Aging U.S. Infrastructure

Neil Clymer

Introduction

Public infrastructure undergirds every large national economy. It correlates with the level of economic development, the power of the government to tax and manage public services, the quality of large scale organizational skills, and the ease or difficulty that domestic foreign firms encounter when conducting just about any type of enterprise. (Edwards, 2013, Schwab and Porter, 2008, Schwab, 2012) Well developed infrastructure is especially critical in and between major metropolises. Concrete and steel facilities and associated machinery and electronics are prerequisite for safe, clean, comfortable, mobile, and well informed lifestyles.

Roads, bridges, tunnels, public transit systems, train stations, airports, shipping ports, dams, levees, reservoirs, water supply systems, sewage facilities, public communications such as satellite weather reporting and air traffic control, schools for primary and secondary education, police, fire protection, jails and prisons, are examples of public infrastructure. Other infrastructure such as electric power distribution systems, railroads, and hydrocarbon pipelines are frequently privately owned. However since these facilities are closely regulated by government authorities, they are also typically circumscribed within the umbrella definition of infrastructure. This definition (although often excluding privately funded assets in econometric analyses) is generally consistent in economic literature and among members of the Civil Engineering community. (Gramlich, 1994, Victor, 2013)

Good infrastructure is not a blank check guarantee that all is well in a society. There are cities in this world with excellent infrastructure where due to high prices, overcrowding, pollution, and restraints on freedom, living standards are less than exemplary, yet the other side of the coin is almost never true. Poor infrastructure is a dead giveaway for low standards of living, inept or corrupt governance, and an indication of weak public sector finance and management (Schwab and Porter, 2008, Schwab, 2012).

Physical infrastructure projects are among humankind's most expensive, most politically controversial, and irreversible endeavors. Decisions to erect and maintain infrastructure bring together the fair winds of social responsibility, public welfare, and national investment with the storms of politics, taxes, and huge business opportunities in construction and operations. The seemingly irreversible and risky nature of infrastructure investment makes for contentious choices that affect the livelihoods of present and future generations.

This research note explores the past and present states of U.S. infrastructure. In the next section of this paper we review extant research related to the economic benefits of past U.S. infrastructure investment. The section that follows summarizes the history of infrastructure creation in the United States and leads to a synopsis of the present state. We continue in the format of a narrative to highlight poignant examples of recent infrastructure failures that may hint at a troubling trend of progressive breakdown. Lastly, we present up to 115 years of consumption statistics of key industrial materials that go into the composition of public infrastructure. This data was obtained from the U.S. Geological Survey. and the U.S. Energy Information Administration. We find that U.S. consumption of these material inputs has generally increased up until the recent economic recession. After 2008 there is a precipitous decline. This may forebode that problems lie ahead for U.S. infrastructure.

Economic research on U.S. infrastructure

Engineering analysis of infrastructure goes back to the ages of antiquity. The Romans studied construction techniques and designs before they built roads and aqueducts. Economic analysis of infrastructure on the other hand is a recent endeavor. Some scholars regard Aschauer's work in the late 1980s and early 1990s to be seminal. (Gordon, 1997, Gramlich, 1994) Aschauer used government infrastructure investment as an input variable in a Cobb-Douglas production function where the output is a measure of U.S. private sector goods and services. (Aschauer, 1990) He investigated the effect of infrastructure on productivity.

Productivity growth in the United States had fallen from 2.8% during a period of heavy infrastructure investment between 1953 through 1969 to 1.4% during a period of much lower infrastructure investment between 1970 through 1988. Aschauer hypothesized that the fall-off in public infrastructure investment may have been a cause for the productivity slowdown. He found evidence to support the conjecture. Ashauer's models showed that infrastructure investment produced such astonishing rates of return of 50 to 60% that the author himself and others were skeptical. (Aschauer, 1990, Gordon, 1997, Gramlich, 1994) Nevertheless, Aschauer opened the door to a research methodology that has been used to this day.

Econometric analysis of the effects of infrastructure investment was then and is still fraught with difficulties. Many empirical studies are built on production functions not unlike those used by Aschauer. These types of models have some weaknesses. Most infrastructure studies focus on public (government financed) infrastructure. Even when user fees are applied, public infrastructure is typically priced below marginal cost. This complicates estimation of elasticity variables. (Gramlich, 1994)

Another problem with economic modeling of infrastructure is endogeneity, cause and effect relationships that operate in both directions. (Chandra and Thompson, 2000) An empirical model may be attempting to investigate whether there is evidence that unbiased decisions to undertake regional construction projects led to job creation in later periods. However, in those same regions prior period absences of jobs may, for example, have lit political fuses that set off acts of legislation to fund that supposedly unbiased construction in the first place. Whether this or some other mechanism is at work, the likely effects of the infrastructure investments will not be independent from the conditions that precipitated those investments.

Some studies of U.S. infrastructure have addressed these issues by analyzing a single type of infrastructure, often roads and highways, and sometimes by limiting the research to rural geographies. Highways and roads are the most widely used form of U.S. infrastructure and they comprise the biggest component of infrastructure expenditure. (Gramlich, 1994, U.S. BTS, 2013) Individual highway construction projects can also be uniquely identified with information from the U.S. Department of Transportation.

