DISCUSSION PAPER

APRIL 2006 ■ RFF DP 06-21

Transit in Washington, D.C.

Current Benefits and Optimal Level of Provision

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RESOURCES FOR THE FUTURE

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Abstract

The discrepancy between transit's large share of local transportation resources and its generally low share of local trips has raised questions about the use of scarce transportation funds for this purpose. We use a regional transport model consistent with utility theory and calibrated for the Washington, D.C., metropolitan area to estimate the travel benefits of the local transit system to transit users and the congestion-reduction benefits to motorists. We find that (i) rail transit generates congestion-reduction benefits that exceed rail subsidies; (ii) the combined benefits of rail and bus transit easily exceed local transit subsidies generally; (iii) the lowest-income group receives a disproportionately low share of the transit benefits, both in absolute terms and as a share of total income; and (iv) for practical purposes, the scale of the current transit system is about optimal.

Key Words: transit, transit subsidies, external transit benefits

JEL Classification Numbers: R40, R41

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1. Introduction

Many local and state governments devote a substantial share of their transportation expenditures to mass transit. In some areas, transit spending can account for more than 50 percent of expenditures in the regional transportation budget.[1] Because most urban transportation programs face tight fiscal constraints and intense competition for funds, the level of transit investment is often a point of contention.

To skeptics, public expenditures on mass transit are often wasteful, particularly considering alternative uses for the money. In most areas, transit handles a very small share of daily trips. Furthermore, with the exception of a few areas, transit's mode share has declined over the past several decades. Nationwide, the percentage of transit commute trips has dropped from 12.6 percent in 1960 to 4.7 percent in 2000 (Pucher and Renne 2003). Critics also point to inefficiencies in transit systems arising from above-market wages and contracts as well as an oversupply of routes to low-ridership but politically powerful suburbs (Winston and Shirley 1998).

Because transportation budgets usually are determined through a political process, it is unlikely the resulting level and pattern of investment in mass transit will be optimal in terms of maximizing net benefits. But some observers, mindful of the apparent discrepancy between transit's share of local transportation spending and share of local travel have questioned whether any public investment in transit is warranted. In other words, does the transit system as a whole produce benefits in excess of its costs? A related question is how dramatically current levels of transit investment differ from the efficient ones.

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[1] For example, expenditures on transit account for 60 percent of total spending in the regional transportation plan for Washington, D.C., and more than 81 percent in San Francisco.

Of course, the answers will depend greatly on the setting. Studies that have looked at the factors explaining transit ridership have found that certain demographic and spatial factors (such as vehicle ownership levels and employment density) play a paramount role (Bento et al. 2003; Baum-Snow and Kahn 2000; Taylor and Fink 2003).

In this paper we address these questions for the Washington, D.C., area, using simulation results from the Washington-START model, an integrated transportation model of the metropolitan Washington region. After reviewing the dialogue between advocates and skeptics of increased transit spending (Section 2), we provide background on Washington's transportation system and the Washington-START simulation model in Sections 3 and 4, respectively. In Section 5 we present our estimates of the net benefits from the existence of the transit system. In addition, we identify the main beneficiaries of the current transit system, both by income group and geographically. The optimal level of transit provision in the area and the relative cost-effectiveness of investments in bus and rail are treated in Section 6. The final section concludes and discusses model limitations.

2. Why Subsidize Transit?

2.1 Arguments for Subsidization

Traditionally, three major justifications have been offered in support of government subsidies to transit. First, numerous social benefits arise from reducing auto travel, particularly improvements in traffic flows and air quality. Drivers do not pay the full marginal social costs of their vehicle use, including increased congestion, pollution, noise, and accidents (Delucchi 2004). In the absence of corrective taxes, which have proven exceedingly difficult to implement, a second-best alternative is to subsidize the automobile's main competitor, public transportation (Lewis and Williams 1999).

Distributional equity is another rationale. Increased investment in transit and subsidized fares expand the mobility options for low-income population. In an auto-dependent transportation system, poor households that cannot afford private vehicles may be limited in their ability to take advantage of economic opportunities. The provision of transit may reduce spatial barriers to employment, especially in large metropolitan areas (Holzer et al. 2001).

