructure on the economy was recently shown to be robust across different methodological approaches (Torrisi 2009), provided that infrastructure is not measured by spending or investment (Sanchez-Robles 1998).

[9] Source: GDP and GDP per capita are from the U.S. Department of Commerce, Bureau of Economic Analysis.

[10] Source: Centers for Disease Control.

[11] Source: U.S. Department of Treasury.

MEASURING "INFRASTRUCTURE REGULATION"

Accounting for the impact of regulations on the economy is the subject of much controversy over recent decades. Businesses must stay abreast of changes in federal policy so they can adjust their corporate strategies accordingly. Changes in policy (and even changes in political party platforms) can materially impact the long-term investment plans of companies. When regulatory policy changes frequently, it introduces additional uncertainty that can frustrate the plans of entrepreneurs and investors, as well as business managers. (See the sidebar for an example in the energy sector). For our purposes, we are primarily interested in controlling for the impact of government policy on the economy. Given the depth and breadth of federal regulatory control over energy and water infrastructure, we want specifically to control for that impact in our model. We use a simple count of significant regulatory actions, policy changes and enacted laws that impact energy, drinking water and storm water (plus Department of Homeland Security rules that affect all infrastructure, including transportation which is also in our model). A complete list of regulations considered is in the Appendix. We make no comparison of the impact or cost of any one regulation over another but only count as "1" each action in the year it was committed. After our basic analysis using the ratio

"Publicly induced disarray is not associated with large rates of economic growth." Xavier Sala-i-Martin (1994)

All businesses actively monitor government policy to assure compliance and to adjust corporate strategies for the future. When the business is a heavily regulated one, like electricity generation, changes in policy (or even changes in political party platforms) can materially impact long-term investment plans. And when policymakers flip-flop, as has been the case in recent decade, these heavily regulated companies struggle to adjust, sometimes incurring unnecessary costs as plans must flip and flop in time with anticipated policy.

Take, for example, the regulations currently aimed at the coal-fired electricity generation. Both the Bush and Obama administrations have attempted stricter controls on emissions of sulfur dioxide (SO2), nitrogen oxides (NOx), and mercury in the burning of coal for electricity. President Bush proposed the Clear Skies Act to accomplish these through a cap and trade program; the law was never enacted. Near the end of the Bush administration, EPA tried to impose similar programs via the Clean Air Interstate Rule (CAIR) and Clean Air Mercury Rule (CAMR); these rules were vacated by the courts. The Obama administration has proposed a suite of rules—the Cross-State Air Pollution Rule and the Utility MACT Rule most notable among them—to control emissions of these pollutants from the coal-fired power generation.

For coal-fired electric utilities caught in the crosshairs of these regulations, the question has always been how long to keep the affected equipment running while absorbing the costs of increased regulation. In recent months, several utilities announced the retirement of coal-fired units before their permits expire. The alternative is to continue planning to install new emission control equipment to meet regulations that have yet to be defined.

of debt-to-GDP, we revisit the model using regulations to represent government policy.

RESULTS

The LRA Index measures the performance of energy, transportation and water components of infrastructure. Underlying the analysis of the components is the framework for measuring three criteria of performance: Supply, Quality of service and Utilization. (See U.S. Chamber 2011b for complete report on the LRA Index. Summary definitions of the components and criteria are included in the Appendix to this report for the convenience of the reader.) In the analysis that follows, we refer to the contribution of the criterion "Supply" as "LRA Supply"; the contribution of the criterion "Quality of service" as "LRA Quality" and the contribution of the criterion "Utilization" as "LRA Utilization".

TABLE 2 *CORRELATION COEFFICIENTS WITH GROWTH OF GDP PER CAPITA*

	LRA Index	LRA Supply	LRA Quality	LRA Utilization	Regulations
Concurrent	0.0584	-0.2203	0.2767	-0.3398	-0.0372
Economy 3 yrs ahead	0.5294*	-0.0453	0.6302*	0.2123	-0.7289*

* Statistically significant at 5% level or better. Correlation coefficients estimated using STATA Intercooled 7.0 with pair-wise restriction. See Appendix 4 for technical specifications.