A thorough study of the effects of 1969 to 1993 highway construction that passed through rural counties looked at cross-sectional industry effects. Highway construction projects are usually undertaken to connect metropolitan areas. Since this study analyzed only the rural counties (and adjacent rural counties) that city to city highways passed through it avoided the endogeneity trap. (Chandra and Thompson, 2000) Chandra and

Thompson's research found that rural highway construction generated no net long term growth advantage for the rural regions (highway transition counties and adjacent counties) however retail and service activity shifted from adjacent counties to transition counties, and regional farming growth declined, while manufacturing showed higher growth than in regions that were distant from highways. (Chandra and Thompson, 2000) Another study provided evidence suggesting that, in the post World War II period, the closing of rural railroads in the United States and consequent shifting of agricultural transport to trucks may have contributed to higher local market price variation of seven crops. (Sharp and Uebele, 2013) Nevertheless, rural America has clearly benefited from other forms of infrastructure, especially dams and water control projects.

Three important recent studies analyzed the effects of transportation infrastructure on employment growth, trade, and innovation in urban America. Prior to this research, there had been relatively few cross-sectional empirical studies of how the economies of cities are affected by additions of highway infrastructure. (Agrawal, et. al., 2014, Duranton and Turner, 2012, Duranton, et. al., 2014) We can look at these three studies together because they are related. In each, the independent variable of concern is highway construction. Employment growth, trade, and measures of innovation are respectively regressed on the additions of metropolitan highways.

Since highway construction projects are not exogenous events untreated values that represent new urban highway construction will not produce unbiased regression estimates. One way to solve this problem statistically is to first regress the highway variable on a combination of control variables and one or more instrument variables. Estimates calculated in this regression are unbiased predictions for values of the highway variable. Values of the highway variable are replaced with these predictions in a second regression where the predictions are the main explanatory variable. In order for this procedure to be valid, the values of the instrument variables must be clearly uncorrelated with error terms in equations that describe relationships between the dependent and the independent highway variables.

Selecting the instrument is no simple matter. The authors of these studies took considerable care. All three of these studies use not one but three sets of instruments that serve to eliminate the effects of endogeneity: a 1947 map of recommended highway construction, an 1898 U.S. railroad map, and a selection of expedition maps from the 16^{th} through the 19^{th} century. (Agrawal, et. al., 2014, Duranton and Turner, 2012, Duranton, et. al., 2014)

The first study found that a 10% increase in the stock of highways could be expected to result in a 1.5% increase in metropolitan employment. There was also indication a reversion to the mean effect in the relationship between metropolitan area size and highway construction, meaning that per capita new highway construction was higher in smaller cities. (Duranton and Turner, 2012) The second study found that a 10% increase in the stock of highways causes a 5% increase in the weight of domestic exports. Another finding from this study was that the export of goods from a city to other cities is more strongly correlated with highway distance rather than Euclidean distance. This suggests that the routes selected for highways can affect trade flows. (Duranton, et. al., 2014) The third study found that a 10% increase in the stock of urban highways can be expected to cause a 1.7% increase in the number of local patents. Urban highways reduce the cost of accessing more distant knowledge, the study indicated, thus increasing the returns on investing in accessing that knowledge. (Agrawal, et. al., 2014)

Quantifying the effects infrastructure investment is complex and beset with caveats yet these and other studies lead to the inevitable conclusion that sound infrastructure imparts economic and social benefits.

Brief history and present status of U.S. infrastructure

Infrastructure creation in the United States began even before the advent of industrial steelmaking. The 1825 opening of the Erie Canal that stretched west-east 340 miles (548 kilometers) from Buffalo at the tip of Lake Erie across the State of New York to Waterford on the Hudson River became a showpiece of what the new nation could accomplish. (Finch, 1925) A few decades later came the Transcontinental Railroad. Completion was commemorated with the driving of the golden spike at Promontory, Utah on May 10, 1869. (Arrington, 1969) The innovative triple arch Eads Bridge over the Mississippi built in 1874 and the Brooklyn Bridge in New York City opened to horse drawn carriage traffic on May 24, 1883, twenty years before incorporation of the Ford Motor Company. Both are still in use today.

The next century witnessed an explosion of railway, waterway, and urban construction. During the four decades from the 1920s through the 1950s the United States, with less than 6% of global population, stunningly manufactured 42% of the steel and 28% of the cement on earth. (See Figures 4 and 6 below) Technological advances in construction technology beginning after the First World War benefited American citizens with pillars of modern transportation, water distribution, and power generation. Prominent bridges and dams, still among the largest in the world, were constructed during economic hardship of the Great Depression.

1931 saw the opening of Upper Level of the George Washington Bridge in New York City and the Hardy Dam in Michigan. The New York City Triborough Bridge, the San Francisco Bay Bridge, and the massive Hoover Dam were completed in 1936. A year later came the center tube of the Lincoln Tunnel, the Golden Gate Bridge, and Bonneville Dam in Oregon. Fort Peck Dam in Montana and Grand Coulee Dam in the State of Washington opened in the early 1940s. Each of these structures is so large that it takes your breath away. You must stand miles away to fit any one of these man-made monuments in a photograph. There were scores of smaller projects across the industrializing nation. The Tennessee Valley Authority, for example, oversaw construction of numerous dams, levees, and electric generation facilities that brought flood control and electricity to Appalachia and southern States.