Third, there are economies of scale to transit investment, particularly for rail. Rail requires substantial investment in right of way and capital requirements that are relatively insensitive to the volume of passengers. Bus investment, while showing only modest economies of scale in terms of cost, demonstrates increasing returns to scale with respect to service provision. As transit frequencies increase, wait times decrease, demand increases, and transit frequencies can increase again (the so-called Mohring (1972) effect). Because marginal social cost is below average social cost for both rail and bus, setting fares equal to marginal social cost will be insufficient to cover the financial requirements of the system. From an economic efficiency perspective, this is the most compelling argument for subsidization, because the aforementioned issues can be addressed more effectively with other instruments (Vickrey 1980).[2]

Critics of public provision and subsidization of mass transit offer several rebuttals to these arguments (summarized in Small and Gomez-Ibanez 1999). First, the cross-price elasticities of auto usage with respect to transit costs are rather small (Hensher 1997), indicating that subsidizing transit may be a relatively inefficient way to discourage automobile use. Transit own-price elasticities are typically low as well—on the order of –0.33 to –0.22 (Kain and Liu 1999; Gillen 1994)—implying that the social benefit from pricing at marginal cost versus average cost may not be very high. On the issue of equity, transit users in dense urban areas are often relatively affluent, and the transfer of income from taxpayers to transit users may not have the desired distributional effects.

2.2 Optimal Provision

A growing literature has looked at optimal transit supply, usually in conjunction with optimized fare levels. Most studies have assumed efficient pricing of all modes, including the automobile. With respect to results, no consensus exists; the optimal fares found in these studies range from close to zero to nearly four times current levels.

Viton (1983) finds that optimal fares in San Francisco and Pittsburgh should be close to zero, producing a substantial increase in transit's mode share supply. On the other hand, Winston and Shirley (1998) employ an aggregate joint-choice model to estimate optimal transit supply in a set of U.S. metropolitan areas and conclude that average service frequencies should fall dramatically for both bus and rail—a 73 percent decline for bus and a 60 percent drop for rail. They also find that fares should double for rail and quadruple for bus, to the point that fares for both modes come close to covering full marginal costs.

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[2] A more efficient way to address motor vehicle externalities would be to price them with congestion tolls and pollution tax. The equity problem can be better addressed through direct monetary transfers.

De Borger and Wouters (1998) employ a model of the Belgian transport market and find optimal fares decreasing and service increasing from the baseline. Transit prices decrease by 61 percent in the peak and 84 percent in the off-peak, while supply rises 13 percent and 54 percent, respectively.

Van Dender and Proost (2003) use TRENEN, a nonspatial partial equilibrium transport model calibrated to specific urban areas, to determine optimum bus and rail fares and frequencies in Brussels and London. Under the assumption of road pricing, optimal fares rise dramatically for both modes. If auto use is not priced, however, optimal fares fall close to zero during peak hours but double those from the baseline during the off-peak. Optimal service frequencies increase for both modes in Brussels during the peak period but fall for bus and increase for rail in the off-peak. For London, optimal frequencies rise for rail and drop for bus in both time periods.

The wide range of estimates can partly be explained by different modeling approaches (e.g., some take into account the marginal cost of public funds and others do not, some account for economies of scale from increased frequency and others do not). Another major factor accounting for the discrepancy is the differing geographic scope of the studies. Those showing increased optimal frequencies are based on specific, relatively dense metropolitan areas, like Brussels, London, and San Francisco. The Winston and Shirley (1998) study is based on a sample of large metropolitan areas in the United States and includes many areas where transit is very unproductive.

2.3 Literature on Transit's Overall Benefits

Estimates of the overall benefits of the transit system are less common, at least in an academic context. The Texas Transportation Institute (Schrank and Lomax 2005) includes a measure of time-savings from the existence of a public transportation system using an aggregated approach based on the relationship between lane miles and vehicle miles traveled in urbanized areas. For 85 urban areas, they find average annual benefits from public transit of $217 million attributable to reduced congestion costs. For the 13 largest areas, they estimate the average savings to be worth almost $1.2 billion annually. This figure is a coarse estimate and excludes the costs of provision.

Winston and Shirley's (1998) examination of U.S. transit policy concluded that on average, reducing rail spending is essentially a break-even proposition, and eliminating bus service would actually increase welfare because of the improvement in the government's fiscal balances. They note, however, that this is a nationwide average. In certain dense metropolitan areas, transit investment may be more attractive.

