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HOW THE PRIVATE SECTOR CAN IMPROVE PUBLIC TRANSPORTATION INFRASTRUCTURE

by Clifford Winston

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This paper draws heavily upon and extends Winston (2013a) and Winston and Mannering (2014).

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Abstract

Transportation infrastructure, including roads, bridges, airports, and the like, significantly contributes to America's prosperity by facilitating access to the workplace, shopping, and leisure activities, as well as giving employers easy access to labor, capital, and potential consumers. However, current capacity for transport has become increasingly strained, and travelers and shippers have experienced more congestion and delays. The public sector's "strategy" to increase infrastructure spending fails to generate the large promised benefits because its pricing and investment and operating policies are so inefficient. Accordingly, this paper explores how the private sector could improve infrastructure performance. I conclude that the most promising approach consists of technological advances in the transportation modes, namely, the driverless car and aircraft that rely on satellite-based navigation, both of which are being developed by the private sector. Those advances will create a new era of highway and air transportation, provided their implementation is not impeded by the government.

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How the Private Sector Can Improve Public Transportation Infrastructure

Clifford Winston

1. Introduction

Transportation infrastructure significantly contributes to a nation's prosperity by facilitating workers' access to employers, consumers' access to shopping and leisure activities, and firms' access to capital, labor, and potential customers. The public sector has generally provided the vast amount of a nation's infrastructure—roadways, waterways, railways, and airways—and expanded it to satisfy users' growing demand for transportation. But as demand has increased and aging infrastructure facilities have required ever-greater funds for maintenance and new construction, capacity has become increasingly strained, and travelers and shippers have experienced more congestion and delays. Policymakers have tried to find new sources of money to finance projects to expand capacity, but congestion and delays have persisted.

The public sector's "strategy" of increasing spending to build its way out of congestion has been entrenched for decades and is unlikely to change for the foreseeable future into a sustainable strategy that could improve infrastructure performance.[1] I therefore consider in this paper three ways that private-sector firms could potentially contribute to that goal:

1. They could purchase infrastructure facilities from the government and operate them more efficiently subject to general business laws (privatization).
2. They could develop technological innovations that the public sector could implement to improve current infrastructure performance.

[1] Peterson (2013) discusses the resistance in the United States to raising the federal tax on gasoline and diesel fuels, which provides revenue for the Highway Trust Fund that finances federal highway expenditures, quoting Representative Steve Southerland (Florida) as saying, "You can't tax your way out of this mess." However, a few months earlier the Obama administration proposed overhauling the corporate tax code to generate funds for infrastructure construction and many Republican lawmakers simply countered by arguing that more transportation funds should be left in the hands of individual states rather than with the federal government. Recently, some states have raised their gasoline taxes.

3. They could make technological advances that greatly improve the operations of transportation modes that use the infrastructure.[2]

In what follows, I explore those possibilities by drawing on evidence based primarily, but not exclusively, on highway and aviation infrastructure services in the United States, which have been the main focus of infrastructure policy discussions. I conclude that privatization, while worthy of carefully designed experiments, faces considerable uncertainties about its long-run success in the United States; technological innovations developed by the private sector are available for the public sector to implement but policymakers have resisted doing so; and, more positively, technological advance in the transportation modes could facilitate significant improvements in infrastructure performance provided its implementation is not impeded by the government.

2. An Overview of Public Infrastructure Inefficiencies

I begin with a brief overview of the economic inefficiencies that have developed under public ownership and management of transportation infrastructure.[3] Although I draw only on the US experience, other countries' infrastructure is characterized by similar inefficiencies.

The United States has grappled with determining the optimal mix of public and private provision of transportation since its founding. Infrastructure was initially developed and operated by the private sector, but the public sector soon played a role. For example, starting with the Ohio Statehood Enabling Act in 1802, states provided limited funds for road building, and in the 1820s state government subsidized and owned some canals and railways. But even by the 1860s,

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[2] In many countries, the public sector has tried to engage the private sector through public-private infrastructure partnerships; but their primary purpose has been to substitute private for public spending and they have not generated notable efficiency gains.

[3] This material is explained in greater detail in Winston (2013a).

cumulative private capital investment in bridges, canals, ferries, railroads, and roads amounted to roughly $3 billion (in 1860 dollars), a significant share of the nation's GDP (Wright and Murphy 2009).[4] Various financial crises subsequently resulted in the government owning and operating most of the nation's infrastructure, although it has been contested whether the government effectively responded or contributed to those crises. For example, Klein and Fielding (1992) argue that government regulation of highway tolls during the 19th century greatly contributed to the failure of private highway companies. And the government takeover of private airports during the Great Depression can be questioned because a better course of action in the long run may have been to allow private airport competition to develop by offering struggling airports financial assistance so they could stay in business and compete.

Funding for public highway and aviation infrastructure is obtained from various taxes and fees. Motorists and truckers are charged gasoline and diesel fuel taxes for their use of the roadways, aircraft are charged a weight-based landing fee for their use of airport runways, and air travelers are charged a fixed rate, currently $4.00 per flight segment, and a 7.5 percent tax on their fare to pay for air traffic control services (Airlines for America 2014).

As auto, truck, and plane traffic has continued to grow, those sources of funds have become inadequate to cover the costs that users impose on public infrastructure. The federal gasoline tax, which is the primary source of highway user-fee revenues, has not been raised since 1993, and Congress has recently been forced to add general funds to the Highway Trust Fund to close what would otherwise be a deficit. Airports are experiencing similar problems. Since 2000, the Aviation Trust Fund has been running annual deficits between $3 billion and $5 billion that have been covered by general taxpayer funds (Winston 2013a). Air traffic

[4] Starkie (2012) points out that, in the United Kingdom during the 18th and 19th centuries, the role of the state was to enable transportation infrastructure to be both planned and developed largely by private interests.

control was forced to cut back operations, which significantly increased flight delays, when the government sequester hit in April 2013 because its funds could not cover current operations (Winston 2013b).

Funding shortfalls have contributed to longer and more frequent travel delays related to pothole-ridden roads. According to data from the Texas A&M Transportation Institute reported in Winston (2013a), the average annual traffic delay endured by motorists in urban areas has more than doubled during the past three decades. At the same time, despite frustratingly frequent lane closures for road repairs, highway crews cannot seem to outpace the rate of pavement deterioration. The Federal Highway Administration (FHWA) compiles annual highway statistics that indicate that, although the condition of the nation's highways and bridges varies with general economic conditions, as much as one-third of the nation's highways may be in poor or mediocre condition and one-quarter of the nation's bridges may be functionally obsolete or structurally deficient for several years before repairs are made. Due to greater airport and airspace demand, congestion—and thus travel times by air in the United States—has steadily increased since airlines were deregulated in 1978.