Here we see results somewhat similar to those found with the TPI: good performing infrastructure has a positive impact on economic prosperity and that effect is stronger after some time has passed – in this case, three years.[12] For the contribution of the criteria of infrastructure performance, we see that LRA Quality – which is weighted 0.49/1.00 for the three criteria (see Appendix) – accounts for more than the lion's share of the connection. The table above also shows that regulations have a negative impact on the economy and that the impact is stronger after some time has passed. This simple univariate analysis tells only part of the story because it

[12] See U.S. Chamber 2010b for more on the selection of a 3 year lead time between changes in the performance of infrastructure and the economy; and for a discussion of the role of infrastructure as a leading indicator of economic activity.

does not allow us to control for important variables – like the starting size of the economy – that are known to have an impact on economic growth.

For this, we turn to the multivariate (time-series) model described above. Our regressions are estimated with robust standard errors. We specify the Huber/White/sandwich estimator, which produces consistent standard errors even if the data are not identically distributed. The results (using the same model applied to the TPI in Trimbath 2011) indicate that improvements in the economy are dependent on improvements in the performance of infrastructure.

TABLE 3 *REGRESSION RESULTS*

	1	2	4
Real GDP (t-1)	-0.0650	-0.0230	-0.0316
	(-2.00)	(-0.95)	(-1.25)
Life Expectancy	0.0255	0.0054	0.0118
	(2.10)	(0.92)	(1.23)
Debt/GDP Ratio	-0.1740		
	(-3.18)		
LRA Index (t-3)	0.0021		
	(3.50)		
LRA Quality (t-3)		0.0021	0.0020
		(2.83)	(2.82)
Regulations (t-3)		-0.0059	-0.0054
		(-3.67)	(-3.16)
Energy Regulations			-0.0038
			(-2.28)
F-statistic	21.42	35.62	36.07
R-squared	0.80	0.86	0.88

Table entries are regression coefficients (t-statistics in parentheses) estimated using STATA Inter-cooled 7.0 software. Dependent variable is growth rate of GDP per capita; Real GDP is for base year of growth rate; GDP and GDP per capita in natural logarithms; 17 observations in all models. Regulations (see appendix for details) and the indices enter the model at (t+3), i.e., we specify that the impact is delayed by 3 years. When Energy regulations are examined separately, they enter the model contemporaneously with the growth of GDP per capita. See Appendix 4 for technical specifications.

The coefficient on the Debt/GDP Ratio is not statistically significant in models (not shown) with the variables measuring infrastructure regulations. The coefficient on LRA Index is not significant in a model with the regulations control variable. We tried the contribution of all three criteria of infrastructure performance – quality of service, utilization and supply – separately and in combination with LRA Index without improving over the results in the models shown. The Index of U.S. Energy Security Risk (U.S. Chamber of Commerce 2011c) and its several components also do not produce statistically significant coefficients in this model. The best results are achieved using the contribution of the quality criterion ("LRA Quality") to the LRA Index.

Given our interest in examining the performance of infrastructure and the regulations that impact it on the economy, we use the Wald test to see if these impacts are statistically significantly different.[13] The results indicate that the absolute value of the negative coefficient on Regulations is greater than the positive coefficient on LRA Quality.

DISCUSSION

The coefficients on the LRA Index and/or the LRA Quality criterion[14] remain fairly consistent regardless of which control variables are added to the specification – there is about a 0.2% impact on the growth of GDP per capita for incremental changes in the performance of infrastructure in the U.S..[15] Regulations, on the other hand, have a slightly stronger impact in the opposite direction – a test of the coefficients indicates that the probability is less than 1% that the benefit of improved infrastructure quality would not be completely negated by increasing major regulations. Further, the strongest impact we found for regulations was about the same as the energy regulations alone (about -0.5% GDP per capita per regulation).

Variations in the quality of infrastructure will be reflected in the impact on growth (though few prior studies have controlled for it). Differences in the efficient deployment of infrastructure spending have been shown to account for between 25 percent and 40 percent of the differences between countries (Hulten 1996, cited in Calderón and Servén 2008a). A comparison to the results in Calderón and Servén (2008a) may provide some insight into our results. They found a

[13] H_0: - Regulations + Quality = 0.0
F(1, 13) = 33.21
Prob > F = 0.0001
See Appendix 4 for technical specifications.

[14] See Appendix 3 for full list of measures included in the contribution of "Quality of Service" to the LRA Index.

