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INFRASTRUCTURE AND URBAN FORM

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ABSTRACT

Cities are shaped by transportation infrastructure. Older cities were anchored by waterways. Nineteenth century cities followed the path of streetcars and subways. The 20th century city rebuilt itself around the car. The close connection between transportation and urban form is natural, since cities are defined by their density. Physical proximity and transportation investments serve the common cause of reducing the transportation costs for goods, people and ideas. The close connection between transportation and urban form suggests the need for spatial equilibrium models that embed a full set of equilibrium effects into any evaluation of transportation spending. Their connection implies that restrictions on land use will change, and often reduce, the value of investing in transportation infrastructure. Future transportation innovations, including autonomous vehicles and telecommuting, are likely to also change urban form, although cities often take decades to adapt to new forms of mobility.

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I. Introduction

Cities are defined by their density, which enables the movement of goods and the connection of people. Transportation infrastructure is also meant to space to flow of goods and people over space. Urban form reflects the interplay between the demand for space and the demand for proximity, and the demand for physical proximity is shaped by transportation technology. In this paper, I review how past transportation innovations have influenced the location and form of cities and discuss both future trends and five policy questions related to cities and infrastructure.

Within metropolitan areas, the dominant effect of transportation technology has been to enable the expansion of cities and increase the amount of living space consumed by households. Horse drawn omnibuses and subways enabled the spread of 19^{th} century cities. Elevators enabled vertical mobility which further expanded the supply of space. Highways and cars expanded the reach of a forty-minute commute more dramatically. The car had a particularly dramatic impact on density and living space because, unlike older communal forms of transit, no outside walking is required at any point along the journey.

Transportation innovations have also shifted populations across metropolitan areas, as well as within metropolitan areas. The advantages of water-born mobility drove the location of most pre-modern cities, from medieval Venice to Minneapolis. Only rarely did the location of roads have so much power before the age of the car, but access to rail seems to boosted urban population during the mid-19^{th} century (Atack et al., 2010).

During the 20^{th} century, the spread of highways was a great spatial equalizer. Transportation costs for good fell dramatically, which allowed people and firms to move from areas where firms had a productive advantage, because of access to rail, water and natural resources, to places where people like to live, such as the temperate locations along the Pacific Ocean. Consumer amenities are powerful predictors of urban growth in the wealthy world (Glaeser, Kolko and Saiz, 2001), but not in the poorer parts of the planet (Chauvin et al., 2017.

The impact of transportation technology on urban form takes decades, and proceeds in three distinct steps. The first step is the vehicular innovation, such as the creation of the steam engine locomotive or the horse drawn omnibus or the car. The second step is to build a transportation network to accommodate the new form of mobility. The third step is to built or rebuild our urban spaces around the new technology and its network. Arguably, much of the world is still in the process of rebuilding its urban spaces around the automobile.

The connection between urban form and transportation infrastructure raises difficulties for the evaluation of transportation infrastructure. The simplest, and often the safest, form of cost benefit analysis simply asks whether the benefits to the users of a new road or highway can justify the costs of that highway. A more complicated task is to consider the entire transportation network and evaluate the overall improvement in mobility created by the new investment holding location constant, as in Allen and Arkolakis (2019).

But the largest question asks value created by infrastructure when the entire system, including housing and businesses, has rebuilt itself around the new roads or subway lines. This is difficult, because there is no such thing as an optimal urban form. The welfare impact that when infrastructure impacts form can be evaluated within the context of specific general equilibrium model, such as Heblich, Redding and Sturm (2018), but we are far from having models that we would fully trust as a basis for future infrastructure investments. The Henry George Theorem (Arnott and Stiglitz, 1979) suggests that it is enough to know the impact of infrastructure on land values to capture the overall social benefit of new investment, but the ex post impact on land values is also unknown at the time of investment decisions, and practically unknowable for land that is sufficiently distant from the infrastructure.

This paper is largely historical and does not try to develop the general equilibrium tools needed for incorporating the impact of urban form on transportation evaluation. I try to illustrate that transportation investments have shaped cities over time, which suggests the value of embedding the malleable nature of the built environment into transportation analysis.

I with a conceptual discussion of three core concepts that shape this note. Transportation innovation always comes in three steps. Cities are nodes of a large transportation network and hubs of a local transportation network. The impact of new transportation is mediated by the elasticity of the supply of local structures.

I then provide three historical sections, which suggest the enormous power that transportation infrastructure has had to shape cities over history. Section VI then discusses two major transportation innovations that are either here or on the horizon: autonomous vehicles and telecommuting.

Section VII discusses five public policy areas that concern the interplay of infrastructure and urban form. Section VIII concludes by emphasizing the limitations of this essay. I have chosen to focus on transportation, but other forms of infrastructure, such as sewers may be at least as important in developing world cities. Just as the urban ripples of transportation investment should be incorporated into transportation evaluation, the city-building effects of sewers and water-pipes should enter into analyses of those investments.

II. Three Concepts

I begin my discussion of infrastructure and urban form by laying out three core ideas that help organize the more historical passages that follow. The first idea emphasizes a three-step process through which transportation innovation shapes cities. The second idea is that most cities are both the hub of a local transportation network and a node in a larger network that connects across cities and countries. The third idea is that both housing technology and regulation often limits the ability of infrastructure to change the built environment.

The Three Steps of Transportation Innovation and Urban Change

Karl Benz built his “Patent Motorwagon” in 1885, arguably the first true car. Henry Ford produced his first Model T 23 years later. By that time, the basic technology of the car had been established, but no country had yet adapted its transportation network or its cities to the car.

Cars first travelled along the dirt roads that were meant to accommodate foot traffic, carts and bicycles, but smooth paving is more important for a car than for a horse or a pedestrian. Both bumps and extra entrants coming onto the road have more impact when vehicles are moving more quickly. America spent at least 60 years after Henry Ford’s first Model T building a new transportation network for the car. The construction of the Eisenhower Interstate Highway

System may be the most famous episode in this network-building odyssey, but the building of limited access highways began in greater New York in 1907.

The final step of the process occurs when urban form reshapes itself around the technology and the network. After World War II, car-oriented suburbs were mass-produced, even within well-established metropolitan areas, to take advantage of the fast commutes made possible by highways. New metropolitan areas like Las Vegas, which lacked access to the older forms of transportation, became accessible and grew, thanks to the car and its network.