Public provision of highway and aviation infrastructure is characterized by growing budget deficits, travel delays, and physical deterioration because it has not been guided by basic economic principles: prices do not reflect social marginal costs, especially a user's contribution to congestion and delays; investments are not based on benefit-cost analysis and have failed to maximize net benefits; and operating costs have been inflated by regulations. In addition, those static inefficiencies have been compounded by dynamic inefficiencies that are attributable to the slow rate of technological advance in infrastructure services.

2.1. *Pricing*

Motorists and truckers should be charged for their use of lane capacity by paying efficient (marginal cost) congestion tolls, which can be assessed using modern technology without disrupting motorists' and truckers' journeys, assuming sufficient safeguards are employed to protect their privacy.[5] By substantially reducing—but not eliminating—delays and reducing residential sprawl because the out-of-pocket cost of commuting would no longer be underpriced, such tolls could generate annual gains of $40 billion. This amount includes the travel time savings for commuters, savings for taxpayers from lower costs of public services due to greater residential density, and greater revenues to the government (Langer and Winston 2008).[6] In addition, truckers should be charged an axle-weight tax that accurately accounts for their trucks' damage to road pavement (for a given weight, trucks with more axles inflict less pavement damage). Small, Winston, and Evans (1989) find that an axle-weight (marginal cost) charge would encourage truckers to shift to vehicles with more axles that do less damage to road pavement, thereby reducing maintenance expenditures and producing an annual welfare gain exceeding $10 billion.

Airport runways become congested—that is, they reach capacity—when planes that take off or land force other aircraft to wait on taxiways and tarmacs to take off or force them to wait in the air by reducing their speeds or circling the airport before they can land. In contrast to weight-based landing fees, efficient takeoff and landing (marginal cost) congestion charges that vary by time of day could significantly reduce air travel delays, generating a $6.3 billion annual

[5] Miller (2014) summarizes research that indicates how a system of road charges could be structured to safeguard privacy.
[6] The benefits from congestion pricing are likely to be understated because they do not include the positive effects on health and the environment and the improvements in travel time reliability. Small, Winston, and Yan (2005) find that the value that motorists place on the standard deviation of travel time (or the difference between two fractiles of the distribution of travel time) was similar to the value they place on average travel time.

welfare gain, accounting for time savings to travelers and reduced operating costs to airlines (Morrison and Winston 1989). Similarly, a marginal-cost user fee that accounts for an aircraft's contribution to congested airspace near airports and to its demand on air traffic control services could reduce delays and traffic control's workload by inducing airlines to schedule flights to use the available airspace more efficiently.

2.2. *Investments and Operations*

Optimal investments in transportation infrastructure should maximize the present value of users' benefits, net of capital and maintenance costs, while efficient operations should minimize costs.

In practice, investments in highway capacity have been excessive because users' prices have been set below marginal cost. Duranton and Turner (2012) conclude from a study covering the period 1983 to 2003 that, at the margin, the benefits from additional roads have fallen short of the costs and that increasing the provision of new roads is unlikely to relieve congestion. In contrast, investments in highway durability have been insufficient. Small, Winston, and Evans (1989) have argued that optimal pavement thickness should minimize the present discounted sum of initial capital and ongoing maintenance costs. They determined that building roads with thicker pavement at an annualized cost of $3.7 billion would generate an annualized maintenance saving of almost four times as much—$14.4 billion—for a net annual welfare gain of $10.7 billion. Improving the durability of a nation's roads is also important because it reduces the wear and tear on motorists' and truckers' vehicles. Driving on damaged roads is estimated to cost US motorists $67 billion in additional annual operating costs and repairs (Road Information Program 2010) and also damages trucks and increases their operating costs.

US airport authorities appear to have underinvested in airport runway capacity at major airports. Morrison and Winston (1989) estimate that the annual gain from combining efficient runway pricing with efficient runway investments, which would reduce delays and airlines' operating costs, was $16 billion. I am not aware of a more recent study, but the growth in air traffic suggests that the gains today from combining efficient pricing with investment would be even greater.

Regulations have significantly raised the cost of infrastructure services. Federal and state transportation departments employ nearly 200,000 workers, in part just to ensure that highway projects meet all regulations. Sherk (2011) finds that the annual cost of Davis-Bacon regulations that stipulate that "prevailing wages"—interpreted in practice as "union wages"—be paid on any construction project receiving federal funds increases the cost of federal construction projects by 9.9 percent; repealing the regulations and paying market wages would have saved taxpayers $10.9 billion in 2010. The savings are not solely transfers from labor because the inflated wage payments are funded by taxation, which generates a cost (excess burden). Finally, the cost of constructing runways has turned into a task that is measured in billions of dollars because it takes decades to meet regulations, especially Environmental Protection Agency environmental impact standards (Winston 2010).

2.3. *Dynamic Inefficiencies*

Government's stifling of innovation and technological advance in highway and aviation infrastructure has deprived travelers of significant benefits. Because innovations and technological change often become apparent only after government impediments have been eliminated by policy reforms, such as privatization and deregulation, they may be difficult to identify and the costs of failing to implement them may be difficult to quantify before the policy change. However, the extraordinary time that the Federal Aviation Administration (FAA) has taken to implement the latest technological advances in air traffic control that could improve the safety and speed of air travel clearly illustrates the nature of the problem.

In the early 1980s, the FAA announced plans to develop an advanced automated system that was scheduled to be completed by 1991 at a cost of $12 billion. As of 2013, the fully upgraded system is more than two decades late, billions of dollars over budget, and still nowhere in sight. Instead, the FAA has turned its attention to transitioning the current radar-based system to a more advanced satellite-based system (Winston 2013a). I discuss the delays and cost overruns associated with implementing that technology in section 4.2.

2.4. *Causes of Inefficient Policies*

Agency limitations, regulatory constraints, and political forces combine to maintain inefficient highway and aviation infrastructure policies and to impede efficient reforms. For example, the FAA is at the heart of airport and air traffic control inefficiencies because it lacks organizational independence and is prevented to a significant extent by both the US Department of Transportation and Congress from using its resources—and from encouraging airports to use theirs—more efficiently. Given that it faces opposition from two powerful branches of government, it is not surprising that the FAA finds it so difficult to reform its policies.[7]

Constructive reforms must also overcome various regulations. For example, I noted the regulatory hurdles that delay airport runway investments. Turning to airport pricing, Levine

[7] Robyn (2007), among others, suggests that re-mandating the FAA with a more independent mission that gives it an arm's-length relationship with Congress and the executive branch, especially in its management of air traffic control, would improve its performance.

(2007) points out that widespread adoption of runway congestion tolls would require airline tenants and their airport landlords to abrogate their existing contracts and to develop an acceptable framework for determining all airport charges.