3. The Washington, D.C., Transportation System

Washington, D.C., is often cited as having some of the worst traffic congestion in the United States (Schrank and Lomax 2005). In Washington, like many large metropolitan areas, investment in new road capacity has failed to keep pace with rising vehicle miles traveled. Severe congestion is now found on most of the region’s major highways, including I-95, I-270, and the Capital Beltway (Transportation Planning Board 2004).

From 1990 to 2000, nearly 900,000 people moved to the region as a whole even as the core city population dwindled by 120,000. Notwithstanding this trend of intraregional outward population movement, the federal government remains the major engine of the local economy, anchoring economic activity in the region’s downtown core. The Washington metropolitan area remains a comparatively dense region, with population densities comparable to those of Boston and Philadelphia.

Given its population density and congestion levels, it is not surprising that the area has one of the nation’s top-performing transit systems. The Washington Metropolitan Area Transit Authority (WMATA), the area’s main transit operator, runs the Metrobus and Metrorail systems. WMATA is the fourth-largest transit system in the United States in terms of annual trips, and the rail system is second only to MTA in New York City in terms of ridership. During rush hour, 18 percent of all person trips in WMATA’s service area use transit, the second-highest percentage in the country. More than 40 percent of peak-period trips to the downtown core use transit (Metro Funding Panel 2005).

However, beyond the city and inner suburbs, transit options are fairly limited, and public transportation accounts for just 3 percent of all trips in the region as a whole. Outside WMATA’s service area, transit mainly consists of two regional commuter rail systems, MARC (serving primarily Maryland) and VRE (serving Virginia), as well as various local jurisdictional bus systems.

WMATA’s heavy rail system recovers around 60 percent of its operating expenses at the fare box, one of the highest recovery rates in the nation. The recovery ratio for bus is only about 30 percent, a relatively low figure, although this is partly because bus is designed to be a feeder into rail. For comparison, in 2000 the nation’s top-performing transit system, New York City’s MTA, had cost recovery factors of 67.3 percent (rail) and 40.9 percent (bus), and the average cost recovery factor across all transit systems nationwide was 39 percent (FTA 2000). WMATA's total operating budget for weekday service in 2000 was $642 million, with subsidies for rail and bus services at $95 million and $170 million, respectively. Also, per trip, bus is cheaper to ride. WMATA estimates the average bus fare is 60 cents versus $1.50 for rail. This is partly because MetroRail riders face congestion pricing, with peak fares costing two to three times more than fares during off-peak times.

WMATA's future funding situation has become a topic of concern, with the lack of a dedicated funding source identified as a major hurdle to WMATA's long-run financial stability (Puentes 2004). In what has become an annual affair, WMATA labors to justify its growing operating subsidy at federal-, state-, and county-level appropriations meetings. More recently, a regional sales tax has been proposed to help with this recurrent problem.

4. Description of the Washington-START[3] Model

Washington-START is a strategic planning simulation model that is rigorously grounded in household optimization, computes welfare measures that take into account behavioral responses to policy changes, and has relatively short run times, enabling a wide range of policy simulations and sensitivity analysis.

The Washington-START model contains 40 travel zones. Each zone contains three stylized links (inbound, outbound, and circumferential) that aggregate arterials and side streets; the model also incorporates various "special links," which represent highway segments and bridges. Six main corridors of special links—I-270, I-95, and US-50 in Maryland and I-66, I-95/I-395, and Va.-267 in Northern Virginia—connect the outer suburbs to the central region within the Beltway, I-495/I-95, as shown in Figure 1. Existing HOV lanes on these freeways at peak period (or at all times, in the case of US-50) are taken into account. Special rail links for the Metrorail heavy rail and VRE and MARC suburban commuter rail systems also span the zones (Figure 2).

[3] The START (Strategic and Regional Transport) modeling suite was developed by MVA Consultancy and has been applied to a range of urban centers in the United Kingdom.