This three-part pattern repeated the earlier path followed by steam-powered trains, which depended even more heavily on the network of rails, and also reshaped cities. In the case of water-borne transportation, there were major innovations (like steam boats) and major network construction (canal systems) that complemented one another. The Erie Canal became more valuable because technology enhanced New York's value as a port. But the new technologies mostly used the old network of oceans and the new network of canals typically relied on traditional barges. Nonetheless, those innovations also reshaped cities. Future transportation innovations, such as autonomous vehicles, are likely to follow a similar course.

Cities are Nodes in the Large Network and Hubs in the Local Network

A map of the London Underground system shows a central oval, which is the path taken by the ancient Circle Line, connected to lines that lead off to far flung parts of the metropolis. That central oval is the hub of the local transportation network. The other lines and above ground roads are the spokes that connect to that hub. The hub is less compact than in smaller cities, for London's center includes both the financial square mile of the old city and the political capital in Westminster. It has seven rail stations with more than ten tracks. Nonetheless, the basic structure of the metropolitan area's internal transport lines is clearly a center linked to periphery.

Almost all pre-car cities have some structure of this form, and often the central hub is literally a rail station. Transport hubs can be at the center of a city because they were placed there to begin with, or because transportation is so important that the hub because the new city center. New York City's Grand Central was originally placed at the edge of the developed city, but the city then reformed itself around the station, which anchors the midtown financial district

The hub of a metropolitan area is less obvious in the polycentric car-oriented cities that have grown up during the age of the car. In Phoenix, a rectangle made by Highway 10 and Highway 17 bounds the central city. Five different highway rays shoot off away to the suburbs.

Cities are also part of an external transport network that links them to other cities close and near. Phoenix's airport lies right outside that rectangle formed by Highways 10 and 17. Los Angeles' Union Station, which is still at the center of the city, was once the western terminus of intercontinental rail trips. The river Thames was once London's connector to the North Sea and the world.

The internal transport network shape the city; the external network explains the location of the city itself. Waterways significantly determined the location of most pre-modern cities. The rise of the train and the automobile has reduced the power of natural geography, and made the accidents of road and rail location far more important. Some also argue that airports have come to play an outsized role in the growth of particularly metropolitan areas (Kasarda and Lindsay, 2011).

Central nodes become more important, when there are larger returns to scale in transportation. In the colonial era of 300 ton ships there was a rough equality between Boston, New York, Philadelphia, Baltimore and Charleston. As ships grew during the early 19th century, New York became the dominant node on America's inter-city Atlantic network. The large economies of scale in rail also abetted the dominance of particular cities, like Chicago and New York. Truck transport has levelled the playing field. The links between within-city network and the across-city network are strong when the same mode travels within and between cities, like rail and cars, and weaker when the modes are distinct, like water and ox-cart.

The Elasticity of the Building Stock determines the Impact of the Transportation on Urban Form

If all structures were malleable clay, then they could react swiftly to changes in any external conditions. If a new freeway was built along a particular route to the central city, then houses would immediately spring up near freeway entrance, and the buildings at the city center would stretch a little higher to the sky. But structures are durable and cannot be easily relocated. Land use regulations and historic preservation commissions further limit streetscapes' ability to change. Natural geography further constrains the reshaping of cities. As Harrison and Kain (1974) emphasized, the many limitations on change meant that obsolete transportation systems have left sizable imprints on most older cities and that the impact of new transportation innovations may be limited.[2]

The older cities of Europe were built when mobility was overwhelmingly pedestrian. Humans on foot and on donkeys are nimble and have little need for wide or even straight streets. Consequently, we still find dense mazes of narrow, winding streets in central Rome, Barcelona's Barri Gotic or even Boston's North End. These neighborhoods still function superbly as pedestrian spaces, attracting thousands of tourists who just want to walk, but they can be practically impassable to automobiles.

Cars are particularly demanding of street space, yet the durability of urban structures meant that many older cities could never really adapt well to the car. Indeed, one reason why Americans left their older eastern cities and moved to newer sunbelt metropolises is that those new cities, like Phoenix and Los Angeles, were built to enable the easy use of automobiles.

The elasticity of housing can also be restricted in green fields by regulation, which also mediate the impact of transportation on urban form. If a new train line into Paris runs through a leafy townlet 50 kilometers away, then the value of space in that townlet will soar and the natural impulse will be to build more housing near the train station. However, if land use regulations block the supply of new housing, then those regulation may also limit the benefits of building the the train line.

III. The Large Network and Urban Form before the Car

Before the automobile, the world was spanned by three important transportation networks made of water, road and rail. The water network was typically the most important for long distance trade, and since it is mostly natural, it persisted even during periods of political chaos. In places

[2] Harrison and Kain (1974) emphasized that post-war building in metropolitan Boston was actually lower density than post-war building in greater Los Angeles. Boston was denser than L.A. because it was built before widespread automobile ownership.

with high state capacity, most notably China, canal building extended the water network. The Romans built a road network that still influences the shape of urban Europe today. During the 19th century, the rail network made swift land travel possible and had a particularly large impact on urban growth in areas with productive land and initially low population densities, such as non-coastal America.

Water and Urban Growth

Throughout most of human history, the connection between water and urban growth has been enormous. Water provided mobility, but also safety, drinking water and energy. If anything, the importance of water to urban location is even more visible in the U.S. than in Europe or Asia. All of America's twenty largest cities were on waterways in 1900.

The power of water in U.S. urban location is so clear both because transportation costs were such an important part of early U.S. history and because the other factors that influenced European and Asian urban development mattered less. Nineteenth century America was a country of great agricultural abundance and enormous distances. Cities like Buffalo, Detroit and St. Louis, all grew up at major nodes of a transportation network that facilitated the flow of agricultural wealth towards the east. Waterways dominated that network until 1850.

Population was dispersed throughout Europe by the 13th century, probably roughly proportional to the ability of the land to feed its own residents. Luxury goods, like high quality wool, were shipped, and cities, like Bruges and Florence, were important centers for the trade in cloth. But regions typically had limited food surpluses. Consequently, European cities did not grow up around the production and shipping of basic foodstuffs, as Cincinnati did as America's "Porkopolis."

Walter Christaller's "Central Place Theory" emphasizes the link between modest local shipping and urban growth that seems to fit many parts of Western Europe. In Christaller's view, small towns served local agricultural communities by providing commonly needed services, like blacksmithing or brewing. Larger towns provided rarer, less common commodities, and so forth. In this view, the point of cities is not to link to each other, but to link to the surrounding countryside. Waterways still mattered for these small local towns, but they matter less than when cities exist primarily to facilitate the flow of grain or beef to the Atlantic and beyond.