Regulations of and expenditures on transportation infrastructure are likely to benefit particular stakeholders, especially those who effectively pressure members of Congress and regulatory officials to support their agenda and to oppose efficient reforms. For example, Stiglitz (1998) describes his efforts as part of the Clinton administration to institute congestion pricing for air traffic control—only to find reform blocked by owners of corporate jets and small planes who have a vested interest in inefficiently low user fees. Other examples of special-interest politics that are transparent in influencing infrastructure policy include the American Automobile Association's and the American Trucking Association's longstanding opposition to efficient congestion tolls and axle-weight charges that are likely to cause some of their members to pay more for using the road system, and labor unions' opposition to removing the Davis-Bacon regulations because thousands of construction workers would see their wages fall.

Finally, because federal transportation legislation reauthorizes hundreds of billions of dollars for aviation and highway infrastructure spending that has the potential to benefit certain stakeholders at the expense of others, members of Congress must continually engage in contentious negotiations to craft the legislation. Compromises broadly allocate federal highway funds to states and federal aviation funds to airports and air traffic control facilities, instead of taking a benefit-cost approach to allocate those funds efficiently to specific locales to alleviate the country's most congested highways and air travel corridors.

In sum, although the public sector has greatly contributed to building America's invaluable highway and aviation infrastructure, its costly policies cannot and should not be ignored. Certainly it would be desirable to reform transportation policy to make it more efficient, but I have argued that this is highly unlikely. Instead, I consider various ways that the private sector could provide constructive change.

3. Privatization

Privatization—namely, a transparent, well-structured agreement in which the government sells, not leases, transportation infrastructure assets to private firms—would give the private sector an opportunity to improve infrastructure performance and social welfare compared with government ownership and provision. Whether privatization succeeds depends, in theory, on the extent of market power that private firms possess, the extent to which incentives influence whether private firms achieve their goals, and whether consumers have any recourse for applying competitive pressure on the private firms to respond to their (heterogeneous) preferences (Vickers and Yarrow 1991; Roland 2008).

Policymakers have privatized infrastructure in many parts of the world, but the preliminary evidence on privatization's economic effects is mixed. Studies of airport privatization, subject to varying degrees of regulation, have found that airport efficiency has improved in Australia (Forsyth 2008) and the United Kingdom (Graham 2008; Starkie 2008). In a worldwide comparison of airports, Oum, Yan, and Yu (2008) find that airport privatization reduced costs by promoting competition and Bilotkach et al. (2012) find for European airports that privatization reduced runway charges to airlines, but Bel and Fageda (2010) find that it increased charges.[8] Comparisons of the US Air Traffic Control Organization with Nav Canada, a

[8] When the three London airports—Heathrow, Gatwick, and Stansted—were privatized, BAA PLC and subsequently Ferrovial SA were allowed to purchase them. The UK Competition Commission eventually required that Gatwick and Stansted be sold to different owners.

private-sector air traffic control organization established in 1996 and financed by publicly traded debt, have found that, under privatization, modernization of technology greatly improved, air travel became safer, and users benefited from improved service quality (Oster 2006; McDougall and Roberts 2008).[9]

Highway privatization has been explored in developed and developing countries (Gomez-Ibanez and Meyer 1993) with varying results and no general consensus on its effects. Australia's Macquarie Bank Limited and Spain's Cintra Concesiones de Infraestructuras de Transportes SA have amassed large infrastructure funds and have been leading investors in private highways throughout the world, but I am not aware of economic assessments of these or any other investors' privatization projects.

As summarized in Gomez-Ibanez (2006), unbundling train operations and track infrastructure maintenance turned out to create coordination problems in the important case of the United Kingdom, where the private train operators, the private infrastructure company Railtrack, and the government regulator often disagreed about the design of the improvements needed to expand track capacity, how much they should cost, and how those costs should be shared. Congestion on the system made maintenance more difficult and contributed to accidents that helped bankrupt Railtrack in 2001. Nash (2006) and Glaister (2006) argue that the UK government deserves considerable blame for Railtrack's collapse because it implemented the unbundling policy hastily and carelessly. Indeed, vertical unbundling did not cause serious problems in the rest of Europe and Australia, but that may be because the rail

[9] Robyn (2007) argues that the shift in the air traffic control system technology from ground-based radar to satellites and cockpit controls presents an opportunity in the future to explore the effects of competition in air traffic control services. Different regional air traffic control service providers could serve different terminal areas—and enter areas that are not receiving state-of-the-art service. Providers could negotiate directly with airspace users and airports to determine the price and the type of service and equipment to be provided.

infrastructure companies were in public rather than private hands or because infrastructure capacity was far less strained.

Evidence for the United States, based on simulating the effects of highway and airport privatization, indicates there are plausible situations where privatization could lead to efficiency gains that improve travelers' welfare, especially if private infrastructure firms respond to travelers' varied preferences for faster and more reliable travel. Winston and Yan (2011) analyzed highway privatization based on motorists' travel on State Route 91 in California. The authors model a competitive environment by assuming the highway takes the form of two routes with equal lane capacities and that both routes could be operated by a private monopolist. Each route could be operated by a different private firm, generating duopoly competition, or one route could be operated by a private firm and the other by the government, generating public-private competition. The authors also address the potential problem of the private highway operators having market power by assuming that motorists, represented by a third party, and private providers negotiate tolls and capacity that generate a contract equilibrium (Meyer and Tye 1988). Finally, they assume that motorists would be refunded the gasoline taxes that currently go into the Highway Trust Fund because the private provider(s) would finance the highway with tolls.

Based on this analysis, Winston and Yan (2011) find that highway privatization could benefit road users and increase welfare by reducing the inefficiencies associated with current (public-sector) road pricing and capacity allocation, even if the highway were owned and operated by a monopolist. Motorists would be able to gain in certain bargaining situations where they are given a choice of paying a high toll to use lanes with little congestion, lower travel times, and greater travel time reliability, or paying a low toll to use lanes that are highly congested and offer higher travel times and lower travel time reliability.[10] Highway privatization could also enhance motorists' welfare and social welfare by generating more efficient investments, improved operations that reduce production costs, and technological innovations. Motorists fail to gain when a private owner sets monopoly charges and negotiations do not lead to price and lane capacity allocations that are aligned with their preferences.

Yan and Winston (2014) develop a model of privatized airports in the San Francisco Bay Area, under which separate owners compete for airline operations by setting profit-maximizing runway charges that reduce travel delays, and airlines compete for passengers. Runway charges are determined through separate negotiations between airlines, which are organized as a bargaining unit, and each of the three Bay Area airports—Oakland, San Jose, and San Francisco.