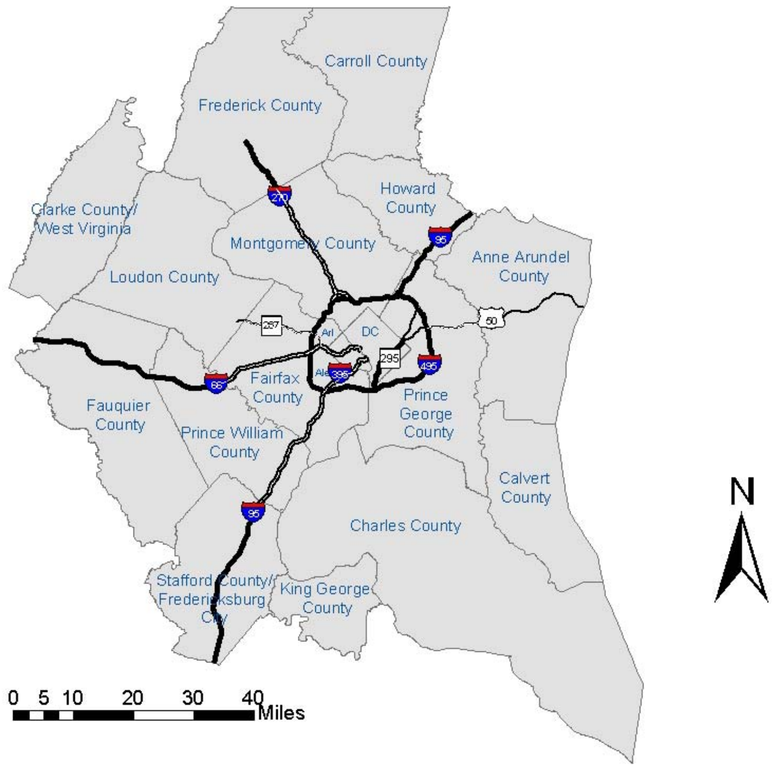

Figure 1: Washington-START Zones

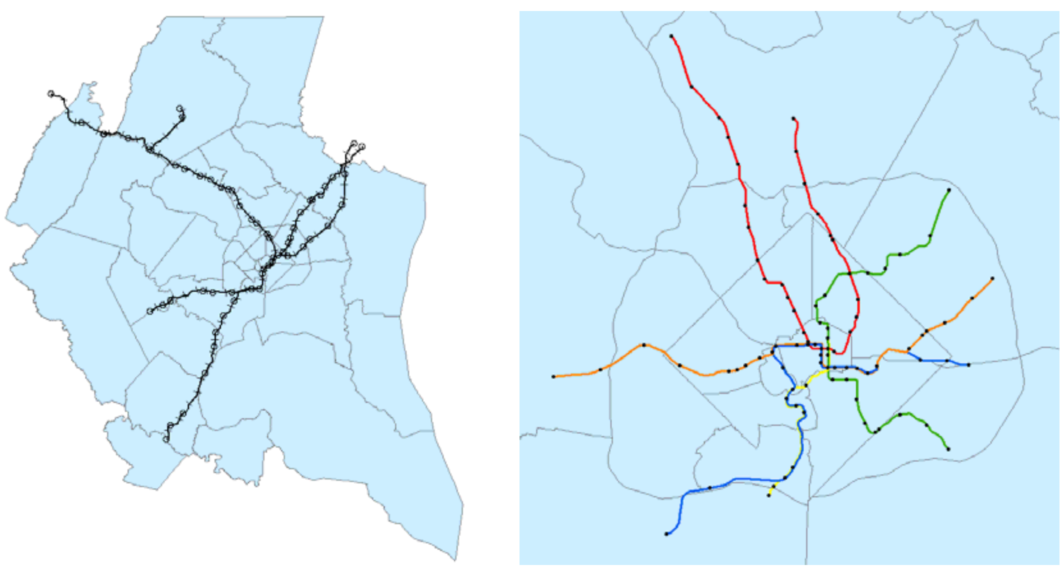

Figure 2: Commuter Rail (Left) and MetroRail

4.1 Public Transit Supply

The public transit system as modeled in the current Washington-START model is broken into two submodes: rail and bus. Data for frequency, fares, and capacity for Metrobus and Metrorail, VRE and MARC commuter rail, and local jurisdictions' bus systems were collected from the agencies directly whenever possible to make the model representation of the two networks maximally accurate.