Political and ecclesiastical factors were more important in the growth of European cities than they were for American cities. Historically, cities were defined by the presence of a Bishop, who could be a major temporal as well as spiritual force. Pre-modern Europe had an abundance of petty potentates, each of which supported a court and often a small city. The cultural flowering of urban Weimar in the 18^{th} century, for example, came out of the interests of Duke Karl August of Saxe-Weimar and his mother.

Nonetheless, almost all of the large, historic European cities are on waterways. As all cities need to import food to survive, the rivers often served as a nutritional lifeline and usually as a means of exporting manufacturing commodities as well. Cites often emerge at points where goods move from water to another transportation mode. Bleakley and Lin (2012) show that American cities remain disproportionately located on the fall lines of major rivers, where goods need to be loaded onto or off of boats.

Exports were less important for imperial cities, such as Rome, that acquired their wealth through political and military power rather than through trade. For some of the most famous political cities, water seemed to have originally served for protection rather than transportation. The original settlement of Paris on the Ile de La Cite seems to have served primarily to protect the residents from raids. Similarly, the Tiber seems to have played a defensive role for the early Romans, even after they built the Pons Sublicius that spanned the river. Horatius allegedly was able to defend the narrow bridge against Etruscan onslaught practically singlehanded. Water similarly served to defend Venice against land-based aggression.

Access to water was also important to provide drinking water and, during the early days of the industrial revolution, power. The capital of Massachusetts, for example, was relocated from Charlestown to the south side of the Charles River to provide better access to a good spring. Larger cities, however, tend to pollute or overtax their local water sources, and must either purify or import water from lower density locales through aqueducts.

Aqueducts represent another form of transportation infrastructure that has played an outsized role enabling city growth. Water-borne pandemics, such as Cholera, can be a particularly fearful scourge on urban life. Other forms of water-related infrastructure, such as purification plants and Singapore's remarkable water-recycling system, can be vital for urban health, but they don't shape the form of cities in the same way as transportation infrastructure. Similarly, power-related infrastructure is also vital for urban survival, but since the coming of the steam engines, sources of power can also generally be relocated and power can be moved along the electric grid.

Before those steam engines existed, waterways also served as a source of power and helped determine the location of early industrial cities. In 1769, Arkwright patented his water frame that used water power to spin thread, and two years later he located his mill at Cromford on the River Derwent Industrial towns then expanded along the Derwent Valley. Some of these early factories were then visited by Americans, such as Samuel Slater and Francis Cabot Lowell, who brought the technology to the United States, and also located along rivers, like the Blackstone River of Rhode Island and the Charles and Merrimack Rivers in Massachusetts. The textile mills on the Merrimack then produced the large factory towns of Lowell and Lawrence.

Steam power eventually made water less important both as a source of power and as a means of transportation, because steam trains could replace canals. But the industrial revolution also made transportation more important, since there was so much more to move, and for a while, waterways became even more important.

Their importance led to increased investment in man-made waterways to supplement rivers, lakes and ocean. The Bridgewater Canal connected Manchester with the port of Liverpool in 1776. Liverpool's access to the waterways of the world would bring raw cotton to Manchester and Manchester's cotton fabric to the world. Between 1811 and 1831, as the cotton industry boomed, Liverpool's population rose from 106,000 to 195,000. Matthew Boulton, proto-industrialist and maker of Boulton and Watt Steam Engines, was one of the early supporters of the Birmingham's Main Line Canal, which would eventually connect the other birthplace of the industrial revolution to the Staffordshire and Worcestershire Canal, which provided access to some of England's greatest waterways.

In the mature urban systems of 19^{th} century England and Europe, canals typically connected well-established urban areas. Cities and towns had emerged over centuries into any area with fertile soil, and canals made it easier for those places to connect with each other. Over a millennium earlier, China's Grand Canal had been built to connect the even more ancient urban areas of that civilization. In sparsely populated 19^{th} century America, canals provided access to the natural wealth of the American interior.

Chicago's real estate boom of the 1830s was precipitated by the news that the Illinois and Michigan Canal would make that city that a major node on a transportation network that spanned from New York to New Orleans. Cleveland's initial growth owed much to its location as the spot where the Ohio and Erie Canal brought commerce from the Cuyahoga and Ohio Rivers into Lake Erie. Buffalo was the western terminus of the Erie Canal. While later rail and road networks were built to accommodate new forms of transportation technologies, canal boats were an ancient form of transport. The innovations came from creating the locks and the organizations that built them.

Roads before Cars

Just as canal boats are ancient, wheeled vehicles pulled by animals have also traversed our planet for millennia. For just as long, it has been known that some form of planking or paving facilitates the speedy rotation of those wheels. When terrain is rough, goods must be carried directly by animals, as they were upon the Silk Road that connected Europe with China, or the Inca roads that spread out from Cusco. Both Bukhara and Samarkand were great cities along that unpaved thoroughfare, although their existence long predated regular trade between Europe and Asia. Transport over land becomes much cheaper if animals can pull wagons.

The first and greatest of Roman roads was the Appian Way, built to enable the passage of both troops and military supplies through the malaria-filled Pontine marshes during the Samnite Wars. By the time of the Emperor Hadrian, you could march along Roman roads from Gesoscribate (Brest) to Byzantium, passing through Lugdunum (Lyon) and Mediolanum (Milan) along the way. It is hard to assess today the exact contribution that road access made to urban growth during the Roman era, since we lack clear data on population growth and on the other factors that might explain growth (Hitchner, 2012). Nonetheless, Milan could not have emerged as the capital of the Western Roman Empire if it did not sit in the middle of the Roman road network.

There is a robust literature that investigates the impact of the Roman road network on cities todays. Dalgard et al. (2018) show a correlation between Roman road density with both population density in 500 c.e. and the density of economic activity today. Interestingly, Roman roads do not predict modern urban agglomerations in those parts of Europe that abandoned wheeled transport during the medieval period. Wahl (2017) finds that even today, the parts of Germany that were in the Roman Empire are more developed, at least as measured by night lights, than the parts of Germany that were non-Roman. Percoco (2016) shows that the location of Roman roads in Italy predicts economic activity there today.

Roman roads also helped to mold the internal shape of cities, by contributing to the internal network that supplements the extent network. Garcia-Lopez (2012) shows that suburbanization in Barcelona followed the path of old Roman roads that formed the basis for subsequent highways. Garcia-Lopez et al. (2015) show that Roman roads helped shape the highways of the Bourbons, and the presence of those roads predicts the level of population decentralization within Spanish cities today.