[15] Another way to think of this result is that a 2% improvement in the LRA Index (an increase of 1) would result in a 0.2% increase in the growth of GDP per capita. U.S. real GDP per capita declined year-over-year in 2009.

positive impact from quality of infrastructure for broadband, energy and transportation that accounted for about one-third of the overall gain in growth of GDP per capita attributable to the development of infrastructure.[16] We can speculate that LRA Quality has a stronger impact than either supply or utilization (indicating capacity to handle expanded demand) for similar reasons. They also reported that roads, power and telecommunications were important for long run economic growth – but not water infrastructure or sanitation. It is possible that supply and utilization are not key economic determinants in the United States where water and energy infrastructure reach 99% of households and businesses.

We note that storm water regulations enter the model with a statistically significantly positive coefficient – an indication that these may actually benefit the economy, although the explanatory power of this model is not quite as strong as is the model using energy regulations. Our interpretation of this result is that storm water regulations may have benefited the economy by providing better controls against, e.g., urban flooding which is known to have a negative impact on economic activity (i.e., through over-powered transportation systems, lost economic activity, etc., in addition to actual flood damage to productive economic assets).[17]

Improvements to the performance of infrastructure may be sustained over long periods of time. For example, the contribution of quality of service to the LRA Index was around 34 in 1993 but improved the next year and stayed around 36 for the following 5 years. In our model, this sustained improvement in quality would generate an on-going increase of 0.2% to GDP per capita. Regulations in our model, on the other hand, are not modeled to endure beyond the initial policy action. Therefore, the -0.5% impact would not continue to detract from economic growth as long as the regulation is in place. We posit that this one-time detriment comes from the burden of adapting corporate strategic planning to accommodate compliance and/or from the cost of implementing changes to bring infrastructure into compliance with regulations.

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[16] They used synthetic indicators for infrastructure quality (Calderón and Servén 2008b), which is not completely unlike the index that we employed. Their measures were limited to quality of service in telecommunications, electricity and roads, with a result that quality of infrastructure added an average of 0.12% to annual growth beyond the growth impact of accumulating infrastructure quantities. Although this study was for developing countries in Africa and south Asia, which have very different dynamics than the U.S., we found few other economic studies that modeled growth using infrastructure performance or quality, largely due to the lack of data.

[17] For example, the 2010 floods in Nashville, after receiving 13 inches of rain, caused an estimated $1 billion in damage, according to Nashville Mayor Karl Dean (CBSNews.com, May 5, 2010, 5:32PM).

As an example, consider the impact of one set of regulations – "clean air" or "cap and trade" – on just the energy component of infrastructure (see sidebar). Policymakers shifted back-and-forth on this issue for decades (see sidebar). This puts unnecessary pressure on business decision making. Business planning takes place on a long-term horizon. Coal-fired power plants in the U.S. have an average age of 43 years (see table). The capacity weighted average age of ALL power generation in the U.S. – including the newest renewable – is 25.8 years (see Table 4). The Environmental Protection Agency held the first auction of air emission allowances at the Chicago Board of Trade in the 1990s. More than 20 years later, policymakers are still debating the issue. This example of air quality regulations impacting power generation exemplifies the problem that businesses have when making long-run investment plans in the face of short-run government policies – and the impact we attempted to capture in our model.

TABLE 4 AGE (IN YEARS) OF OPERATIONAL GENERATORS BY MAIN FUEL OR ENERGY SOURCE USED

Main Fuel/Energy Type	Oldest	Average	Capacity Weighted Average[a]
Coal	89	43	37
Biomass			
Wood[b]	81	33	30
MSW combustion	62	25	22
Landfill Gas	41	9	11
Geothermal	39	21	24
Hydro	119	60	50
Natural Gas	95	23	18
Nuclear	41	30	29
Petroleum	87	30	35
Pumped Storage	82	36	32
Solar	26	6	17
Wind[c]	35	8	5

[a]Indicates average age of the majority of the capacity in category.
[b]Wood and wood derived fuels, mainly paper mill sludge.
[c]Wind projects/farms, many with multiple turbines.
Source: http://www.eia.gov/tools/faqs/faq.cfm?id=110&t=3

SUGGESTIONS FOR FURTHER RESEARCH

This initial analysis only scratched the surface of the work that can be done using the LRA Index to examine the economic importance of well-performing infrastructure in the United States. There are several variations that might improve on the results – i.e., that may reveal a stronger impact than the 0.2% we uncovered here. The first would be to use the Input-Output (I-O) accounts available from the U.S. Department of Commerce's Bureau of Economic Analysis. The I-O accounts provide data showing how the output from one U.S. industry becomes the input to another. One simple idea is to use these accounts to remove "infrastructure" providing industries from the measures of GDP, thereby removing the final bit that could be attributed to two-way causation. Another idea is to focus a study on the industries that make the most use of "infrastructure" as an input. For example, our initial review of the I-O tables revealed that management consulting as an industry relies more heavily than any other on "transportation" as an input to production.[18]