After the Second World War, American citizens were venturing to the new boom towns in the west. Cars were larger and faster, suburban sprawl was lengthening the time spent behind the wheel, and grown children were more often moving away from their hometowns to where ever their employment took them. In 1956, after extensive research and Congressional debate President Eisenhower signed into law the Federal-Aid Highway Act that set into motion the construction of a comprehensive interstate highway network. 15 States had already built turnpikes that were subsequently integrated into the system. The U.S. interstate highway system was officially complete in 1991 with over 45,000 miles (73,000 kilometers) of road however almost 90% of this eventual length had already been constructed by 1973. (Lemer, et. al., 2006) Millions of miles of additional roads in the United States were also built over the past 80 years. Most are maintained by states, counties, and local municipalities.

Your American grandfather's homeland was a country with the world's best infrastructure. The United States once had what might have been a called a "First Mover Advantage" in modern public works. It led the world throughout most of the 20th century in the efficiency of its transportation, the coverage of its electric power and communications networks, and the ability to hold up under the vicissitudes of nature. For decades, the scale and advancement of U.S. transportation, energy, water distribution, and communication networks were the envy of the world.

But time marches on. Over the past generation, things have changed. Western Europe, Japan, and Canada, then the tigers of Asia and the oil rich states, and more recently China and many other countries have more than caught up. They invested prodigiously while the U.S has lagged. America's early advantage in erecting its 20th century physical foundations is reversing course and is gradually becoming a disadvantage. The replacement rate is not keeping pace with the hands of time. The average age of government structures in 1970 was 18 years, by 2009 had become 25 years (FEMA, 2011).

Over the last 50 years, the developed countries of Europe have spent a far higher percent of Gross Domestic Product (GDP) on infrastructure than the United States. Gross Domestic Product represents the overall size of a national economy. As European GDP per capita levels rose to rival U.S. levels, absolute European infrastructure investment pulled ahead of the United States. As of the end of the first decade of the 2000s, the United States was spending only 2.4% of GDP on infrastructure while Europe was spending 5%. This helps to explain the generally shorter commuting times in Europe, the notably better rail systems, and the clearly more modern electric power and water facilities in northern European cities. (Economist (a), 2011)

The World Economic Forum ranks the quality and competitiveness of national infrastructures for over 140 countries on a periodic basis. The United States slid to 25th in quality and 14th in competitiveness in the 2012 report. These ranking were lower than they had been in the 2008 report when the Forum listed U.S. at 9th for quality and 7th for competitiveness. The scores are composites of measures for roads, railroads, ports, air transport, available seat kilometers, electric supply, and telephone lines. (Schwab and Porter, 2008, Schwab, 2012)

A thorough review of U.S. infrastructure is presented in a quadrennial "Report Card" compiled by the American Society of Civil Engineers (ASCE), the leading U.S. organization for the profession. The “Report Card” is an evaluation of the 16 different categories of infrastructure and infrastructure systems, roads, bridges, railroads, transit, aviation, inland waterways, ports, dams, levees, energy, schools, parks and recreation, drinking water, wastewater, solid waste, and hazardous waste. The ASCE selection of categories introduces complexity. Some of the categories, roads, bridges, dams, levees are structures. Others are facilities, self contained systems where structures play a predominant role, inland waterways, ports, parks and recreation, drinking water, waste water, solid waste, and hazardous waste. Yet three of the ASCE categories, transit, aviation, and schools are integrated systems that include structures, people, equipment, and information. For aviation and schools in particular, the non-structural elements are more complex and expensive than the structural. The energy category includes two types of systems, one, systems for the processing and transport of hydrocarbon fuels, and two, systems for distribution of electricity. The focus of the ASCE report card is on the structural aspects of each category. (Victor, 2013)

Civil engineers and the firms that employ them have a vested interest in spotting every incidence of rust and cracked concrete that can be found. So it may come as a no surprise that these ASCE “report cards” consistently give the United States poor marks. The average grade in 2012 for the 16 categories was D+, up slightly from a D in 2008. The best score went to the solid waste management category with a B-, the worst two, inland waterways and levees came in as D- performers. Yet as harsh as these grades may seem, the ASCE assessments are grounded in detailed factual information. The report cards are an alarming reminder that delaying upkeep and replacement of worn and inadequate infrastructure is like a broken branch waiting for an unlucky squirrel.