The authors find that it would be essential for the Bay Area airports to be sold to different owners to prevent carriers from facing monopoly charges that would be passed on to travelers. They also find that, by allowing the airports to set different charges for different classifications of airport users, they would gain from privatization. Commercial carriers would be better off when they negotiate charges that lower their operating costs because of reduced delays, including the delays caused by general aviation. Under these arrangements, the general aviation users face airport charges that are more in line with their contribution to delays, and reflect higher airport charges. Although air travelers would pay higher fares because airport charges to airlines would increase, their time savings from less-congested air travel would more than offset that cost. The higher charges faced by general aviation passengers would also be softened if policymakers

[10] The option to pay a toll and travel in less-congested lanes is available in some major US metropolitan areas that have high-occupancy-toll (HOT) lanes. The HOT lanes that opened in 2013 in the Virginia portion of the Washington, DC, Capital Beltway appear to be successful. As reported by Halsey and Craighill (2013), more than one-third of surveyed motorists indicated that they have used these lanes and that they have obtained notable travel time savings.

expanded airport privatization to encourage (smaller) private airports to compete for (smaller) aircraft operations. This could be achieved, for example, by taking advantage of improvements in global positioning system (GPS) technology that have enabled general aviation to have easier access to smaller airports, by upgrading runways and gates, and by offering van and rental car services to improve travelers' access to the central city and other parts of the metropolitan area. Travelers in low-density markets could especially benefit from privatization because they would have more flight alternatives if private airports nationwide offered commercial service.

Unfortunately, the available evidence on the effects of privatizing transportation infrastructure is not sufficiently developed to rule out the possibility that privatization could result in market failure attributable to the abuse of monopoly power or inadequate management of uncertainty in demand, costs, and the like that could lead to a financial collapse because, for example, demand is much lower or costs are much higher than anticipated.[11] In addition, many questions can be raised about how privatization should proceed. For example, what is the most efficient way for the government to transfer public infrastructure to private firms? What should the sale prices be for those assets? What role, if any, should the public sector have in the privatized system? How much time will be needed for competition to develop in privatized markets? Should regulations be implemented during the transition to effective competition? What contingency plans should be developed in the event that privatization results in a financial collapse of a significant part of the system or in a monopoly provider that faces no competitive discipline?

[11] Dezember and Glazer (2013) describe some examples where private investors have invested in toll roads in the United States before the Great Recession and were forced to declare bankruptcy when their traffic forecasts failed to meet expectations. However, selectivity bias is present in this evidence because investors were not free to invest in any part of the US highway system they desired. The privatized toll roads entailed considerable risk because they were not major thoroughfares that generated a high and reasonably predictable level of traffic.

Accordingly, Winston (2010) argues that it is important for policymakers, in collaboration with scholars, practitioners, and users, to carefully design and execute experiments to obtain additional hard evidence of the effects of infrastructure privatization before considering nationwide adoption. As the experiments evolve, analysts should evaluate their economic outcomes and, if necessary, propose supplemental policies that could enhance the infrastructure's performance.[12]

4. Private-Sector Innovations

4.1. *Public Highway Infrastructure*

Even without privatization, private-sector firms could still contribute to improving public highway infrastructure performance if policymakers expeditiously implemented technologies that they have developed. The FHWA must rely on the private sector for research and development because its budget allocates only a small amount of funds for that purpose.

Based on benefit-cost analysis, general-purpose and specific technologies could be implemented to improve the efficiency of highway pricing, investment, and operations that affect safety. General purpose technologies include GPS satellite navigation services that, among other things, can collect information about motorists, such as their location, their speed, and alternative routes for their journeys; Bluetooth signals that can be detected to monitor the speed of cars and trucks through the road system in real time to assist drivers' route decisions and to adjust traffic

[12] Successful experiments with privatizing certain, albeit limited, transportation services throughout the world have shown benefits that are slowly gaining attention and possibly generating support for additional explorations. For example, The Mass Transit Railway (MTR) Corporation manages the subway and bus systems on Hong Kong Island and the northern part of Kowloon and, in contrast with most other transit systems, turns a profit. Its strategy is to operate as a vertically integrated entity that provides transport services and owns or accepts development fees from property within or next to its stations. Its profits from real estate ventures and transit revenues have been used to properly maintain its transit operations, which reduces operating costs and service interruptions and encourages patronage. In the United States, the Detroit Bus Company is a recent experimental private bus service, which provides transportation for school children and enables travelers to know the location of its buses with bus trackers.

signal timing; and mobile software applications (apps) and websites that provide motorists with real-time information on traffic speeds and volumes, conditions on alternative routes, and available parking spaces. Motorists are becoming increasingly aware of the benefits of GPS services and the share of cars on the road that are equipped with those services is expected to climb from 10 percent as of 2013 to 50 percent by 2015.

Specific technologies include weigh-in-motion (WIM) capabilities, which provide real-time information about truck weight and axle configurations that can be used by highway officials to set efficient pavement-wear charges and enforce safety regulations efficiently; adjustable lane technologies, which allow variations in the number and width of lanes in response to real-time traffic flows; improved road construction and design technologies to increase pavement life and to strengthen roads and bridges; and photo-enforcement technologies to monitor vehicles' speeds to improve traffic flow, capacity, and safety.

4.1.1. Congestion pricing. As noted in the introduction, policymakers have been seeking additional sources of highway funding so they can increase spending to expand capacity. But as Downs' Law predicts, such spending would not reduce traffic congestion for very long because peak-hour congestion would rise to meet maximum capacity as motorists shifted from less preferred routes, modes, and times of day (Downs 1962). Downs' Law would not apply, however, if policymakers set tolls that were adjusted in real time to traffic flows and congestion. Some motorists who previously avoided highly congested highways and local streets would be discouraged by the initial toll levels from using those thoroughfares even when travel speeds improved, while others would be discouraged by the increase in tolls if traffic became more congested.

The informational requirements to set an accurate optimal congestion toll τ_l (on highway link l in a road network consisting of L links) can be seen from equation 1. For a given volume of traffic per unit of time, v_l, and the link's vehicle-carrying capacity per unit of time, K_l, the toll that a highway authority should set, as shown in Lindsey (2012), is expressed as

$$\tau_l = \frac{\partial c_l(v_l, K_l)}{\partial v_l} v_l, \quad l \in \boldsymbol{L}, \tag{1}$$

where c_l is the user cost function, which includes the private costs of a trip, such as fuel consumption and other vehicle operating costs like depreciation, as well as travel time costs.

As indicated by equation 1, the highway authority must first determine the traffic volume on a specific stretch of road during a given time interval to implement an accurate congestion toll. It can make this determination by using GPS navigation services and then drawing on plausible cost estimates that are available in the literature—for example, Small and Verhoef (2007)—to set the specific charge. Using information technology, such as an app, this charge and estimated travel times on different routes can be communicated to motorists before they reach the tolling area, giving them sufficient time to decide whether to take the tolled route or an alternative that offers their preferred combinations of out-of-pocket costs and travel time. Those motorists who choose the toll road would have the charge deducted electronically via their vehicle transponders without their journeys being disrupted or their privacy invaded. (Of course, it would be a motorist's choice whether to use the available technology to obtain pricing and routing information.) Motorists would also have the option to vary their value of time for different trips depending on their purpose and on the activity at the destination.[13] Implementing

[13] I do not want to minimize the potential practical issues with motorists using information technology to improve their trips. For example, real-time information could lead to a "herd effect," where many users shift simultaneously to a route and make it more congested. In that case, prices would have to increase accordingly, and some travelers might revise their choices. Such issues may have to be resolved by further improvements in the information technology that is used for highway travel.

available technologies would therefore improve pricing efficiency and, as noted, generate substantial welfare gains by providing the highway authority with the critical traffic information that it would need to set efficient tolls throughout the day, as well as by providing motorists with the pricing and routing information that they would need to optimize their journeys.