Another interesting application of the LRA Index would be to examine dependencies with foreign direct investment (FDI), similar to what we did with the TPI (Trimbath, 2011)[19]. Job creation and new business start-ups have been used in the past on studies of the availability (supply or utilization) of infrastructure – the LRA Index might provide more stable results since it helps to remove the impact of building new infrastructure from the equation. Although we found no significant impact on the growth of GDP per capita from the Energy Risk Index (U.S. Chamber 2011c), combining it (or its components) with the LRA Index might produce interesting results for the dependency of FDI for new businesses and new jobs. It is, by now, well-established that quality infrastructure attracts jobs, capital and "know-how" that enhances the ability of a nation to compete in the global economy (OECD 2006 and McKinsey 2011).

There may be multiple ways to improve the policy variable we used to control for the impact of regulations on infrastructure. However, given the interdependencies and the complexity of the regulatory framework (e.g., one new law could impact several infrastructure components), we suspect that the best new work that can be done will require a narrow focus on only one

[18] Transportation is about 14% of the inputs; see U.S. Chamber 2010a for sources and more on this point.
[19] No new observations on the FDI establishing new enterprises in the U.S. have been made available from the Bureau of Economic Analysis since our analysis in July 2011.

component or perhaps only one regulation as it changes (amendments, enactments, etc.) across time.

Finally, some work is being done now to place a total value on infrastructure using the market valuation of private infrastructure investment funds (e.g., Howard 2011). As a point of reference, it would be interesting to compare the LRA index to this valuation as a proxy for "spending". In our parallel analysis on transportation infrastructure performance, the data indicates that spending was largely unrelated to performance.

THE OUTLOOK FOR INFRASTRUCTURE INVESTMENT

Our analysis leaves unanswered the question of how it is that the U.S. economy continued to thrive while infrastructure remained in such decline. Except for the most recent period beginning in December 2007, throughout the time covered by the LRA Index (1990 – 2009), the U.S. experienced only two short (8 months each), mild recessions: from July 1990 to March 1991 and again from March 2011 to November 2011. Yet, the U.S. remains home to 22 of the top 100 owners of infrastructure in the world (Bentley 2010a).[20] About two-thirds of the world's infrastructure is built and maintained by private companies, including (in the U.S.) Exxon Mobil Corporation (energy), AT&T Incorporated (information communication technology), and Burlington Northern Santa Fe Corporation (transportation). Was this a period of profit without re-investment in productive assets? Or is it simply that the public investment in infrastructure has fallen significantly behind what private companies are doing for themselves?

Between 2007 and 2009, the share of global institutional investors who considered "infrastructure" as a separate asset class rose from just ten percent to nearly half (Tal 2009). Pension fund allocations to "alternative" investments in infrastructure are increasing and are expected to continue to trend upward.[21] Of the 10 largest infrastructure funds, five are focused on the U.S., four on Europe and one on the rest of the world. The UK, with about one-fifth the

[20] We acknowledge that Bentley measures "infrastructure" more broadly than we do and that some "private" companies in the top 22 currently have high percentage ownership by the U.S. Government (i.e., Motors Liquidation Company and American International Group (AIG)).

[21] Data on pension investments used in this paragraph come from *Infrastructure Spotlight*, Vol 3(8), page 13, August 2011, Preqin, Ltd., London [Online preqin.com].

population of the U.S., had almost as many private deals for investment in infrastructure close from 2008 to 2011 (136 versus 144). Globally, there are 229 public pension funds investing in infrastructure projects. With a median of $5.7B assets under management, these public pension funds have roughly 2.6 percent invested in infrastructure and intentions to raise that allocation to 4.2 percent. The Ontario Municipal Employees Retirement System (OMERS), the largest pension fund in Canada, has 29 percent of assets allocated to investments in infrastructure. In contrast, the California Public Employee Retirement System (CalPERS), the largest in the U.S., has a target of allocating two percent of assets to infrastructure investment, and less than 60 percent of that is targeted for investment in the U.S.. CalPERS recently announced plans to invest up to $800 million in energy-related projects in California, which will absorb about one-third of their infrastructure investments designated for the U.S..[22]