Much of the dilemma lies in the sheer magnitude of the task at hand. The United States is a vast country; the world's 4^{th} largest in land area and 3^{rd} in population. The U.S. has 4.1 million miles (6.6 million kilometers) of roads and highways, 160,000 miles (257,000 kilometers) of railroad track, 2.5 million miles (4.0 million kilometers) of natural gas and distribution pipelines, 180,000 miles (290,000 kilometers) of oil and oil product pipelines, almost 400,000 miles (644,000 kilometers) of electric transmission lines, 100,000 miles (161,000 kilometers) of levees, approximately 1 million miles (1.6 million kilometers) of water mains, 700,000 miles (1.1 million kilometers) of public sewer lines, 180 commercial shipping ports, 542 certified airports, 170,000 public drinking water systems, 98,800 public school facilities, and 607,000 bridges. (U.S. BTS, 2013, U.S. BTS, 2015, Victor, 2013)

Recent examples of infrastructure failure

The experienced Canadian truck driver had embarked on what he expected to be a routine delivery. Forty one year old William Scott of Alberta was hauling a tractor trailer carrying an oversized load of just one enormous steel boxlike container used to hold oil drilling equipment. He was driving south along U.S. Interstate Highway 5, the main north-south corridor through Washington State. Scott had been working as a contractor for a Canadian trucking company for better than eight years. His destination on this assignment was Vancouver, Washington in the southwest corner of the State. The trucking firm had performed its due diligence. The company had obtained from the Washington State Department of Transportation a route permit for the oversized load. The report read, "Route OK – WSDOT Does Not Guarantee Height Clearances."

The devil in this story was in the disclaimer.

At about 7:00PM, Thursday, May 23, 2013 Scott had reached the four lane 1,112 foot long (337 meter) steel truss bridge that spans the west-east Skagit River at a point 60 miles north of Seattle. Crossing the bridge, his truck was in the right-hand lane. Had he been traveling in the center-left the 15 foot 9 inch tall (4.8 meter) cargo would have safely cleared the overhead structure. But the steel trusses of the Skagit River Bridge do not run horizontally across the width of the road below. Instead the steel girders that support the roadway arch downward toward the railings. The lowest clearances are less than 15 feet. The right top edge of the truck's rectangular load clipped one of the bridge's steel trusses.

There are 7,840 road and highway bridges in the State of Washington. Bridges are built to withstand most calamities. Trucks striking bridges in that State have been neither common nor rare events. Washington State Department of Transportation reports indicate that strikes had averaged 20 a year during 2010 through 2012. After a bridge strike occurs there is usually a few hours for inspection and at most a few days for repair before the bridge is reopened for traffic. This was not what transpired on that cool May evening.

When the cargo hit the steel beam the driver glanced in his left and right rear view mirrors and was unnerved to see an enormous section of the roadway and the entire steel upper superstructure disappear from sight. A 160 foot (48 meter) section of the bridge, hundreds of tons of metal and concrete, instantaneously crashed into the river below. Like a scene out of a Hollywood movie, Scott's big rig made it safely off the bridge but three other motorists were not so lucky. Two vehicles plunged off the newly fashioned concrete ramp. Miraculously there were no serious injuries. The Skagit River structure was later deemed to have been "fracture critical" meaning it was just waiting for one mishap too many, and Scott's load was that mishap. (Heffter, 2013, Valdes and Baker (a, b, c), 2013)

Collision or no collision, bridges should not spontaneously fail like this. Infrastructure failure in the United States has, in the past, been relatively infrequent. Yet anecdotal evidence from the most recent decade suggests that incidents like this may become disturbingly more common. Just two days after the bridge north of Seattle on Interstate 5 crumpled a train collision in Missouri damaged a pillar supporting a highway overpass and caused the roadway above to tumble down. Five people who had been driving on the highway and two in the trains were injured. A week earlier, a cracked section of railroad track in Connecticut caused the derailment and collision of two commuter trains with 700 passengers onboard. Several dozen people were injured; luckily there were no deaths. (Branch, 2013, Christoffersen, 2013)

Ironically, the reason for the fortuitous absence of train wreck fatalities may have been because the trains probably were not moving very quickly. The Acela, the fastest passenger train in the world's greatest superpower, travels on the same stretch of Connecticut railway track. Between Washington and Boston it averages only 70 miles per hour (113kph), less than half the speed of the French TGV bullet train between Paris and Lyon or the Japanese Shinkansen between Tokyo and Osaka. (Economist (a), 2011)

On the lucky end of the spectrum U.S. infrastructure failure causes inconvenience without loss of life. At 3 : 27PM on September 8, 2011, routine maintenance on a distant transformer at an electric power substation in the desert community of Yuma Arizona caused a voltage imbalance. Any problem at a substation should have been isolated to a small area that services no more than about 90,000 customers. However, like much of the equipment in America's grids, the age of transformers at substations like the one in Yuma are often 40 years old. The amount of money the U.S electric industry spends on maintenance has progressively shrunken by 1% per year since 1992.

The fault in the Arizona dessert set off a ripple across a wide swath of power grids stretching west to San Diego and south into parts of Mexico. Fifteen power stations automatically took themselves off the grid to avoid damage including the huge 2,200 megawatt San Onofre nuclear power plant. Close to 7 million people were left without electricity. Gas pumps and ATMs would not work stranding people and San Diego was left to swelter in near record heat without air conditioning. (Economist (b), 2011, Villasenor, 2011)

Other failures have ended with tragic consequences. Dozens of Minneapolis commuters were the victims on August 1, 2007 when the eight lane Interstate 35W Bridge suddenly tumbled into the Mississippi River during a Wednesday evening rush hour claiming the lives of 13 people and injuring 145.