Information technology could be implemented to price traffic lanes while informing motorists of their options on all parts of the road, including shoulders on highways for emergency purposes. Because automakers have continued to improve vehicle reliability since the automobile was introduced, breakdowns do not occur as frequently today and the benefits to motorists from opening a shoulder to increase highway capacity and reduce congestion are likely to exceed the cost of limiting space for vehicle incidents.[14] The Bureau of Public Roads (BPR) formula, which determines travel time on a road accounting for delays due to congestion, can be used to get a feel for the potential benefits. The formula indicates that opening a shoulder to traffic (in the peak travel direction) on a four-lane freeway that is operating with a traffic flow that is 90 percent of highway capacity would reduce motorists' travel time on the freeway by roughly one-third (Mannering and Washburn 2013).[15] Pricing the shoulder efficiently would further increase travel time savings and the benefits from road pricing.[16] As noted, motorists could use an app to get knowledge in advance about whether the shoulder is open to traffic and the price to drive on it.

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[14] Vehicles on US roads have never been older, now averaging 11.3 years, as the quality of vehicle construction has improved. Some of the aging is undoubtedly attributable to the slow recovery from the Great Recession, which has caused people to hold onto vehicles longer in order to avoid a big purchase.
[15] The BPR formula for travel time on a highway link is given by $t_l = tf_l\,[1 + \alpha(v_l/K_l)\beta]$, where t_l is the travel time in minutes on highway link l, tf_l is the free-flow travel time in minutes on this link, v_l is the traffic volume on the link, and K_l is the capacity of the link. The parameters α and β take the values of 1.1491 and 6.8677 for freeways.
[16] Minneapolis has begun to explore this policy by introducing "dynamic priced shoulder lanes" on Interstate 35W.

4.1.2. Pavement and bridge wear pricing. Because pavement damage is related to a truck's weight per axle and bridge stress is related to a truck's total weight, efficient highway prices for trucks should encourage truckers to reduce those weights whenever possible. The damage caused by an axle is defined in terms of the number of "equivalent single-axle loads" (ESALs) causing the same damage; the standard is a single axle of 18,000 pounds. An efficient short-run marginal cost pavement-wear charge (SRMC) would induce truckers to reduce their ESALs by encouraging them to shift to vehicles with more axles that do less damage to road pavements, thereby reducing maintenance expenditures and producing welfare gains. The informational requirements to set this charge can be seen from equation 2, which is given per ESAL mile as (Small and Winston 1988):

$$SRMC = \frac{\alpha C(W)}{N(D)}, \tag{2}$$

where α is a parameter; $C(W)$ is the cost of resurfacing a highway of width W, measured by the number of lanes; and $N(D)$ is the lifetime of a road of durability D, as determined by the number of ESALs that can pass over it before it must be resurfaced.

A highway authority can estimate a truck's ESAL miles to charge it accurately for its contribution to pavement damage by using high-speed WIM technologies. WIM uses sensors that are installed in one or more traffic lanes to identify a vehicle and record its number of axles, vehicle load, and journey (that is, the roads it uses) while it continues to travel in the traffic stream, thus not disrupting its operations (Jacob 2010). The total charge would then be sent to the truck's owner as the product of the truck's ESAL miles and a plausible estimate of the resurfacing costs per ESAL mile.

WIM technologies could also be used to measure the considerable stress caused by trucks crossing a bridge (National Cooperative Highway Research Program 2003) and to determine efficient bridge-wear charges as a function of vehicle weight and bridge age; the latter consideration is important because older bridges become more susceptible to heavy loads as a result of metal fatigue and the possibility of age-related deterioration of concrete reinforcing bars (Barker and Puckett 2007). Truck operators could submit their planned routing in advance and be informed of those charges online, and could either reduce their loads or take an alternate route to avoid higher-priced bridge crossings, thereby extending the design life of the bridge and reducing the likelihood of catastrophic bridge failure, expensive repairs, and loss of life.

4.1.3. Truck size and weight limits. Truck size and weight limits have been established in the United States to keep trucks off certain roads if the trucks might cause excessive pavement or bridge damage or jeopardize safety. At the same time, those limits raise the costs of trucking operations by requiring trucks to disrupt their journeys to stop at weigh stations for inspection, and by forcing trucking companies to use smaller trucks and make additional trips to move the nation's freight. WIM technologies could enable highway authorities to accurately monitor truck sizes and weights, thus eliminating the need for them to be inspected at weigh stations.[17] And information technology that facilitated more efficient highway pricing could spur vehicle design improvements, such as stronger brakes that would allow trucking companies to use larger trucks to reduce average operating costs without compromising safety.[18]

McKinnon (2005) provides some illustrative evidence from the United Kingdom that relaxing truck size and weight limits could significantly increase trucking productivity and reduce social costs. McKinnon estimated that increasing maximum truck weights by 6,700

[17] Something akin to weigh stations may be desirable to inspect trucks for other safety-related matters.
[18] Truckers have adopted improvements in vehicle design to reduce operating costs. For example, in response to higher fuel prices, some truckers increased their vehicles' fuel economy by using the TrailerTail, developed by ATDynamics, to reduce the aerodynamic drag generated at the rear of a trailer.

pounds (a modest 7.3 percent increase over the previous weight limits) resulted in trucking industry annual operating cost savings of nearly $250 million (in 2013 dollars). Significantly reducing vehicle miles traveled also reduced congestion and greenhouse gas emissions. Similarly, the US and other nations' surface freight transportation systems stand to increase their efficiency without necessarily increasing accident costs by implementing technology that permits more flexible and higher truck sizes and weight limits.

4.1.4. Investments in capacity and durability. Technology could be implemented to facilitate investments that expand highways' vehicle-carrying capacity and increase durability of these highways at reasonable cost. Ng and Small (2012) point out that most highways in major metropolitan areas operate in congested conditions during much of the day, yet highway design standards are based on free-flow travel speeds. Highway authorities could effectively expand capacity during peak travel periods to reduce delays by adjusting the number and width of lanes on a freeway in response to real-time traffic volumes that are measured by GPS navigation services. Thus to enable vehicles to move faster, heavy traffic volumes would call for more but narrower lanes, while lighter traffic volumes would call for fewer but wider lanes. Technology exists to install lane dividers that can be illuminated so that they are visible to motorists, and can be adjusted in response to changes in traffic volumes to increase or decrease the number of lanes that are available. As noted in the case of opening a highway shoulder to traffic, creating an additional lane during peak travel periods would result in substantial travel time savings for motorists. And although it would be easier and less costly to install variable lane widths for new roads than for existing roads, implementing this technology whenever possible would be less expensive than constructing an additional lane that meets standard width requirements, especially for freeways in dense urban areas where land is scarce and adding to road capacity is a very expensive proposition.