This influx of capital to infrastructure is occurring around the world out of necessity. OECD (2006) estimates that the cumulative infrastructure investment requirements from 2000 to 2030 globally for ground transportation, telecoms, energy and water will reach $71 trillion. This figure includes only surface (road and rail) under transportation infrastructure – including ports, airports, etc. would drive the figure higher even faster since their estimate anticipates a decline in land transportation (and telecom) infrastructure investment over the next twenty years. The investment requirement is estimated to be about 3.5% as a share of World GDP (OECD 2007). For comparison, U.S. businesses spent an amount equal to 12% of GDP on the assets used in current and future production.[23]

[22] "CalPERS eyes $800 million for California infrastructure", by Arleen Jacobius, *Pensions & Investments*, September 13, 2011. [Online] http://www.pionline.com/article/20110913/DAILYREG/110919964#ixzz1Xy8WVIdw

[23] World Factbook available at www.cia.gov. Gross Fixed Investment is "total business spending on fixed assets … gross of the depreciation of the assets, i.e., it includes investment that merely replaces worn-out or scrapped capital.) On this measure, the U.S. ranked 143rd out of 149 countries examined.

TABLE 5 *ANNUAL INFRASTRUCTURE INVESTMENT REQUIREMENTS (U.S. DOLLARS, BILLIONS)*

Type of Infrastructure	2010 to 2020	2020 to 2030	Percent of World GDP by 2025
Road	245	292	0.29
Rail	54	58	0.06
Telecoms	646	171	0.17
Electricity [1]	180	241	0.24
Water [2]	772	1,037	1.03
Total Annual Average	1,897	1,799	

Source: Adapted from OECD 2006
1. Transmission and distribution only.
2. Only OECD countries, Russia, China, India and Brazil are considered for Water Infrastructure.

We can use the OECD estimate and the result of our analysis to illustrate the payback period for investments in infrastructure. For simplicity, we'll demonstrate the concept using an economy where GDP is $100. In the first year, an investment of $3.50 is required to build, maintain and enhance infrastructure. Investments in infrastructure are long-lived, but we will assume that this investment is able to make an incremental improvement in infrastructure performance that will endure for 20 years before performance reverts to the pre-investment level. If this makes only a 0.2% increase in the economy each year that the performance improvement holds, then the initial investment of $3.50 is paid back in 17.2 years – significantly less than the life-cycle of a power plant, energy transmission lines, dams and reservoirs, bridges, etc. etc.

TABLE 6 *ILLUSTRATION OF CASHFLOWS AND PAYBACK FOR INFRASTRUCTURE INVESTMENT*

Outflow	Year	Inflow	GDP
$ 3.50	2010	$ -	$ 100.00
$ -	2011	$ 0.20	$ 100.20
$ -	2012	$ 0.20	$ 100.40
$ -	2013	$ 0.20	$ 100.60
$ -	2014	$ 0.20	$ 100.80
$ -	2015	$ 0.20	$ 101.00
$ -	2016	$ 0.20	$ 101.21
$ -	2017	$ 0.20	$ 101.41
$ -	2018	$ 0.20	$ 101.61
$ -	2019	$ 0.20	$ 101.81
$ -	2020	$ 0.20	$ 102.02
$ -	2021	$ 0.20	$ 102.22
$ -	2022	$ 0.20	$ 102.43
$ -	2023	$ 0.20	$ 102.63
$ -	2024	$ 0.21	$ 102.84
$ -	2025	$ 0.21	$ 103.04
$ -	2026	$ 0.21	$ 103.25
$ -	2027	$ 0.21	$ 103.45
$ -	2028	$ 0.21	$ 103.66
$ -	2029	$ 0.21	$ 103.87
$ -	2030	$ 0.21	$ 104.08
$ 3.50		$ 4.08	

Cash flow analysis by author. Internal rate of return is 1.5%, compared to 1.4% average interest rate paid by the U.S. Treasury for long-term (greater than 10 years) borrowing January 3, 2011 through September 26, 2011 (www.treasury.gov/resource-center).

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The U.S. is now and is projected to remain through 2050 the 3rd most populous nation on earth (behind only India and China).[24] With the influx of money being made available for infrastructure investment, it is time to get it right. The U.S. Chamber of Commerce, with the release of the LRA Index, is introducing recommendations for taking this opportunity to build *quality* infrastructure that performs in ways that *support* economic activity.