The National Transportation and Safety Board conducted a post failure analysis. This bridge, like the smaller one in Washington State was known to be fracture critical. The failure of just a few crucial elements cascaded into a chain reaction of breaks that ultimately brought down the entire 1,000 foot (303 meter) main deck into America's most well known river. Engineers were later surprised to find that gusset plates, rarely a source of concern, had ruptured. This tragedy set off a brief nationwide soul searching and a call for bridge inspection and investment. Within months the federal government and several states passed bridge and highway spending bills however the gargantuan task of keeping hundreds of thousands of U.S. roads, bridges, dams, tunnels, dikes, water, sewer, and other infrastructure up-to-date is overwhelming. (NTSB, 2008)

Infrastructure failure sometimes occurs as the result of a natural disaster.

An intense weather event stresses physical public works. When Hurricane Sandy hit the populous U.S. Atlantic coast in 2012 it caused damage and loss of life. Coastal regions of New York State and New Jersey took the brunt of the impact. In the aftermath many areas suffered lengthy power outages. The flagship German news magazine Der Spiegel noted, "The power lines in Brooklyn and Queens, on Long Island and in New Jersey, in one of the world's largest metropolitan areas, are not underground, but are still installed along a fragile and confusing above-ground network supported by utility poles, the way they are in developing countries." (Fichtner, et. al., 2012) Casualties during and after Sandy were not nearly as serious as the calamitous losses that beset New Orleans seven years earlier when Hurricane Katrina ravaged that city. The swamping of New Orleans became a political plaything for the media establishment yet the root causes for breakdown had nothing to do with partisan politics.

Historic New Orleans was built on a bed of marshland and sediment deposits near the mouth of the Mississippi River. Civil engineers have known for over a century that this settlement is particularly vulnerable to the dire effects of flooding yet into the dawn of the 21^{st} century New Orleans still lay prone waiting for waterlogged ruin. The American Society of Civil Engineers published a post mortem of the infrastructure failure and found a long list of engineering design decisions, management policies, and institutional constraints on funding that went back decades leading up to the fateful day of August 29, 2005. The report concluded, "What is unique about the devastation that befell the New Orleans area from Hurricane Katrina – compared to other natural disasters – is that much of the destruction was the result of engineering and engineering-related policy failures." (Anderson, et. al., 2007, Quote: page 47) Most of the deaths and property damage in the jazz capital were attributed to the hopelessly inadequate levee and flood control structures that supposedly had been designed to protect the Big Easy from just such an event.

Well over 1,000 people lost their lives; property damage ran into the high tens of billions of dollars. In the wake of Katrina, 80% of New Orleans lay submerged in a gigantic pool of dirty contaminated water, sewage, and oil, over ten feet (3 meters) in places. The worst hit neighborhoods remained uninhabited for years. Much of New Orleans has still not returned to pre-Katrina population levels.

The engineers who surveyed the damage found that the immediate causes were countless breaches in the labyrinthine levee system that runs throughout the city. Levees are barriers made of compacted soil and clay often buttressed along the centerline with a fencelike structure of concrete and steel. Levees are positioned between bodies of water and low lying land on the protected side. The purpose of the levee is to serve as a water barrier when the river, lake, or canal overflows due to wind induced storm-surges and rain.

Floodwalls, floodgates, pumping stations, other flood control hardware, and particularly the levees in New Orleans were, in many cases, under-designed, or poorly maintained, or too old, or badly supervised; overall the network was not up to the task of protecting the city from this once in a 50 year hurricane. Had Katrina struck a citadel built on hilly bedrock it would have been just another bad storm but low, flat, sandy New Orleans, surrounded by water on almost all sides was the wrong town to be caught in the bull's-eye of a killer cyclone that came ashore concurrently with heavy rains and a high tide.

There were lessons, or as U.S. media types like to say, "It was a teachable experience." The U.S. has long rested on its proud legacy of early 20th century leadership in infrastructure that remains fixed in the American mind. Yet time had passed since much of the construction and built-in errors that condemned New Orleans. The United States obdurately clings to a national culture of decentralized decision-making that in New Orleans resulted in a patchwork of levees. Floodwater is smart; it found the weak spots. Foolhardy optimism and long term inattentiveness to one small detail after another finally tallied up the odds in favor of a metropolitan apocalypse. Catastrophic infrastructure failure like this tears at the fabric of public trust.

The bulk of U.S. infrastructure was built in those halcyon days of black and white television and vinyl records. The Skagit River Bridge that fell apart in Washington State was erected in 1955; the ill fated Interstate 35W Bridge in Minneapolis was constructed in 1967. Some of the levees in New Orleans overrun by Hurricane Katrina dated back to 1946 and a few failed pumping stations were over 100 years old. The average age of dams in the United States is 52 years of age; bridges on average are 42 years old, and levees, 55 years old. More than half of the locks in the nation's inland waterway systems are over 50 years old. Many are not large enough to accommodate modern barges and are often shut down for maintenance leading to long delays. Some drinking water pipes in major U.S. cities have been around more than a century and occasionally are built of wood. (Anderson, et. al., 2007, Economist, 2013)

One of the most alarming examples of outdated infrastructure can be found in the nation's busy Northeast Corridor railway network. This extensive system of tracks, railway power, tunnels, bridges, train stations, switches and other equipment crisscrosses 12 States along the eastern seaboard from Boston and Albany, New York in the north down to Richmond, Virginia. It carries over 260 million passengers and 14 million car-miles of freight per year.