The rapid evolution of material science (including nanotechnologies) has produced advances in construction materials, construction processes, and quality control that have significantly improved road pavement design. This has resulted in greater durability, longer lifetimes, lower maintenance costs, and less vehicle damage caused by potholes. For example, Little et al. (1997) estimated that the SUPERPAVE effort in the late 1980s and the 1990s (Transportation Research Board 2005), which developed new asphaltic binder specifications for repaving, produced roughly \$0.6 billion (in 2013 dollars) in benefits. Other investments that apply recent advances in material science technologies are also possible, but they are often delayed because state departments of transportation try to minimize their expenditures rather than the sum of these and highway users' costs. Delays in the uptake of technology also occur because state departments of transportation award contracts on the basis of the minimum bid, not the technological sophistication of the contractor (Winston 2010).

Finally, state departments of transportation have been slow to implement advances in roadway structural monitoring technologies that would allow them to monitor the health of both pavements and bridges on a continuous basis, providing valuable information for optimal repair and rehabilitation strategies that could reduce the cost of highway services (Lajnef et al. 2011).

4.1.5 Safety. Policymakers and highway authorities have attempted to promote safety by setting speed limits, instituting traffic signals, enforcing traffic laws, and responding to traffic incidents. Technology could be implemented at modest cost to improve the effectiveness of those actions.

Congressional action set a national maximum speed limit of 55 mph in 1974, but subsequently abolished it in 1996 and allowed states to set their own maximum speed limits. Lave and Lave (1999) conclude that this experience shows that higher speed does not necessarily kill, and that lives could be saved by setting speed limits that people would obey because they are aligned with driving conditions. Accordingly, highway authorities could implement technology to improve safety and reduce travel times by setting variable speed limits (VSLs) that are properly aligned with real-time traffic flows and other driving conditions such as weather. Papageorgiou, Kosmatopoulos, and Papamichail (2008) find that VSLs displayed on roadside variable message signs have led to substantial improvements in safety in many countries. There is also evidence that they have improved highway safety in the United States (Washington State Department of Transportation 2007).

The traffic control systems in most US cities were developed by inexperienced public officials when the automobile was a new mode of transportation. Todd (2004) points out that in many driving situations, all-way stops (where vehicles approaching intersections from all directions are required to stop) and roundabouts would be more effective than traffic signals at reducing motorist and pedestrian fatalities, as well as reducing traffic delays. To add to the problem, poor signal timing and coordination, often caused by outdated signal control technology or reliance on obsolete data on relative traffic volumes (Atkinson and Castro 2008), contributes to some 300 million vehicle hours of annual delay on major roadways (National Transportation Operations Coalition 2007). Technology that enables traffic signals to respond to real-time traffic flows by optimizing the duration of traffic signals could be more widely applied to enhance safety and reduce travel times. Such optimization would also result in the use of a flashing red signal instead of the conventional red-yellow-green traffic signal at intersections with very low traffic volumes. In addition, a signal could warn motorists stopped at traffic lights of an impending green light. This would reduce start-up delays, which amount to about 6 percent of the time that a traffic signal is green at a typical intersection. Mannering and Washburn (2013) estimate that cutting start-up delays in half could reduce the delays caused by signals by nearly 20 percent, with little effect on safety.

Finally, the costs of enforcing traffic safety laws, which include high-speed police chases that occasionally result in fatal accidents, could be substantially reduced by using photo-enforcement technology (roadside cameras) to identify and issue citations to motorists who run stop signs or traffic signals, or who exceed the speed limit by a predetermined amount, such as 15 mph.[19] Shin, Washington, and van Schalkwyk (2009) evaluate an experiment in Arizona and find that automated speed enforcement on an only 6.5-mile stretch of freeway in Scottsdale reduced enforcement costs by as much as $17 million per year.

Vehicle incidents (accidents and disablements) account for a large share of traffic congestion and they can be very costly.[20] Garrison and Mannering (1990) estimate that the average per-minute cost in travel time delays of incidents on Seattle freeways was $3,500 (in 2013 dollars). In accordance with benefit-cost considerations, including any additional costs to taxpayers, highway authorities could make much greater use of communications technology to reduce incident costs and help accident victims receive assistance more quickly by detecting disruptions in traffic flows and speeds that indicate an incident has occurred. Incident response teams, including tow trucks to remove disabled vehicles, could then be quickly alerted and dispatched, while motorists on the road could be notified of disruptions and advised to avoid the

[19] Photo-enforcement technology has encountered legal challenges in some but not all US states.
[20] The Federal Highway Administration puts the share as high as 25 percent (FHWA 2013), while the Texas A&M Transportation Institute's *Urban Mobility Report* puts the share closer to 50 percent (TTI 2012).

troubled area and to make way for response teams that are addressing the problem. Wilde (2013) estimates that a one-minute increase in response time could increase the victim-mortality rate by as much as 17 percent; hence, reducing response times could also potentially save the lives of many motorists involved in accidents.

4.1.6. Impediments to adopting technology. Technological innovations have long been recognized as a major source of economic growth and improved living standards, but analysts have been hard-pressed to explain how policymakers can spur such innovations. In the case of a public-sector facility like highways, policymakers are responsible for using the latest technology to provide this service in accordance with benefit-cost considerations. Accordingly, they are clearly impeding technological change by failing to implement recent innovations that could, at modest cost, significantly improve the speed, reliability, and safety of motorists' trips, while reducing the cost of highway services.

Why has the public sector failed to implement those technologies in a timely manner to realize their social benefits? As discussed previously, the federal government is biased toward the status quo in managing and operating the nation's transportation system because of agency limitations, regulatory constraints, and political forces. In the case of the FHWA, lack of expertise may prevent technologies that improve the highway system from being implemented effectively and efficiently. Indeed, I noted above that the FHWA's budget does not place a priority on developing new technologies to improve highways. Like other agencies, the FHWA may also be risk averse and want to avoid the mistakes and well-publicized delays in implementing technology that, for example, have tarnished the FAA's reputation for managing air traffic control effectively (as discussed in section 4.2.3).