4.2 Rail

In the current version of Washington-START, rail routes are modeled as a series of "special links," where each rail line in each zone is modeled as an individual link, complete with individual capacity and frequency characteristics. Rail routes consist of a succession of links along a path of zones leading from origin to destination and were created based on usage patterns derived from a 2002 WMATA passenger survey and MARC and VRE boarding numbers. This disaggregated modeling is feasible because of the small number of Metrorail and commuter rail lines in the D.C. metro area.

In addition to rail links, usage-weighted park-and-ride legs on the road network are added to all rail routes. Thus urban commuters, who generally do not drive to the rail station, face short to nonexistent park-and-ride legs, but suburban commuters face longer park-and-ride routes.

Both the special-link rail routes and the park and ride legs are upgrades to Washington-START since Safirova et al. (2004).

4.3 Bus

Bus routes are much less tractable and thus are defined to be routes on the existing road network[4] for each origin-destination pair. For each time period, buses are assumed to travel the most frequently used car route from the origin to the destination. In this way, congestion on the road network also affects bus riders. It follows that benefits from reduced congestion can also accrue to bus users. This is a marked improvement over the state of Washington-START in Safirova et al. (2004), in which buses were modeled as if they operated on a distinct network of bus lanes and bus travel times were unaffected by automobile congestion.

[4] As traditional in transportation network modeling, a bus is considered to consume the equivalent of two "car units" of road space on the network.

4.4 Transit Trip Cost Calculation

Transit users face monetary costs as follows:

Bus:

$$P = f + 2v^*(1+2\pi)w + v^*(1+\rho)t$$

Rail:

$$P = f + 2v^* w + v^*(1+\rho)t + \tilde{d} + \tilde{f} + v^*\tilde{t} + 2v^*(\tilde{s} + \tilde{e})$$

Where:

f is the transit fare

v^* denotes value of time, set at 40 percent of the wage rate for all purposes except nonhome-based work trips. For nonhome-based work trips, it is assumed that the traveler is “on the clock,” and the value of time is therefore set at the wage rate. For waiting time, parking egress time, and parking search time, the value of time is doubled, since time spent in these activities is considered more unpleasant than time spent in-vehicle.

π denotes the probability of missing a bus and having to wait for the next one (this constant also helps address the bunching effect often seen on bus routes) and is a function of the fullness of the bus.

w denotes the waiting time.

ρ denotes an increase in perceived time resulting from crowding (to be explained in the next section). This perceived crowding penalty is purely psychological; it does not represent any real factor contributing to trip time.

t denotes the travel time, including transfers between bus or rail lines.

The following variables pertain to the park-and-ride leg of rail routes. The park-and-ride leg is weighted to accurately represent the tendency of rail users to drive to and park at the origin rail station.

$\tilde{d}$ denotes the monetary driving costs for the drive from home to the rail station.

$\tilde{f}$ denotes the parking fee associated with the route.

$\tilde{t}$ denotes the time required to drive from home to the rail station.

$\tilde{s}$ denotes the time required to find a parking space and is a function of the fullness of the parking area and one's parking category (reserved versus unreserved space), as well as of the physical characteristics of the parking area, such as lot size.

$\tilde{e}$ denotes the time required to go from one's car to the rail station entrance.

Rather than working with absolute costs, the Washington-START model uses cost differentials between the calibrated baseline and simulated policy scenarios to determine the costs that drive the logit model. For this reason, some costs do not need to be included in the formulas above. For example, time needed to walk to a bus stop is not included in the bus cost formula because this time is assumed to be the same in the baseline and policy scenarios.

4.5 Transit Crowding Curve

A crowding curve, established at four comfort levels (sitting comfortably, sitting crowded, standing comfortably, standing uncomfortably) is used to determine the increase in perceived trip time as passengers are subjected to more crowded public transit vehicles (Lam et al. 1999). The same crowding formula applies to bus and rail trips. The crowding formula is applied in a time-windowed approach, using WMATA data on demand characteristics broken down into half-hour intervals over each time period. This method ensures that the crowding calculation fully captures the "peakiness" of the morning and afternoon rush hour periods. Taking into account peaking attributes is important: there are 2.7 times as many peak rail trips as off-peak. For bus, the ratio is 2.4 (FTA 2000).