State and national authorities have acknowledged that the network needs to be upgraded. A master plan issued in 2010 called for $52 billion in funding, a steep request, for new facilities over the next 20 years. Three years later a review commission issued a dire assessment of the system. "Hundreds of its bridges and tunnels are now over a century old; major portions of its electric traction power supply system date from the 1930s or earlier…" read the report. It indicated 32 critical infrastructure needs. Just west of Baltimore on the line linking Washington, D.C trains pass through three narrow tunnels that were constructed out of brick and stone masonry in 1873. Another 10 mile segment, "the most densely traveled stretch of railroad in the Western Hemisphere" between Newark and New York City is still equipped with electrical components dating back to 1910 and operates at full capacity during rush hour. The same people who trade tens of billions of dollars of derivatives over microwave links commute each morning on an Edison era railway system. (NECWG, 2010, NECIOAC, 2013)

Current levels of infrastructure investment and conclusion

In this final section of this research note we address the issue of recent infrastructure investment. We find that there has been a post 2008 falloff in government infrastructure spending. We explore some of the reasons for this trend.

Figure 1 below shows U.S. Federal and States expenditures for transportation infrastructure investment from 1995 through 2009 with a lacuna of data until 2014. Data up through 2009 comes from the 500 page U.S. Department of Transportation, Bureau of Transportation Statistics "2014 Edition of National Transportation Statistics." This document contains numerous tables of transportation statistics. Most of these statistics are fairly up-to-date. Figures for government finance are the exception. Federal and

State government expenditures on public highways, air transport, metropolitan transit, water transport, railroads, and pipelines can be found in Table 3-35. There is no expenditure data beyond 2009. The Bureau of Transportation Statistics also published a document entitled, "Government Transportation Financial Statistics 2012" that also posted expenditures but no data subsequent to 2009. The financial figures in this 2012 document are different from those in the 2014 Statistics summary. (U.S. BTS 2013, U.S. BTS 2014)

On March 2, 2015 the Congressional Budget Office published on its website a document entitled, "Public Spending on Transportation and Water Infrastructure, 1956 to 2014." It is a pretty brochure but an exercise in obfuscation. Post 2009 expenditure data had not been previously published yet the authors only reveal year 2014 expenditures and no figures for the intervening years. The document contains no tables of financials and what data there is can be found in small scantily labeled graphs or embedded in prose. It is a perplexing read. Earlier versions of this document included tables of figures. 2014 expenditures from this CBO report and earlier data from the 2014 BTS statistics summary appear in Figure 1 below. Values are in current dollars not adjusted for inflation. There is a 14.7% drop in government spending from 2008 to 2009 and another 5.4% decline between 2009 and 2014. (U.S. BTS 2014, CBO, 2015)

Fortunately, not all government reporting is Byzantine. If any one Federal agency were to be nominated as champion of statistical clarity, the nomination should go to the U.S. Geological Survey (USGS). Among its releases are annual and monthly Mineral Commodity Summaries, Historical Statistic spreadsheets, Yearbooks, and other resources. The USGS web based information portal is well organized, accessible, up-to-date, and informative.

One way to enhance our understanding of recent infrastructure

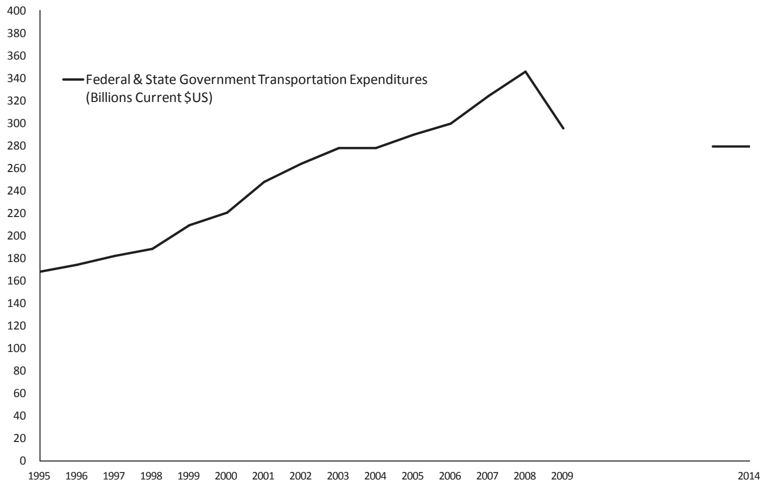

Figure 1: Federal & State Transportation Expenditures

investment is to plot material consumption data from the USGS. There are five major primary material inputs that go into the construction of most forms of infrastructure, steel, two types of aggregates, construction sand and gravel and crushed stone, and two types of binders, Portland cement and asphalt. Since infrastructure is the largest source of consumption for the last four of these inputs, and infrastructure is also a big user of steel, we can gain understanding of recent infrastructure expenditure by tracking the total consumption of these materials. The data in the Figures 2, 3, 4, and 6 below comes from USGS 2014 and USGS 2015. The data in Figure 5 covering a shorter period comes from U.S. EIA 2015.