The fundamental problem of assessing the impact that inter-urban roads had on urban growth during the pre-modern era is the endogeneity of road locations. Roads and cities grew side-by-side. While the course of the river Thames was in place before the Tower of London was built, every road that led out of London owed its existence to the presence of the city.

The United States did build several large-scale roads to the west that clearly preceded the existence of the cities and towns that would spring up along their routes. The Philadelphia and Lancaster Turnpike connected Philadelphia with the west after 1795. That paved road reached the Susquehanna River and Columbia. While it was an impressive piece of engineering, none of the cities along its path exploded in population during the road's brief heyday. The National Road or Cumberland Pike was an even more impressive stretch of Macadamized road running from the Potomac to the Ohio Rivers and then further west. Towns like Unionville, Pennsylvania, and Zanesvillle, Ohio, gained population due to their position along the road, but these early roads were just far less important pieces of infrastructure that either the waterways that preceded them or the highways that followed them.

The Train and the City

The train is our first full example of the three steps in technological innovation: vehicle invention, network-building and urban transformation, which includes both the reshaping of older cities, like London and New York, and the emergence of newer cities, like Los Angeles, whose growth was enabled by rail, such as Los Angeles.

The steam-powered vehicle itself required several distinct breakthroughs. James Watt first had to create his separate condenser steam engines, which required his to connect with and learn from a top scientist (Joseph Black at the University of Glasgow), a superb ironmaker (John Wilkinson in Birmingham) and a brilliant entrepreneur (Matthew Boulton). Converting reciprocating motion into the rotary motion that would turn a wheel then requires the sun and planet gear devised by Boulton and Watt employee William Murdoch, and used both for the first working model of a locomotive and for a steam-powered paddle-wheeler. Even so, it took 17 more years before Richard Trevithick built a steam locomotive that carried passengers up a hill.[3]

While steam powered cars can travel on streets, the early engines were both heavy and fragile. Trevithick's own engine appears to have lasted only three days before it was grounded by an accident in a rough road. Locomotives were better matched with rails that could reduce friction, and the chance of becoming bogged down in soft earth. Luckily, short stretches of rail already existed in the late 18th century. The Middleton Railway started hauling coal in 1758 by horse.

Building the world's rail network is one of the greatest industrial sagas of the 19th century. George Stephenson was an early locomotive builder, but he is even more important railway developer.[4] His first railways carried coal, like the Hetton Colliery Railways and the Stockton and Darlington Railway, but then moved to passengers, as the Stockton and Darlington did after 1833. Stephenson then built the Liverpool and Manchester Railways, which was the first railway to carry passengers between two major population centers

The vast scale of railway building in North America required both engineering and organization innovation, which was also true for large scale infrastructure investment. Nineteenth century U.S. cities were able to invest in sewers and watermains because bond markets were increasingly willing to trust those cities with financing (Cutler and Miller, 2007). The creation of railroads was associated with the growth of stock markets, the development of the modern corporation (Jenks, 1944, Chandler, 1993). Railroads, like the Union Pacific, were also subsidized with vast Federal land grants.

The third step of the innovation process occurred when railroad transformed cities. The literature on the economic impact of railroads is dominated by the enormous contributions of

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[3] Cugnot created an earlier steam wagon, but his work was abandoned in 1772 with little obvious impact on the later development of transportation technology.

[4] He was most certainly not the first railway builder, however. Jessop, for example, engineered the Kilmamook and Troon in 1812, and I have already mentioned earlier railways built for horse-drawn carriages.

both Fogel (1964) and Fishlow (1965). Fogel famously concluded that railroads contributed little to America's economic transformation, because canals could have done the work. Fishlow estimated that a larger impact of railroads, because he compared railroads only with the canals that did exist in 1840.

Even if Fogel is right, the coming of the railroads still shaped the locational choices of both people and firms. Los Angeles' population would not have reached 320,000 in 1910 – four years before the opening of the Panama Canal— without railroads. Los Angeles' own boosters fought hard to bring the Southern Pacific Railroad to the city.

Atack et al. (2010) compare Midwestern counties that received rail station between 1850 and 1860 with comparable control counties that did not have a rail connection. In 1840, neither the counties that were treated by rail nor the control counties had an average urbanization rate over three percent. By 1860, the treated counties had an urbanization rate of 14.3 percent while the control counties had an urbanization rate of 2.5 percent. Berger and Enflo (2017) perform a similar analysis on railroads and urban growth in 19th century Sweden and draw similar conclusions about the last impact of railroad access on population growth.

Donaldson and Hornbeck (2016) advanced the methodology of 19th century railroad analysis by using the market access measures that come from international trade. Their work recognizes the general equilibrium nature of a rail network, which means that a new railroad in Ohio can increase the value of agricultural land in California. Their focus is on agriculture, rather than urban growth, but they conclude that removing access to all railroads in 1890 would reduce the value of U.S. agricultural land by 60 percent.[5]

Nagy (2016) also uses a formal general equilibrium model with specialization and innovation to assess the impact of railroads on the urbanization of 19th century America. He estimates that "railroads were responsible for 23% of U.S. growth before the Civil War," and that much of their impact occurred because they enabled urbanization. Fajgelbaum and Redding (2018) use similar methods and draw similar conclusions about the Argentine rail network.

This general equilibrium approach raises the even larger question of whether overall U.S. urbanization would have been significantly lower in 1890 without access to the rail network,

[5] Donaldson (2018) similarly found large impacts of railroad on the 19th century economy of India.

because eastern cities needed to import food from midwestern farms. Perhaps that transportation could have been done by canal, but Donaldson and Hornbeck's work seems to suggest not. Developing country cities today can import their food by water, which perhaps explains why urbanization in the developing world can proceed despite low levels of income (Glaeser, 2014).

IV. The Local Network and Urban Form before the Car

While the larger network shapes where cities locate within a country or a continent, the local network determines the shape of the city itself, most obviously in the pre-modern commercial cities, such as Venice, Bruges and Amsterdam, that relied on canals for local movement. Almost all cities bear the imprint of the transportation technology that was dominant during the epoch in which that city came of age.

Walking, Wagons and the Rise of the Grid

Amsterdam and Venice were exceptions. Movement within most older cities depended on walking, animals and vehicles drawn by animals. Few cities predate the wheel or domesticated animals, and so these modes of transportation have been almost universally available in urban history.[6]

Pedestrians and animals can easily walk narrow, curved streets. Consequently, many of our oldest urban spaces have densely packed dwellings separated by semi-lightless alleys. Short blocks aid pedestrian maneuverability, but in weak legal environments, defending road space against encroachment is difficult. A clear system of roads is a boon for strangers, but what strangers would be wandering around a modestly sized 11th century town? Consequently, travelling through a medieval quarter can be dank and disorienting.