4.6 Trip Demands

On the demand side, households are aggregated into four income groups. Five trip purposes, in addition to freight, are distinguished: home-based trips either originate or terminate at home and are classified as commuting to work, shopping, or other (such as recreation), and nonhome-based trips are distinguished between work-related and nonwork-related. There are four travel modes, including single-occupancy vehicle (SOV), high-occupancy vehicle (HOV), bus/rail and walk/bike. And there are three times of day: morning peak, afternoon peak, and off-peak (weekend travel is excluded).

Trip demands are estimated for each of these origin, destination, purpose, mode, and time period nests using methods discussed in Safirova et al. (2004). Data sources used include the Census Transportation Planning Package (CTPP), the Metropolitan Washington Council of

Governments (COG) Version 1 transportation planning model and 1994 Travel Survey, as well as wage and price indices obtained from the Census and Bureau of Labor Statistics. The model has been recalibrated since the Safirova et al. (2004) study using more recent CTPP 2000 data.

Washington-START takes the distribution of households by demographic segment and residential location as given. Travel decisionmaking is modeled as a nested logit tree; in successive nests, households choose first whether to take a trip, then destination, mode, time of day, and route. Utility functions at each nest are linear in full travel costs, which combine time and money costs. Travel demand response parameters were chosen to satisfy the hierarchical structure of the logit model and to be largely consistent with empirical literature. For example, Washington-START's computed fuel price elasticity of vehicle miles traveled is –0.169. Because this elasticity value is not a model parameter but the result obtained from model runs, it reflects not only the direct effect of increase in fuel price, but also the secondary effects related to reduced traffic congestion. This value corresponds well with values in the literature of –0.16 (de Jong and Gunn 2001) and –0.1 (Goodwin et al. 2003). See Table 1 for more model elasticities.

Table 1: Washington-START Computed Elasticities

Elasticity	*Washington-START*	*Compare with*
PT trips WRT fuel price	0.088	0.07 (Luk and Hepburn 1993)
Bus trips WRT bus fare	–0.291	-0.28 short run, –.55 long run (Goodwin 1992)
Train trips WRT train fare	–0.732	–0.65 short run, –1.08 long run (Goodwin 1992)

5. Estimating the Benefits of the Washington, D.C., Transit System

The policy scenarios here look only at weekday transit supply. Fares, the geographical pattern of investment, and the relative mix of peak and off-peak service do not change from the baseline. These simplifications help us to best characterize the transit system as it is, rather than as it optimally could be. The simulations use 2000 as the analysis year for traffic patterns, prices, and travel levels.

In these simulations, expansion or contraction is measured as a percentage change of rail and/or bus revenue miles operated by the transit agencies in the modeled area. The revenue mile increase or decrease is achieved by simultaneously manipulating both route frequency and vehicle capacity, leaving the network of routes unaltered. From the users' perspective, frequency affects waiting time at the bus or rail station, and capacity affects the number of potential passengers on each transit vehicle. We model scenarios where we change the frequency and capacity by the same percentage.

To estimate total benefits of the weekday Washington-area transit system, we reduce transit supply to zero and calculate the resulting aggregate welfare change. The decline in traveler welfare minus the savings in operating costs can be interpreted as a measure of the benefits of the existing system. Obviously, such an extreme scenario raises questions about what the results mean and whether we are exercising our model beyond its ability to tell us anything useful. We discuss these issues of interpretation below, but for now let us present some reasons why we think the analysis is useful. First, it enables a comparison with other studies that have estimated the aggregate value of the transit system (e.g., Winston and Shirley 1998 and Winston and Maheshri 2005). It can also produce estimates of partial measures of benefits, such as changes in travel times for road users. Finally, it provides a picture of the distribution of current benefits from the transit system.

5.1 Total Benefits and Comparison with Other Studies

The benefits generated by transit system are the inverse of the welfare losses incurred when the transit system is eliminated. We test three scenarios: eliminating bus and rail separately, and eliminating both modes together. Thus we estimate the benefits of all transit, the benefits of rail in the presence of the existing bus system, and the benefits of bus in the presence of the existing rail system. The basic results are shown in Table 2.

Our first result is that the time savings to motorists alone easily exceed operating subsidies for both the entire system and the rail system. Thus it seems to us that transit advocates in the Washington metropolitan area are on solid ground when they cite rail transit’s effect on highway congestion. The bus system alone generates relatively little in the way of driver time savings, both because buses and cars compete for scarce roadway space and bus users who switch to rail do not affect drivers. Of the benefits to drivers, about two-thirds are congestion-related; the rest are parking search costs.