From a political perspective, implementing the latest technology may be helpful in overcoming highway users' opposition to certain policies such as congestion pricing and pavement-wear pricing. Motorists have indicated that they value the option to pay an electronic toll to expedite their trips, as indicated by the growing adoption in several areas of the country, such as Atlanta, Los Angeles, Salt Lake City, and Washington, DC, of high-occupancy-toll (HOT) lanes, where solo motorists can pay a toll to travel in a less-congested carpool lane. As more motorists use GPS services to expand their route choices, they may become more enthusiastic about comprehensive road pricing, especially if prices and travel time vary on different lanes to cater to motorists' heterogeneous preferences for travel time and reliability (Small et al. 2006). In response to political pressures, policymakers could reduce charges on a given lane to selected users, such as carpoolers and low-income travelers.

Trucking interests have been able to dissuade policymakers from significantly reforming truck charges despite repeated protests from railroad and automobile interests that the fuel tax does not fully charge trucks for their fair share of highway costs (Winston 2010). WIM technologies would make the trucking industry's highway costs more transparent and may eventually break the stalemate among the transportation modes, while truckers' resistance to reforming truck charges might be lessened if they were given greater flexibility in their choice of trailer sizes and loads that they could carry.

I speculate that, although implementing new technologies could help address political impediments to efficient pricing, transportation officials continue to maintain status quo policies because they fear certain users' objections to higher charges and because the FHWA may not stand to gain much from technology that reduces the cost of building and maintaining highways if those savings lead to reductions in its budget. In sum, the FHWA, like other public-sector agencies, appears to lack sufficient incentives to summon the political will to change.

4.2. *Public Aviation Infrastructure*

The FAA is responsible for managing and implementing major research and development projects in the private sector to improve airport operations and modernize air traffic control. The Transportation Security Administration (TSA) is responsible for managing airport screening and security. Both agencies rely on the private sector to provide state-of-the-art equipment and are responsible for managing projects and adopting the new technologies in a timely and cost-efficient manner.

4.2.1. Airport runway operations. Tens of thousands of flights are canceled or delayed every year in the United States because of snowstorms. One of the contributing factors is that plows and sweepers cannot clear snow off runways fast enough to allow aircraft to take off and land safely. Heated runways could potentially solve that problem and provide billions of dollars of benefits in time savings to travelers and cost savings to airlines.[21]

Private homes and businesses have been using heating systems to keep snow off their driveways and walkways for decades. In fact, since 1967 the Green Bay Packers have used an underground system of electric coils, subsequently replaced with a system of pipes filled with a solution including antifreeze, to keep their football field soft for games that are played in subfreezing conditions.[22] Airports, however, have not been installing heating systems on their

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[21] See, for example, McCartney (2014).

[22] Some readers will recall the famous incident in which the system failed during the National Football League championship game, played on December 31, 1967. The entire playing surface froze, earning the game its popular

runways. The FAA claims that heating large airport surfaces is too expensive, but with roughly 100,000 flights in the United States canceled during the admittedly severe 2014 winter season, policymakers should take a careful look at the costs and benefits of heated runways at major airports.

4.2.2. Airport security. An efficient airport security system allocates resources based on costs and benefits by directing expenditures toward detecting the greatest threats to safety and preventing them from materializing. It is, of course, difficult to assess the benefits of TSA screening because no data are available about terrorist attacks that screening has prevented. Nonetheless, the TSA has been criticized for expending too much time and money confiscating firearms—almost all of which were probably intended for recreational use—instead of trying to keep dangerous people off airplanes (Poole 2009). To that end, greater efforts should be made to classify travelers according to their risk to airline passengers' safety. More rapid implementation of advanced screening technologies would enhance the approach. After a long delay, the TSA has introduced full-body scanners at US airports, which are more effective than metal detectors at spotting potentially dangerous objects and substances, and can do so with minimal radiation exposure. Some European airports have begun to use biometrics—computers verifying identities through physical characteristics—to detect terrorists and expedite screening so that it is more efficient. The TSA currently uses biometrics to control employees' access to secure areas and to verify the identities of passengers who enroll in its traveler program PreCheck, but it does not have any plans to use the technology to process passengers at the airport. The TSA's slow

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title, "The Ice Bowl." Officials concluded, however, that the extraordinary cold that day—the temperature was recorded at 15 degrees below zero—overwhelmed the system, and no similar incidents have been reported in the 47 years since then.

adoption of biometrics to screen all passengers may expose it to additional criticism if European airports find that it is a valuable complement to human screeners.

4.2.3. Air traffic control. The FAA has turned its attention to expediting the transition from the current radar-based air traffic control system that uses imprecise, decades-old technology to a next generation satellite-based system known, appropriately, as NextGen (Winston 2010). Radar updates aircraft positions only every 5 to 10 seconds and forces controllers to separate aircraft by several miles to provide a safety buffer and avoid collisions. In contrast, the automatic dependent surveillance broadcast (a key component of NextGen) updates positions every second. Aircraft equipped with GPS technology would enable pilots to fly directly to their destinations instead of following indirect routes to stay within the range of ground stations. By enabling pilots to be less dependent on controllers, to choose the most efficient altitude, routing, and speed for their trip, and to operate in cloudy and foggy weather much as they do on clear days, a NextGen satellite-based system could reduce travel times, carrier operating costs, and airplane emissions throughout the system while improving safety. The FAA (2012) estimates that, compared with the current system, NextGen would enable the airspace to handle three times as many planes with half as many air traffic controllers. The FAA estimates the benefits from avoided delay, time savings, and reduced cancellations and carbon-dioxide emissions will amount to $106 billion between now and 2030.

Unfortunately, government officials expect NextGen to take much longer to deliver and cost billions of dollars more than they originally expected. Calvin L. Scovel III, the inspector general of the US Department of Transportation, said in testimony before Congress that NextGen's completion could slip by at least a decade and its cost could triple (US Department of Transportation 2013).

4.4.4. Impediments to adopting technology. Poole (2013) evaluates seven critical elements of NextGen to shed light on why progress toward implementing the system has been much slower than anticipated. As in the case of the FHWA, Poole identifies a status quo bias that resists innovation as well as problems in identifying promising technologies and in efficiently procuring those that it does identify. Over the years, the FAA has lost its best and brightest engineers to the private sector and lost its program management expertise, making it overly reliant on contractors that it has difficulty controlling. Given NextGen's troubles, it is possible that policymakers will aim to keep the existing system operating and postpone NextGen even further. If so, the US air traffic control system will fall behind those of other countries, including Australia, New Zealand, Canada, Germany, and the United Kingdom. Air traffic control providers in those countries have embraced new technologies and procedures much faster than the FAA. The systems have been reorganized as self-supporting corporate entities, charging aviation customers directly for their air traffic control services and issuing bonds backed by their revenue streams. Serious doubts exist that US policymakers can summon the political will to reform the air traffic control system to emulate the more successful "corporate" model that has developed abroad.

4.3. *Transportation Modes*

All modes of transportation have improved their performance and safety regardless of the state of their infrastructure. For example, automakers have continued to improve vehicle engines, designs, and structural strength by installing seatbelts, antilock brakes, air bags, and the like. More recent safety innovations include electronic stability control, warning and emergency braking systems, speed alerts, and mirrors with blind spot warnings. Those innovations will also increase road capacity by enabling vehicles to drive closer together without compromising speed (Winston and Mannering 2014).