Wagons, which require less human labor per pound carried, benefit from wider, straighter streets. Urban thoroughfares that could accommodate the cart had the added advantage of providing fine marching space for triumphs or other displays of the power of potentates. The Romans built

[6] The Incas may have had one of the few great civilizations without the wheel, and even their greatest cities, such as Cusco, had a population of less than 50,000 at the time of the Spanish conquest.

relatively wide, paved roads even in lesser cities like Pompeii, presumably to accommodate both the legions and wagons. Julius Caesar was sufficiently interested in the problem of street congestion that he banned wheeled vehicles form Rome for much of the day.

Street widening is a simple accommodation of wheeled vehicles. A grid is a more complete restructuring of urban space to accommodate movement. Nowhere is that fact more obvious that in Barcelona, which provides pedestrians with a dramatic shift from the medieval alleyways of the Barri Gothic to Cerda's unique design for Eixample.

Grid plans are ancient. Mohenjo-Daro appears to have been built on a grid 4500 years ago. Yet urban spaces have gone back and forth in their use of rectilinear grids, depending on the state of both transportation technology and political order. Grids also need to be defended against encroachment by abutters, who may put a structure in the middle of thoroughfares, and convert public spaces into private space.

Bertaud (2018) provides a compelling argument for the case for laying down grids, even in areas that will not be occupied for decades. Certainly, grid users often express considerable satisfaction with the clarity of their street plan (Ballon, 2012). Yet we have relatively little hard evidence on the longer-term benefits of different road structures. We know only that these structures, such as Haussman's Parisian Boulevards or the dense warren of streets in old Jerusalem, shape our experience of a city.

Streetcars and Omnibuses

New York adopted its' grid in 1811, sixteen years before Abraham Brower's horse drawn omnibus provided the city's first public transportation. Horse drawn buses or streetcars are a relatively simple technology, relative to the steam engine locomotive, but cities still went through the three stages with omnibuses. The basic technology was just a long carriage pulled by a horse, and that could travel on existing streets, like Trevithick's steam carriage. However, also like steam engines, horse drawn omnibuses work better with rails that reduce friction. Rails were embedded into existing city streets to enabled buses to move more quickly.

Finally, as streetcars made it far easier to commute longer distances, the city began to sprawl outwards. New York's Greenwich Village was an early example of a leafy suburb that became connected to the city through a streetcar. Warner (1978) describes the growth of "streetcar suburbs" outside of Boston that were connected to the city through streetcar lines.

The streetcars reshaped the city mostly by expanding its size, but there were more subtle changes as well. The streetcar was the mode of the prosperous; feet were the mode of the poor. Since the mode of the poor was so much slower, the poor started to live closer to the city center after the coming of the streetcar. Gin and Sonstelie (1992) document how this pattern of centralized poverty emerged in 19th century Philadelphia. The poor were only able to afford proximity to the city center because they crammed into less than hygienic tenements. The rich who paid for streetcars gained access to cheaper land that enabled them to build more comfortable homes, such as brownstones in Greenwich Village and detached cottages in Brookline.

The streetcar, like the elevated railway that followed it, did not, completely alleviate the need for walking. Travelers typically walked from their streetcar stop to their home. This meant that while streetcars could expand the city, buildings still needed to be close enough to a streetcar line so that they could be reached on foot. Streetcars enabled sprawl, but still required density.

Subways and Elevators

In the first half of the 19th century, urban public transit innovation made animal power more efficient. In the late 19th century, transit innovations replaced living sources of energy with steam and electricity. Intra-urban rail provided a faster alternative to the horse. Overhead electrification and traction provided mobility with less burning of coal. Vertical mobility increased with Elisha Otis' safety elevators that were powered first by steam and then after 1880 by electricity.

Cities built new networks for their intra-urban railways both to save space and to reduce the smoke created by the steam trains. London puts its trains below ground. New York initially ran them above ground. At their most basic, these urban trains were just like omnibuses on steroids. The city could expand further. The rich were more likely to take the train than the poor, and so this continues to abet the pattern of decentralization of the wealth. Yet still, people had to walk to their train stops and so the basic pattern of walking densities persisted.

The revolution in vertical transportation may have had the most visible impact on urban form. Powered, safe elevators were as crucial to the success of skyscrapers as the steel frames that define them. Before the elevator, residential buildings almost never reached above six stories, which still defines the upper limit of many older European cities. These two revolutions in urban mobility – urban rail and the elevator – shaped the city of 1910. The new towers rising in Chicago's Loop or on Wall Street reflected both the ability to build up, thanks to the elevator, and the apartment buildings in the Upper West Side of Manhattan reflected the ability to build out.

Heblich, Redding and Sturm (2018) provide a quantitative assessment of the impact of the London underground on the development of that metropolis between 1801 and 1930. They document that the introduction of the underground is associated with the spatial segregation of residences from workplaces, and with the overall growth of the city. They provide a counter-factual of removing trains from London that suggests that "removing the entire railway network reduces the population and the value of land and buildings in London by up to 51.5 and 53.3 percent respectively, and decreases net commuting into the historical center of London by more than 300,000 workers."

V. The Automobile and the 20th Century Restructuring of Urban Areas

While the 19th century's transportation innovations produced tall downtown buildings and immense public transit systems, the 20th century's dominant transportation innovation was the mass-produced, inexpensive internal combustion-engine powered vehicle.

Cars and Suburbanization

German engineers, including Nikolaus Otto, Gottfried Daimler and Karl Benz, developed the internal combustion engine and the first cars. American entrepreneurs, including Henry Ford, Billy Durant and Ransom E. Olds, developed the mass production techniques that made cars affordable. A new network was then built up around cars, that included paving and limited access highways. The Federal government became a large-scale highway funder during the New Deal and especially after Federal Highway Aid Act of 1956.

The rebuilding of urban space around the car began before World War II, with car-based suburbs such as Palos Verdes Estates outside of Los Angeles. After World War II, the process expanded dramatically, with help from the highway system and an expansion of Federal support for home lending. The view that cars enabled the growth of suburbs seemed obvious even before economists had solid empirical tools for estimating the impact of highways on suburbanization. How could the vast number of American suburbs without any public transportation have grown without the car?

Baum-Snow (2007) uses the 1947 Highway Plan which designated routes between metropolitan areas based largely on military, rather than economic, benefits, to identify the causal impact of highways on suburbanization. He found that each new highway that run through a city increase suburban population, relative to central city population, by eighteen percent. He also documents the clustering of new developments around the highway routes than provide fast access into the central city. In one way, the highways were just like 19th century streetcars and subways in that they allowed the central city to sprawl.