Figure 2 shows 112 years of construction sand and gravel consumption in the United States. Figure 3 shows 115 years of crushed stone consumption. By weight and volume, these aggregates (and coal) are the most voluminously mined substances on earth. The United States consumes more than 2 billion metric tons annually, approximately 7 tons per person.

Construction sand and gravel consumption peaked at 1.34 billion metric tons in 2006 declining and then rising slightly to 914 million tons in 2014. The current level of consumption is about the same as in the mid-1980s through mid-1990s. Crushed stone consumption also peaked in 2006 at 1.81 billion metric tons declining and then rising slightly to 1.31 billion tons in 2014. The current level of consumption is about the same as in the mid-1990s. Approximately 73% of crushed stone is used, without binders, as road base, railroad ballast, construction fill, landscaping, and in other applications. The largest of these applications is road base. In the construction of an interstate highway for example, a 21 inch (53 centimeter) thick base aggregate layer is laid on top of compacted soil. Pavement is then laid on top of the aggregate. Approximately 38% of construction sand and gravel is used without binders for these same applications. (Kelly, 1998, USGS, 2006, Wilburn and Goonan, 1998)

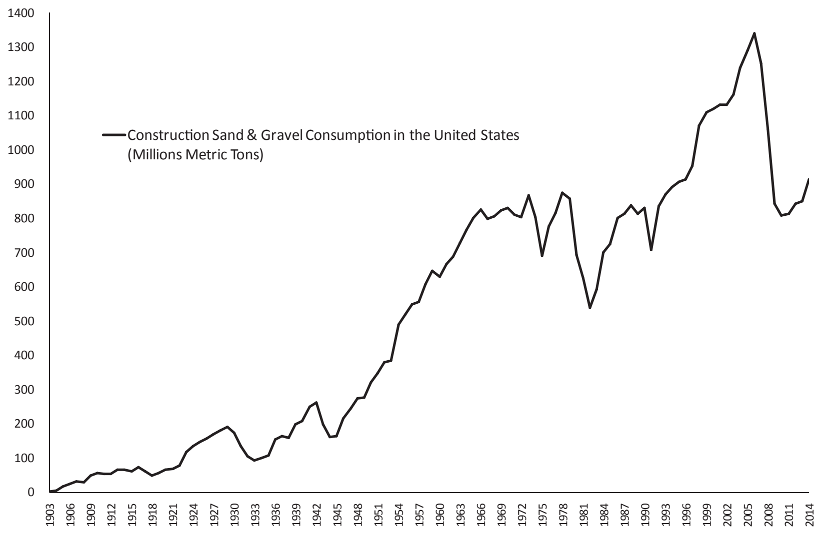

Figure 2: U.S. Construction Sand & Gravel Consumption

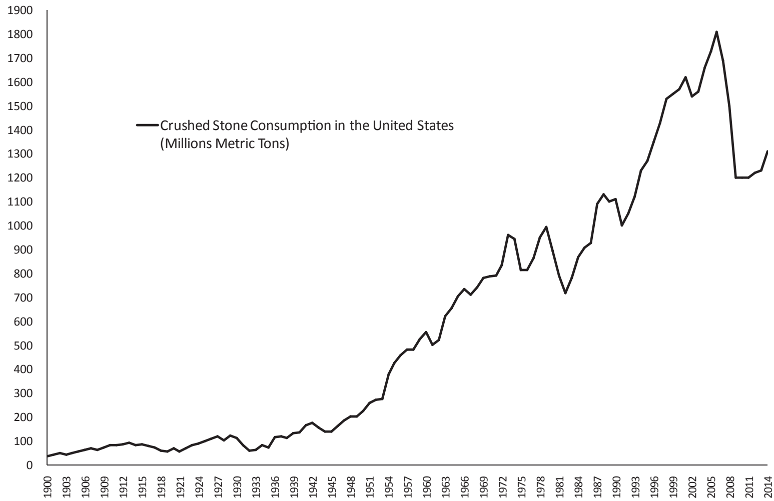

Figure 3: U.S. Crushed Stone Consumption

Consumption trends for the two binders, cement and asphalt appear respectively in Figures 4 and 5. Asphalt is also known as bitumen. For most applications, these commodities are used in combination with the two previous discussed aggregates. Concrete is comprised of cement, aggregates, and water. Asphalt pavement is made from about 5% asphalt and aggregates. A typical concrete mix contain 5 to 6 parts aggregate, mostly sand and gravel, for each part cement. A typical asphalt pavement mix consists of 5 parts sand and gravel and 9 parts crushed stone for each part bitumen. Over 90% of the paved roads in the United States are paved with asphalt although about 60% of the interstate highway pavement is concrete. Concrete is also used in other types of infrastructure, bridge foundations, tunnels, dams, etc.