Airlines have improved their fleets by acquiring aircraft with more powerful and fuel-efficient jet engines and they are planning on incorporating improvements in wing design to reduce fuel consumption (Karp 2014). They have also fit aircraft with navigational aids, such as wind shear avoidance and alert systems, to improve passenger safety.

The recent revelations of "autonomous vehicles" and aircraft that rely on advanced navigation equipment raise the possibility of an entirely new era of highway and air transportation. This provides an additional way that the private sector could improve infrastructure performance. To be sure, those improvements are further in the future than efficient policy reforms, privatization, and the adoption of existing technologies, which are actions that could be taken now. At the same time, no doubt exists that the technological innovations in vehicles and aircraft will occur; hence, a critical issue is whether highway and aviation policymakers will facilitate the introduction of those innovations in a timely manner.

4.3.1. Autonomous surface vehicles. Autonomous or driverless cars and trucks do a human driver's normal job and much more. Driverless cars are operated by computers that obtain information from an array of sensors on the surrounding road conditions, including the location, speed, and trajectories of other cars. The onboard computers gather and process information many times faster than the human mind can process it. By gathering and reacting immediately to real-time information and by eliminating concerns about risky human behavior, such as distracted and impaired driving, the technology has the potential to prevent collisions and greatly reduce highway fatalities, injuries, vehicle damage, and costly insurance. It can also significantly reduce delays and improve travel time reliability by creating smoother traffic flow and by routing and, when necessary, rerouting drivers who have programmed their destinations.

Driverless trucks are also in the developmental stage. For example, dozens of such trucks are being used to haul materials in an iron-ore mine in Australia and at other locations away from public thoroughfares (Winston and Mannering 2014). In addition to contributing to improved traffic flow and motorists' safety, driverless trucks would benefit industry, and ultimately consumers, by substantially reducing labor, insurance, and operating costs.

Thus far, seven US states—including California, Florida, and Nevada—have legalized the testing of driverless cars, and several other states are considering doing the same. Competition among automakers and other firms to develop the best technology is already underway: Google has logged nearly 500,000 miles testing its version of a driverless car; General Motors is working on a model with researchers at Carnegie Mellon University; Audi, BMW, Toyota, and Volvo have demonstrated their driverless models; and Nissan has claimed that it will offer a full line of driverless cars in the next decade (Winston and Mannering 2014). In short, some, admittedly optimistic, forecasts indicate that driverless cars could be a common sight on US roads by 2025.

Empirical estimates of their benefits are sparse but Fagnant and Kockelman (2013) show that they are highly dependent on the speed of adoption and extent of market penetration. Accounting for the reduction in fatalities and injuries, less vehicle damage, and savings in travel time, fuel, and parking costs, these authors estimate that even a modest 10 percent penetration of driverless cars would generate annual benefits of $40 billion. Annual benefits amount to an eye-popping $200 billion if market penetration reaches 50 percent. An additional benefit is that city residents will need far fewer cars—perhaps only one-third of the cars that they have now—for their vehicle travel (Spieser et al., forthcoming).

Driverless vehicles are inevitable, but the major obstacle to their adoption as soon as they are available is uncertainty about whether the government will take prudent and expeditious approaches to help resolve important questions about assigning liability in the event of an accident, the availability of insurance, and safety regulation. The National Highway and Traffic Safety Administration (NHTSA), which is responsible for regulating automobile safety, has issued cautious recommendations about driverless cars (Winston and Mannering 2014). That may be appropriate at this stage of the vehicle's development, but NHTSA should also be cautious about sharing FHWA's legacy of not promoting timely innovation in highway travel.

4.3.2. Air travel using advanced navigation systems. An essential component of air travel is that it requires communication between aircraft and air traffic control to maintain safe distances between aircraft and accurate flight paths from the origin to the destination. As discussed by Poole (2013), the substantial improvement in communications provided by technologies such as digital communications and GPS could facilitate automating much of the routine separation of aircraft, permitting far greater use of the entire airspace than the limited airways defined by ground-based navigational aids. As noted, the benefits in time and cost savings and safety for aircraft operators and air travelers in the new environment would be significant.

High-end general aviation and commercial air carriers—Southwest Airlines is a notable example—have taken the step of carrying advanced navigation equipment in their aircraft. However, they cannot use the new equipment because the FAA has been slow to put in new facilities, train controllers, and approve new flight procedures. Indeed, the FAA has no economic incentive to implement the new technology rapidly. Thus, air service providers are frustrated and some are even reluctant to purchase new equipment because of their concerns with the FAA's management of NextGen (Poole 2013).

New communications technology would also allow for the introduction of unmanned aircraft (drones) into the aviation system for commercial purposes. For example, new start-ups hope to launch delivery of textbooks in Australia using drones and Amazon has indicated an interest in drone deliveries. However, the FAA has banned the commercial use of drones and the United States again appears to be falling behind other countries because its regulator and infrastructure provider are moving too slowly (Pasztor 2013).

5. Conclusions

The creation of new modes of transportation in the United States by the private sector has resulted in new infrastructure investment (Schweikart and Folsom 2013). Cars were introduced by private entrepreneurs, who also built private roads including parts of the Lincoln Highway in 1913, the first transcontinental highway. The federal interstate highway system then followed in 1956. Airplanes became a major industry and were flying passengers domestically in the 1920s and overseas in the 1930s. During that period nearly all airports were privately funded. Public airports appeared in large numbers when military airfields were converted after World War II.

The justification for government takeover of private highway and aviation infrastructure continues to be debated today, but what cannot be debated is that inefficient and intractable public policies have significantly compromised the performance of those public facilities. I have therefore explored three ways that the private sector may be able to help. First, privatization—returning the public infrastructure into private hands—could potentially lead to efficiency improvements; but the outcome is uncertain and such fundamental institutional change would require carefully designed experiments to generate widespread public support. Second, the private sector has developed technological innovations, especially in information technology, that public providers of infrastructure could adopt to improve performance. But public agencies have a strong status quo bias and they have been very slow to introduce such innovations.

Because the public sector constitutes a strong impediment to privatization and the adoption of improved technologies, I am more optimistic about the long-run success of the third possibility explored in this paper, that is direct actions taken by the private sector to improve the transportation system. In particular, the modes of transportation themselves are well along in the process of adopting innovations that could significantly improve the efficiency and safety of infrastructure. Thus history appears to be repeating as transportation modes, automobiles and airplanes, are exhibiting technological advances that will usher in a new era of highway and air transportation. As noted, modes of transportation lead infrastructure, so history will hopefully also repeat with modal advances spurring infrastructure to improve. Research and experimentation should then continue to explore the synergies between the modes and their infrastructure and determine whether they would be even greater if both were in private hands.

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