The motorist benefits are dwarfed by the total benefits of the transit system, \$2.3 billion per year. As seen from Table 2, traveler benefits from the weekday bus system are \$975 million per year, or \$7.57 per bus trip in 2000 dollars. Weekday rail produces about \$833 million in traveler benefits and a per rail trip welfare benefit of \$5.16. Taking into account the regional subsidies for the two modes, these per trip net benefits drop to \$5.81 and \$4.51 for bus and rail, respectively. These per trip benefit figures are substantially higher than those estimated by Winston and Shirley, who found benefits from bus and rail to be on the order of $3.10 and $2.96 per transit work trip.[5] Winston and Shirley's calculations are for a national average in 1990, so the fact that Washington, D.C., is a relatively hospitable setting for a large transit system undoubtedly explains a large part of the discrepancy.

Table 2: Overall Benefits of the Weekday Washington, D.C., Transit System ($2000)

	Bus	*Rail*	*Both modes*
Daily ridership (000s)	515.2	646.2	1161.5
Traveler welfare per transit trip	$7.57	$5.16	$7.97
Annual motorist benefits (millions)	$68	$454	$736
Annual traveler welfare (millions)	$975	$833	$2313
Annual operating subsidy (millions)	$228	$110	$338
Annual net benefits (millions)	$743	$728	$1975
Net benefits per transit trip	$5.81	$4.51	$6.80

Shutting down both modes simultaneously produces an estimate of total weekday traveler benefits of around $2.3 billion annually and a per trip figure of $7.97. The benefits from the complete system are greater than the sum of the benefits for each individual system (superadditivity). This is to be expected, since bus and rail are close, albeit imperfect, substitutes.

Of course, capital costs are also an important element of the total costs the transit system. A large portion of the Washington transit system's capital outlays are paid for by the federal government rather than by local and state governments (Siggerud 2005). As a result, these costs are often ignored in local discussions of transit's performance and cost-effectiveness. From an efficiency perspective, however, they should be taken into account. This is not a straightforward exercise, unfortunately, because capital outlays for the D.C. metro system stretch back more than 35 years. A simple approach to come up with a capital cost can be created by collecting historical capital outlays (Siggerud 2005), and assuming the money spent was raised via 30-year bonds yielding 5 percent (see Figure 3). Under these assumptions, the expenditures on repaying debt from capital spending amount to payments of around $225 million per year in 2000. Adding this capital cost figure to the operating costs in Table 2 results in annual net benefits of the system of more than $1.7 billion for the year 2000, or $6 per transit trip.

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[5] Figures are updated to 2000 dollars using CPI. For a direct per transit work trip comparison, we calculate $22.94 dollars in benefits per bus work trip and $7.12 per rail work trip.