[24] Source: www.census.gov

The U.S. Chamber of Commerce is not alone in recommending policy changes for the sake of infrastructure.[25] Not only in the U.S., but across the developed nations, there is no component of infrastructure – with the possible exception of information communication technology – that has a regulatory structure in place "that allows for the full and effective participation of private actors" (OECD 2006). The OECD (2006 and 2007), in their review and analysis of infrastructure needs through 2030, concludes that economic prosperity "is inextricably intertwined with the policy environment and the governance context in which infrastructures are developed."

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APPENDIX 1: DEFINITIONS USED IN LRA INDEX

The following definitions apply to the LRA Index which was used in the present analysis. (See U.S. Chamber 2010a and U.S. Chamber 2011b for additional information.)

COMPONENTS OF INFRASTRUCTURE AND CATEGORIES OF COMPONENTS

Component Energy – "Energy infrastructure includes: (1) networks that produce or import raw energy materials and distribute them to conversion infrastructure, such as pipes for oil and natural gas; (2) facilities that convert raw energy materials to useful forms of energy resources (fuels and electricity), such as refineries and power plants; and (3) networks that deliver refined fuels and electricity to end users in households, businesses, industry, mining, agriculture and other activities, such as electricity transmission lines and other means of transportation."

Energy Categories: Electric, oil, gas, nuclear

Component Transportation - "the fixed facilities (roadway segments, railway tracks, transit terminals, harbors, and airports), flow entities (people, vehicles, container units, railroad cars), and control systems that permit people and goods to transverse geographical space efficiently and in a timely manner in some desired activity. Transportation is provided by modes or categories -- highway, rail, air, and marine."

Transportation Categories (modes): Highway, transit, air, rail, marine, intermodal

Component Water – "The part of the total water system – which includes rivers, lakes, rainfall, etc. – that is the man-made portion (the controllable portions) as infrastructure to supply water for communities, economies, and agriculture. The facilities, such as the reservoirs, towers, pipes, pumps, sewers, treatment plants and drainage systems that we rely on every day to store, transport and treat our water are commonly divided into drinking (potable) water, wastewater and storm water infrastructure. Watersheds and water resources are important for flood control, reducing the impact of droughts and supporting both agriculture and recreation."

Water Categories: Potable, waste

CRITERIA FOR PERFORMANCE

Supply: captures availability and coverage ("What geographical area is covered?")

Quality of service: captures inconvenience, cost of disruption and reliability ("How well is service provided?")

Utilization: captures whether growth can be accommodated ("How fully the are existing facilities used?")

SUMMARY OF WEIGHTS BY COMPONENT AND CRITERIA

Criteria	Supply		Quality of Service		Utilization		Totals	
Component	# of Indicators	Weights	# of Indicators	Weights	# of Indicators	Weights	# of Indicators	Weights
Energy	5	0.084	7	0.129	6	0.176	18	0.389
Transportation	8	0.096	9	0.144	4	0.066	21	0.307
Water	2	0.021	10	0.220	3	0.064	15	0.305
	15	0.200	26	0.493	13	0.306	54	1.000