But highways were also quite different from these older forms of mobility because cars are generally use from start to finish and require almost no walking at all. Indeed, that fixed time cost, is responsible for most of the gap in average commute times between cars and public transit (Glaeser, Kahn and Rappaport, 2008). Office buildings clustered around stops on Chicago's El or New York City's Grand Central Station, but cars allowed dispersed low-rise offices and housing, enabling the consumption of vast amounts of land relative to all previous transportation modes. The ease of driving led many businesses to relocate away from dense urban centers to suburban office parks, where the space was cheap and there was plenty of parking. Garreau (1992) called these sprawling areas "edge cities," which captures the reality that both jobs and homes moved away from older, urban cores.

Glaeser and Kahn (2004) discuss the decentralization of employment across American cities, and argue that few modern urban areas fit the monocentric structure of the Alonso-Muth-Mills mode. People may commute as long as always, but the most common commute is now from one non-central location to another, often at relatively high speeds. Space-intensive industries, such as manufacturing, were particularly prone to decentralize after the coming over the car.

Cars and the Rise of the Sunbelt

Cars and highways moved people across metropolitan areas, for three distinct reasons. Some areas received more highways than others and those areas with more highways grew more (Duranton and Turner, 2012). It was easier to add car-oriented infrastructure into newer cities and consequently, there was a shift away from old metropolitan areas to new metropolitan areas. Highways eliminated most of the remaining transportation cost related advantages of the countries northern and midwestern cities. Firms and people could move to areas that had other advantages, including both car-based infrastructure and a warm climate. That combination of rising populations and declining prices in America's sunbelt is best understood as reflecting a highly elastic supply of housing that is created by the combination of abundant highways, simple topography and few restrictions on local land use.

The coming of the highway decreased the cost of moving goods over space. The real cost of moving a ton over a mile of rail has declined by over ninety percent since the late nineteenth century (Glaeser and Kohlhase, 2004). In the 19th century, cities grew because of access to waterways or coal mines, even in climates that were less than hospitable. In the 21st century, low transportation costs mean that few locations offer any natural production advantages because of proximity to either inputs or outputs.

When traded goods are easy to ship, then it makes sense to build cities around amenities that are valued by consumers. The rise of Los Angeles in the late 19th and early 20th centuries provides an early example of a city whose appeal was tied to its Mediterranean climate. Over the 20th century, January temperature has regularly been the strongest predictor of metropolitan area population growth.

Retrofitting Older Cities for the Automobile

The final shift in urban form occurred within older cities that tried to fit cars into older urban infrastructure. In some cases, older neighborhoods were leveled to create space for highways. In other cases, highways were elevated to add extra road space and leave existing arrangements intact. As cities became more concerned about the local disamenities of elevated highways and neighborhood destruction, tunneling became more appealing despite its high cost.

Many of the most spectacular infrastructure projects of the past 75 years can be interpreted as attempt to retrofit older cities for the car. While many of Manhattan's bridges predate the automobile, the George Washington and Triboro Bridges were both built to enable more driving, as were the major tunnels under the Hudson and East Rivers

Caro (1973) argues that Robert Moses' attempts to allow cars into New York City were misguided failures, but there are no compelling economic studies analyzing the counter-factual. Older cities, like New York, were competing against cities like Los Angeles that were overwhelming car-based. New York City suffered in the 1970s, but it is hard to know if that suffering was exacerbated or alleviated by Moses' infrastructure.

VI. Current Innovations and Urban Change

In the speculative section, I consider two innovations that both have the potential to shift urban form in the future: autonomous vehicles and telecommuting. These discussions are brief, because these topics are more fully addressed by the Verma chapter in this volume on automation and the Agarwal and Salzberg chapter on the sharing economy.

Autonomous Vehicles

Autonomous vehicles can, in principle, eliminate the need to human labor to direct the path of a moving vehicle, which effectively reduces the time cost of driving. The first order impact of autonomous vehicles will presumably be an increase the number of vehicles miles travelled. Lower costs of drive should increase the willingness to drive long distances and leisure which would normally lead to even more decentralized cities.

Autonomous vehicles are easy to fit with real time pricing mechanisms that toll based on route travelled. Limiting congestion pricing to autonomous vehicles might also reduce the political backlash to congestion pricing. If autonomous vehicles then lead to a wider embrace of congestion pricing or automobile sharing, then autonomous vehicles might do less to decentralize urban arears. If the congestion charge was applied following the standard Pigouvian formulas, then it would only offset the lower cost of driving on crowded highways and in the urban core. On lower density roads away from the city center, autonomous vehicles would work to lower the cost of driving, and generate even more development on the exurban fringe

Autonomous vehicles create particular advantages for the mobility of the young and the elderly. With autonomous vehicle, older people with weak eyesight could remain in homes that were only accessible by car. Autonomous vehicles might also reduce time spent by suburban parents ferrying teenage children to far flung activities. These possibilities increase the centrifugal power of driverless cars.

Autonomous vehicles have a particular advantage in ride sharing, because autonomous vehicles can travel around the city on their own. Improved bus or ride sharing will be move valuable in moderately dense environments. The ability to design dedicated neighborhoods for autonomous vehicles, as Sidewalks Labs designed in Toronto, enhances natural complementarity between autonomous driving and urban density. An autonomous on a dedicated highway may be able to drive safely at 150 miles per hour, thereby eliminating much of the speed advantage currently enjoyed by inter-urban rail. The more that autonomous vehicles are shared vehicles, the more that they are likely to increase the demand for urban proximity.

Telecommuting

For decades, pundits have predicted that the ability to connect electronically would make face-to-face interactions and the cities that enable those interactions obsolete. For decades, those seers have largely been wrong, perhaps because electronic interactions and face-to-face interactions have largely been complements rather than substitutes or perhaps because other forces made cities more attractive in the late 20th century (Gaspar and Glaeser, 1998).

Yet the COVID-19 pandemic has made working from home the new normal for vast swathes of the global economy. Bureau of Labor Statistics data founds that about 50 million Americas had switched to remote work in May of 2020. The education gap associated with telecommuting was enormous. Almost 70 percent of Americas with advanced degrees but only five percent of high school drop outs were remote working. The knowledge workers in the large cluster known as professional and business services were able to keep working on-line, but the thirty-two million Americans working in retail trade, leisure and hospitality had a more difficult time.