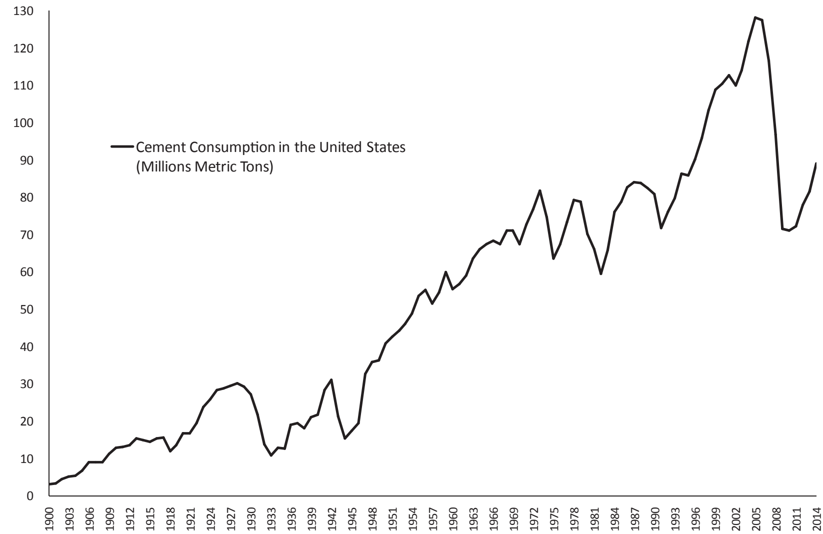

Figure 4: U.S. Cement Consumption

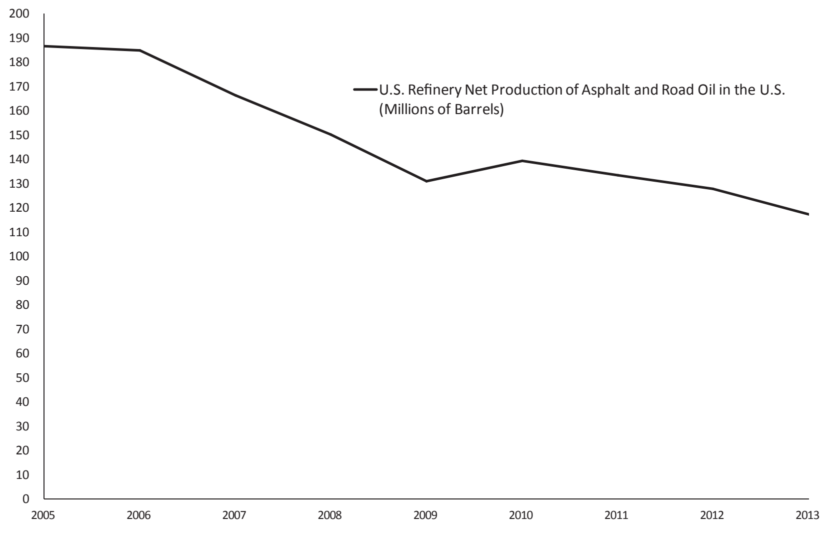

Figure 5: U.S. Asphalt Production

Finally, 115 years of steel consumption is shown in Figure 6. All forms of construction, including infrastructure, represent about 50% steel consumption. (Kelly, 1998, Wilburn and Goonan, 1998, Worldsteel, 2008)

Decline in the construction and maintenance of infrastructure has had a substantial effect on the consumption of these five materials, construction sand and gravel, crushed stone, cement, asphalt (bitumen), and steel. The collapse of the U.S. housing market has also had a dire effect. Single family housing "starts" peaked at about 1.8 million units in 2005 and are currently tracking at about 600 thousand units per year. (http://www.calculatedriskblog.com/) From the peak year of 2006 through 2014, steel consumption is down 15%, cement is down 30%, construction sand and gravel is down 32%, crushed stone is down 28%, and asphalt (through 2013) is down 36%. The falloff in housing would at most explain no more than 2/3 of this decline. These material consumption figures have given us a fuller picture of infrastructure expenditure during the last few years.

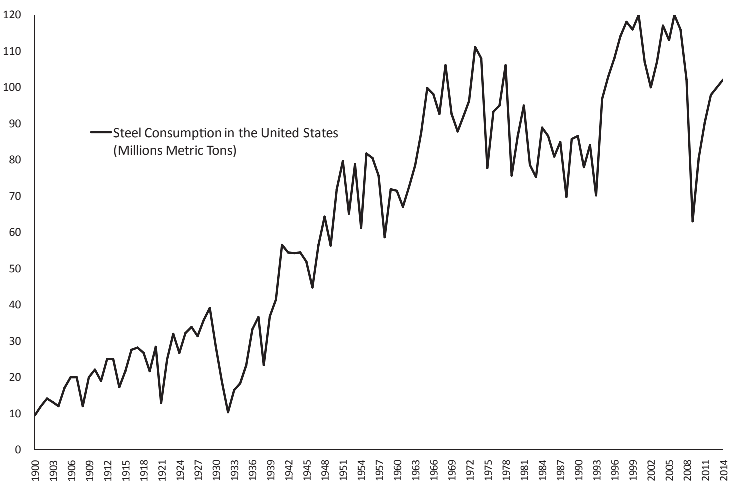

Figure 6: U.S. Steel Consumption

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