APPENDIX 2: INFRASTRUCTURE REGULATORY ACTIONS BY YEAR

Year	Type	Name
1990	Drinking Water	Lead and Copper Regulations (under Safe Drinking Water Act (SDWA))
1990	Energy	Clean Air Act amendments
1990	Energy	Oil Pollution Act
1990	Storm Water	National Pollutant Discharge Elimination System (NPDES) Regulations for storm water discharges
1990	Storm Water	Great Lakes Critical Programs Act
1991	Storm Water	Water Quality Standards Regulation amended
1992	Energy	United Nations Framework Convention on Climate Change
1992	Energy	National Energy Policy Act of 1992
1996	Drinking Water	SDWA Amendments
1996	Drinking Water	Information Collection Rule
1997	Energy	Kyoto Protocol
1997	Energy	EPA revises NAAQS for Ozone and Particulate Matter
1998	Drinking Water	Interim Enhanced SWTR
1998	Drinking Water	Disinfectants and Disinfection By-Products (D-DBPs) Regulation
1998	Drinking Water	Contaminant Candidate List
1998	Storm Water	Clean Water Action Plan
1999	Drinking Water	Unregulated Contaminant Monitoring Regulations
1999	Storm Water	National Pollutant Discharge Elimination System final rule on storm water discharges
2000	Drinking Water	Lead and Copper rule – action levels
2000	Energy	Commodity Futures Modernization Act (affected energy trading companies)
2000	Storm Water	"Alaska" Rule established water quality-based effluent limitations under CWA
2001	Drinking Water	Filter Backwash Recycling Rule
2002	All	Critical Infrastructure Information Act (DHS)
2002	Drinking Water	Long Term 1 Enhanced SWTR
2002	Drinking Water	Unregulated Contaminant Monitoring Regulations
2002	Energy	Brownfields Revitalization and Environmental Restoration Act
2002	Energy	Clear Skies initiative announced, followed by unsuccessful multi-pollutant legislation
2002	Energy	EPA issues changes to New Source Review (NSR) program
2004	All	Feb 2004 Interim Rule on Protected Information
2005	Drinking Water	Drinking Water Contaminant Candidate List 2
2005	Energy	Energy Policy Act of 2005
2005	Storm Water	NPDES Storm Water Rules

2006	All	Final Rule for "Procedures for Handling Protected Critical Infrastructure Information"
2006	Drinking Water	Long Term 2 Enhanced SWTR
2006	Drinking Water	Stage 2 D-DBP Rule
2006	Drinking Water	Ground Water Rule
2006	Energy	EPA revises NAAQS for Particulate Matter
2006	Storm Water	NPDES Storm Water Rules
2006	Storm Water	Energy Policy Act (storm water discharges)
2007	Drinking Water	Lead and Copper rule – short-term revisions
2007	Drinking Water	Unregulated Contaminant Monitoring Regulations revised
2007	Energy	Energy Independence and Security Act of 2007
2008	Energy	Food, Conservation and Energy Act of 2008 (Farm Bill) (incentives for biofuels, etc.)
2009	All	National Infrastructure Protection Plan
2009	Drinking Water	Aircraft Public Water Systems
2009	Drinking Water	Stage 2 D-DBP Rule correction and changes
2009	Energy	American Recovery and Reinvestment Act (stimulus)
2009	Energy	Waxman-Markey passes in the House
2009	Energy	EPA expands scope of existing laws through regulation

Sources: Energy regulations from U.S. Chamber of Commerce; Drinking Water regulations 1990 through 2006 from CDC (2008, Table 1, page 41). Drinking water regulations 2007 through 2009 and Storm Water regulations compiled by author based on EPA.gov and regulations.gov; and regulations affecting all components of infrastructure compiled by author based on DHS.gov.

APPENDIX 3: QUALITY OF SERVICE PERFORMANCE INDICATORS

Component	Category	Description	Measure
Energy	Electric	Distribution Losses	Percentage of electric generation, transmission, and distribution losses
	Electric	Loading Reliefs	# of Transmissions Loading Reliefs (TLRs)
	Electric	Electric Outages	Customer hours of electric outages
	Oil	Oil Pipeline Incidents	Oil pipeline incidents per million cubic feet of oil transported
	Gas	Gas Pipeline Incidents	Gas Pipeline Incidents per million cubic feet of gas transported
	Oil	Underground Storage Tank Leaks	# of leaking underground storage tanks
	Oil	Navigable Water Oil Spills	Gallons of pipeline petroleum oil spills at navigable U.S. waterways
Transportation	Highway	Travel Time Reliability (Variability in travel time due to congestion)	Travel Time Index
		Safety (Fatal highway crashes)	Fatalities per 100 million Vehicle Miles Traveled
		Road Roughness (Highway ride comfort)	Percent of lane miles in poor or fair condition (based on an International Roughness Index greater than 170 in/mi)
		Bridge Integrity (Ability of bridges to meet the needs of the users)	Percent of bridges structurally deficient or functionally obsolete
	Transit	Safety (Transit incidents)	Number of incidents per million Passenger Miles Traveled
	Aviation	Congestion (Airport congestion)	Percent of on-time performance for departures
		Safety (Chances of crashes)	Runway incursions per million operations
	Rail	Safety (Railroad incidents)	Number of incidents per million train miles
	Marine	Congestion (Delays on inland waterway)	Average lock delay per tow
Water	Potable	Non-Violation System Accessibility	% of population served by systems not reporting any health-based violations
	Potable	Water Borne Disease Incidents	Waterborne Disease in Drinking Water - Incidents
	Potable	Water Borne Disease Population	Waterborne Disease in Drinking Water - Population impacted
	Potable	Water Borne Disease Deaths	Waterborne Disease in Drinking Water - Deaths
	Potable	Infrastructure Quality (Potable)	Drinking Water Investment Needs