Many businesses have already declared that they are sticking with remote working after the pandemic ends. Bartik et al. (2020) report that more than 40 percent of firms in their sample of small businesses say that forty percent of more of their workers who switched to remote work will continue to work remotely.   Some firms have discovered that working remotely is less painful than they expected, and they have now paid the fixed costs of learning the new technology.   Nonetheless, a switch to telecommuting could easily reduce the demand for big city office space going forward. Even a modest switch to tele-commuting, involving a few days a week or ten percent of the population, could have a significant impact on urban traffic congestion and commuting costs.

A post-pandemic increase in telecommuting will have more of an immediate effect on urban rents than on urban form. In the world's more expensive cities, the gap between current commercial rents and the rents that can cover maintenance costs are sufficiently large so that the offices will remain occupied even after rents.   In the medium term, lower commercial prices mean that fewer downtown high rises will get built. Some office buildings in low cost metropolitan areas may actually go vacant. Others will convert to residential uses.

A switch to remote working could lead both to a shift away from commercial districts within metropolitan areas, but also a shift across metropolitan areas. If remote work is concentrated in highly educated, better paid workers, then some of those workers will choose to move to metropolitan areas with robust consumption amenities. Vacation destinations and college towns seem most likely to attract more footloose knowledge workers.

The rise in remote working may not mean an urban exodus. Many of our cities have succeed over the past forty years as places of consumption as well as production (Glaeser, Kolko and Saiz, 2001). The young, in particular, are likely to continue to demand the pleasures of city life, even if they do their jobs from their apartments. As cities switch from production to consumption, intra-urban trips will be increasingly motivated by leisure rather than work.

VII. Policy Choices about Infrastructure and Urban Form

In this section, I discuss five policy decision that impact both infrastructure and urban form. These are meant to provide example of the integration of urban form considerations into transportation policy analysis.

Policy Decision # 1: Subsidizing Infrastructure and its Use

Governments have subsidized infrastructure and its usage for centuries. The connection between infrastructure and urban form should enter into any evaluation of transport subsidies. Subsidizing highways implicitly subsidizes the move from cities to suburbs. Do those spatial consequences cause the optimal highway subsidy to rise or fall?

The Whig Party advocated so-called "internal improvements," including both canals and railroads, as "nation-building" investments that would create common markets and a common national identity. Transportation links, including both the railroads the enabled speedy German mobilization in 1914 and the Eisenhower interstate highway system, were also understood to have national security value. If roads and rails carry sizable fixed costs and low marginal costs, then subsidizing construction enable more efficient use, although economists have long questioned the existence of a large gap between marginal and average costs. Finally, subsidizing public transportation is also seen as a tool for reducing traffic congestion and enabling the labor market access of the poor.

Americans have used general tax revenues to fill the highway trust fund for almost 15 years. Europeans significantly subsidize passenger rail. Few if any public transit systems cover their full costs. In every canonical urban model, subsidizing the cost of mobility will induce people to live further away from the city center. Glaeser and Kahn (2004) found that countries that with higher gas taxes have higher levels of urban density.

We also subsidize public transportation, which should induce consumers to live near existing public transit stops and encourage more building near those stops.[7] Yet, many of America's older cities have inelastic housing supply either because prices that are below construction costs (Glaeser and Gyourko, 2005) and because new construction is highly regulated. The more

[7] Baum-Snow and Kahn (2005) suggest that demand has been limited for new American metro systems built since the coming of the car, which seems likely to limit their impact on urban form.

elastic supply of housing in the exurbs than in the urban core suggests the new highways will have a larger impact on urban form than new mass transit stops.

Policy Decision # 2: Urban Land Use Regulations and Infrastructure Usage

In the United States, a plan to build a new rail line would emanate typically from a State Secretary of Transportation, usually with support from a state Governor and probably with some additional funding from the national Department of Transportation. Yet the social value of that speedy rail line depends on the number of people who will take it each morning to get into the city. The number of people who will get on the train depends on the amount of new housing that is built around the new rail stations, and those decisions are made at the hyper-local level, by the dispersed townships that maintain iron control over the ability to build any new housing. The possibility that only a small amount of new housing will be built, in turn radically reduces any benefits that might come from this new construction.

Coordinating land use decisions and infrastructure decisions is an old problem, because infrastructure itself requires land. In the days of corrupt urban machines, overcompensation for land purchases produced rents for privileged insiders. As George Washington Plunkitt of Tammany Hall explained that when "it's a new bridge they're goin' to build," then "I get tipped off and I buy as much property as I can that has to be taken for approaches," only to "sell at my own price later on" (Riordan, 1995). Twentieth century infrastructure projects, such as those run by Robert Moses, were more honest, but also more likely to meet with neighborhood opposition to the use of eminent domain. The strength of local community opposition to rail lines has bedeviled attempts to straighten the Acela route in New England and to build the California High Speed Rail.

As Altshuler and Luberoff (2004) demonstrate, community power to block new projects expanded steadily from the 1950s to the 1970s, which led to the emergence of more sensitive, and more expensive projects, like the Big Dig. Communities have also become more empowered in their ability to block new buildings, and that creates an indirect challenge for infrastructure spending. When rails were laid down along the course of Manhattan, developers could easily erect high rises to take advantage of the speedy access to the city's business districts. When the Eisenhower highway system connected cities with the open space surrounding them, developers similarly enjoyed a free hand in building suburban tract housing. Today, however, communities are far more likely to block the new construction that would increase the value of the infrastructure (Glaeser, Gyourko and Saks, 2005).

If infrastructure planners are hoping to deliver more value to their users, then the regulatory environment matters. If place A is likely to build 1,000 new homes in response to a new rail stop and place B is only like to build 10 new homes in response to a rail stop, then a planner that desires to deliver more value may want to build in place A rather than place B, even if place B is better from an engineering perspective. The number of people who will actually move in response to new infrastructure is presumably significant for any cost-benefit analysis.

A second implication is that there may be gains from integrating land use planning with infrastructure provision. At the small scale, this integration occurs already. Towns control both local roads and new building. But the transportation agencies that oversee large scale projects rarely have control over new building. It is at least be legally possible, if politically difficult, for a state government to impose a new zoning code along with new infrastructure.

Policy Decision # 3: Durability vs. Flexibility; Rail vs. Bus

Economists have been skeptical about intra-urban rail transit since Meyer, Kain and Wohl (1965) pointed out that a bus on a dedicated lane could achieve almost all of the speed of rail at a fraction of the cost. From the perspective of city spaces, the most obvious distinction between bus and rail is permanence. Bus routes can change quickly. Even, designated bus tunnels can be repurposed. Train routes can be even more durable than housing. Routes designed for 19th century needs still shape the 21st century city.

Most train systems use rails that allowed George Stephenson's steam engines to glide over the English countryside, which are not compatible with any other transit mode.[8] Buses can be

[8] Some light right system share road infrastructure with cars, but others do not. Gomez-Ibanez (1981) discusses many of the ways in which light rail systems are not so different from heavy rail systems.

rerouted over the existing road network or removed altogether. The flexibility of the bus would seem to be a major advantage in an uncertain world.

Yet that flexibility has sometimes been seen as a downside of buses. The durability of trains is seen as a way of resolving uncertainty and coordination problems. For example, a real estate investor who is considering building a new project on the edge of a high poverty neighborhood may take confidence from a new rail line is much less likely to be rerouted. A new bus route carries no security.

In a sense, the decision to invest fixed local infrastructure can be understood as a game between the public sector and private investors, where all actors want someone else to bear the risk. The permanence of rail loads the risk onto the public sector and makes the private sector less vulnerable. But in many cases, the public sector will benefit from keeping its options open.

Policy Decision # 4: Public Health and Public Transportation

Cities are defined by the absence of physical space between individuals, but that urban proximity becomes a threat during a time of pandemic. The density of travelers on an urban bus or rail car can seem life-threating in a time of plague. In a Suffolk University PRC/WGBH/Boston Globe Poll of Massachusetts residents taken from April 29 to May 2, 2020, 79.2 percent of respondents said that they would not be "comfortable riding buses, subways and commuter trains when it is allowed." Even if there was treatment (but not a vaccine), 56.6 percent said that they would not be comfortable taking public transit.

If the threat recedes quickly, then the simple steps that are being taken now should help bring riders back onto public transportation. Regular disinfection and a norm of wearing masks should help a bit. Plastic barriers can reduce the risk of infection for drivers; autonomous vehicles would pose even less of a risk. Riders are already receiving real-time information about the level of crowding, but we lowering the density level in buses and trains is a two-edged sword. If public transit runs at 25 percent of capacity for the foreseeable future, then it will be even further away from covering its costs.

If the threat of pandemic persists, and all shared public transit is shunned, then cities will have to fall back on three older technologies-- walking, cars and bicycles—and hope that new technologies can help fill in the gaps. Autonomous cars and buses with airtight barriers between passengers might provide a feasible form of ridesharing. Walking and riding are easiest at high densities, where there is proximity between workplace and home.   Cars and lower density ride sharing will work better at more suburban densities.

To allow more space for bicycles and walking, the inner city could in principle ban cars altogether, and have parking structures at the end.   Health concerns can further limit high densities if elevators or shared air systems are also seen as dangerous.   In that case, we may see an even larger move away from high density metropolitan areas altogether, especially in the U.S. In that case, cars rather that walking or bicycling seem like to be the dominant transportation mode in a world with recurring pandemics, just as cars are the dominant mode in lower density America today.

Policy Decision # 5: Infrastructure and Natural Disasters

Before the coming of COVID-19, urban leaders were far more worried about the threat of global warming than the threat of pandemic.   Climate change is more addressed in the Henry Lee chapter of this volume. Here I will briefly discuss responding to the possible impacts of global warming rather than reducing the extent of global warming.   These issues are handled far more completely by essays later in this Those impacts include rising sea levels, rising temperatures and the increased threat of natural disasters, especially hurricanes. The potential responses include relocation, shields and more resilient infrastructure.

Many cities are near the water and close to sea level, precisely because waterways were the critical inter-urban transportation network in the pre-modern period. Access to those waterways is less valuable today, and urban populations can potentially be moved out of range of water-related risk.   If urban infrastructure was mobile, then relocation provides a relatively easy solution to flood.   Indeed, a crucial issue is the speed of climate change relative to infrastructure depreciation. If change is sufficiently slow, then perhaps we can gradually move population centers away from high risk areas.   Yet it seems unlikely that we will even abandon the enormous investments that have been made in cities like New York, Boston and San Francisco. Cities of the developing world have less infrastructure to lose, which might make the case for relocation stronger in poorer places. Yet the political capacity to move large population will be limited in poor countries.

If cities remain vulnerable to the sea, then shields, such as sea walls, become a plausible solution to climate risk. In principle, such barriers can protect both against storm surges and against the relentless rise of the seas, but the costs can easily be enormous. The political norm in which protection from natural disasters is the job of the Federal government seems to reward risky behavior. If the owners of the sea-front property pay for their sea walls, then there are stronger incentives again building in more vulnerable settings.

A third response is to make structures and infrastructure more resilient to flooding. Resilience is unlikely to solve the problem is the city is going to be under a foot of water, but public transit systems and power grids can be protected against the threat of flood. Again, this increases costs and helps make the case for building in less vulnerable areas in the future.

I chose not to dwell on the goal of reducing carbon emissions, but that goal will remain and shape both urban form and infrastructure. Looking forward, this goal will create a conflict between the post-COVID-19 desire to segregate oneself in a car and the pre-COVID-19 desire to reduce carbon usage.

VIII. **Conclusion**

Infrastructure has shaped cities for thousands of years, since ancient walls provided protection against marauders and paved roads made it easier for the passage of wheeled vehicles. This essay has focused primarily on the transportation infrastructure that has played a primary role in shaping the cities of the wealthy world today, and that seem most likely to influence the future of those cities. Water, sewers and power generation have played much less of a role in this essay, and yet these are particularly central to life in developing world cities today.

Manila is a metropolitan area with more than twelve million inhabitants, yet only a small fraction of that population has access to sewers. Septic tanks are a far more common, even if extremely dense parts of the region. In many cities of India and Sub-Saharan Africa, pit latrines are far more common than either sewers or septic tanks.   The cities of the west only became healthy by spending vast sums on their sewers. Will the cities of the developing world continue to grow without spending on public health related infrastructure?

The current residential electricity demand of much of the developing world are relatively limited, because populations are too poor to expect their homes to artificially air conditioned throughout much of the year. As these populations become richer, their desire for electricity at home seems likely to increase enormously. That demand for electricity will either require more power generating infrastructure or will lead to prices that are so high that they are sure to engender discontent.

Infrastructure is at the center of our urban world.   The connection between transportation and urban density is particularly tight, since the ultimate purpose of density is to reduce transportation costs between people and firms. That is also the purpose of transportation infrastructure. The need for serious cost-benefit analysis to bring intellectual rigor to future infrastructure investments is one of the great policy planning tasks of the 21st century.

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