	Potable	Treatment Failures	Potable water boil order incidents
	Potable	Water Security	% of high hazard potential dams requiring rehabilitation
	Potable/ Waste	Restricted use	% of stream miles impaired
	Waste	Infrastructure Quality (Waste)	Wastewater and stormwater management investment needs
	Waste	Distributed Infrastructure Effectiveness	Non-point source pollution investment needs

Source: U.S. Chamber 2011b

APPENDIX 4: METHODS AND FORMULAS

MODEL SPECIFICATIONS

The analysis uses a basic growth model to determine the impact of infrastructure on economic growth, given the size of the economy, the health of the population and government policy. In the text, we use the simple description:

Economic Prosperity = f (Infrastructure | size of economy, population health, government policy).

Here we present the same model in more formal terms. We estimate the model:

$$\Delta \ln GDPpc_{(t-1,\, t)} = \beta\ LRA_{t-3} - \delta_1 \ln GDPpc_{t-1} + \delta_2 LifeE_t - \delta_3 Debt/GDP_t + \varepsilon$$

where the variables are as described in the text. $\delta_1 < 0$ is hypothesized based on well-accepted results in the economic literature that smaller economies grows faster. The expected signs on δ_2 and δ_3 are similarly hypothesized. Additional results are reported for models substituting the contribution of quality to the LRA Index ("LRA Quality") for the term "LRA" and a proxy for government regulation of infrastructure (described in the text) for Debt/GDP.

PAIR-WISE CORRELATIONS (TABLE 2)

Correlation commands in Stata (as in most statistical software) calculate correlation coefficients using case-wise deletion. If any variable is missing observations, no correlation coefficients are calculated for any of the other variables in the matrix for that year. Pair-wise correlation coefficients use all available observations where two variables are observed.

The estimate of the product-moment correlation coefficient p is

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where $\bar{x}$ is the mean of x and $\bar{y}$ is the mean of y. Then, the unadjusted significance level is calculation by State in the pairwise correlation command as

$$p = 2 * \boldsymbol{ttail}(n - 2, \hat{p}\sqrt{n-2}/\sqrt{1-\hat{p}^2}$$

where ***ttail*** is a Stata command (performed internally to the command for pair-wise correlations) to calculate the reverse cumulative Student's t distribution which returns the probability $T >$ t.

ROBUST VARIANCE IN REGRESSION (TABLE 3)

The calculation is

$$\hat{V} = q_c\, \hat{\boldsymbol{V}} \left(\sum_{k=1}^{N} \boldsymbol{u}_k^{(G)}{}' \boldsymbol{u}_k^{(G)} \right) \hat{\boldsymbol{V}}$$

where

$$\boldsymbol{u}_k^{(G)} = \sum_{j \in G_k} w_j\, \boldsymbol{u}_j$$

G_1, G_2, … G_M are clusters (if specified); and w_j are user-specified weights, in our case equal to 1 (since no weights are used). Further

> $\hat{\boldsymbol{V}}$ is a conventionally calculated variance matrix;
>
> u_j, $j = 1$ …, N is a row vector of scores; and
>
> q_c is a constant finite-sample adjustment.

Therefore, we can define q_c by the formula

$$q_c = \frac{N}{(N-k)}\,.$$

The asymptotic-like formula for q_c is

$$q_c = \frac{N}{(N-1)}\,.$$

WALD TEST (FOOTNOTE 13)

Stata performs Wald tests using the following specifications;

Let the estimated coefficient vector be **b** and the estimated covariance-covariance matrix be **V**. Let **Rb** = **r** denote the set of q linear hypotheses to be tested jointly. Then, the Wald test statistic is computed as

$$W = (\mathbf{Rb} - \mathbf{r})'(\mathbf{RV}\mathrm{R}')^{-1}(\mathbf{RB} - \mathbf{R})$$

The estimation command reports its significance levels using t statistics with d degrees of freedom, so that an F statistic is computed as

$$F = \frac{1}{q}W$$

and an F distribution with q numerator degrees of freedom and d denominator degrees of freedom is used to compute the significance level of the hypothesis test.