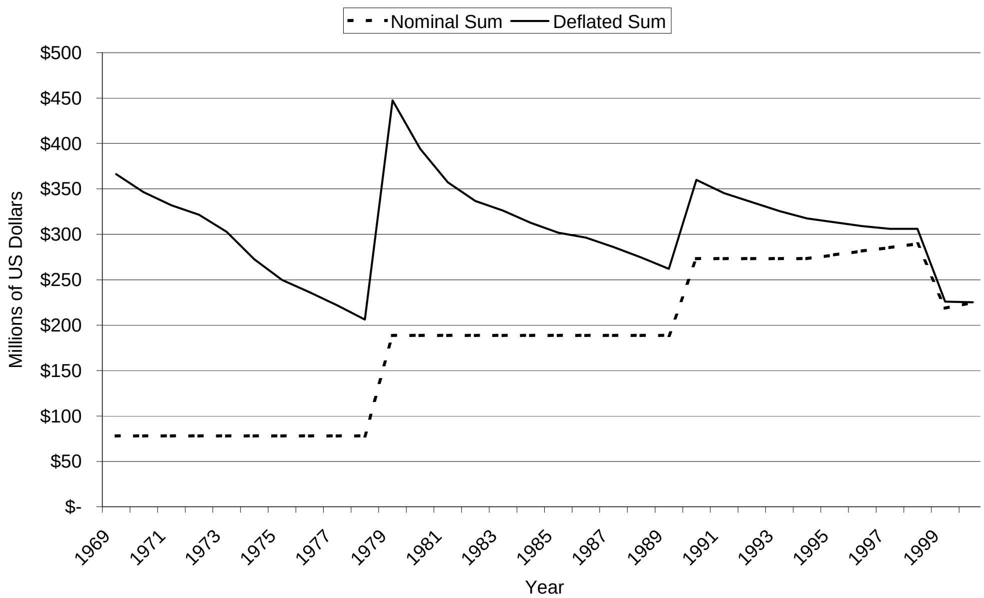

Figure 3: Hypothetical WMATA Capital Payment Stream

That estimate is obviously imperfect; such an analysis ignores important long-term land-use changes and other adjustments associated with the development of a major transit system over many decades. Thus, rather than testing the costs of the "what if there was never a transit" counterfactual, we are looking at the costs of a shutdown of the current system, or the benefits provided by that system.

The fact is, our total benefit estimate is a mix of some extremely short-term effects, some medium-term effects, and some long-term effects. For example, if we scale the traveler benefit numbers presented in Table 2 to an unanticipated one-week shutdown, such as might result from a sudden transit strike, the loss from a rail disruption amounts to $16.6 million, a bus disruption $19.5 million, and $46.3 million for both modes. These losses appear to us to be quite reasonable, and they are incurred by travelers only. It is certainly possible that they would pale in comparison with the economic costs to businesses associated with a strike. However, losses of this magnitude are not likely to endure, or be endured, for a year, so we suspect our $2.3 billion estimate of the annual losses is a bit high.

Indeed, as we reduce the revenue mileage of the transit system from 100 percent of the current system to 0 percent, we find that the welfare losses increase very rapidly as 0 percent transit supply is approached. For example, when both frequency and vehicle capacity are 25 percent of baseline (and system vehicle revenue miles are 6 percent of baseline), the welfare losses compared with the baseline are $894 million, quite a bit smaller than the $2.3 billion loss from a complete shutdown of transit. Whereas the shutdown case assumes that no private party would step in and fill the gap, one way of thinking of the 6 percent scenario is that it illustrates a possible outcome if market forces created some transit provision along profitable routes. At this level of reduction, providing options that offer even a relatively small expansion of travel opportunities could have a large effect on traveler welfare.

START, as a logit-based choice model, imposes high welfare costs for completely eliminating traveler options. But a severe change in those options could lead to the development of new options not previously available. On the demand side, travelers would adjust to the loss of the transit system by moving, purchasing vehicles, changing jobs, or using van or car pools in the medium to long term. These options are also outside the model. We note that the losses resulting from elimination of bus alone or rail alone are much smaller than the losses from eliminating both, further suggesting that the elimination of the transit choice altogether is very costly until there is some adjustment to it. However, it is not the case that *all* the losses are short term. For example, driver costs from increased congestion and unavailability of sufficient parking ($736 million at 0 percent transit provision) will not be easy to overcome quickly.

The results presented here are dramatically different from those estimated for Washington by Winston and Maheshri (2005), who find that WMATA's rail system produces *negative* net benefits of more than $200 million a year in 2000, compared with the $700 million-plus in benefits that we find for the rail system alone. Our results differ for several reasons. The main differences seem to be in the figure used for the transit agency deficit ($110 million versus $657 million) and in the benefits to drivers ($453 million versus $181 million), which together account for more than 80 percent of the gap. Concerning the transit agency deficit, we use the operating deficit for WMATA rail, but even if we add WMATA capital expenditures for bus and rail ($232 million), we would arrive at only $342 million. In any case, the source of Winston and Maheshri's $657 million is not clear to us. As for the driver benefit discrepancy, part of the difference is accounted for by the scope of the benefits. Whereas Winston and Maheshri's estimate includes only time savings (their number is estimated for San Francisco and applied to Washington), ours also includes parking search time. A final difference between our approaches is that START includes commuter rail in addition to the WMATA rail system and encompasses a greater geographic area.

5.2 The Distribution of Transit's Benefits

The benefits of the transit system accrue both to transit riders, who take advantage of the increased travel options, and to drivers, who benefit from reduced congestion. The impact of transit on driving times is greatest on especially crowded roads. To take one example, removing transit reduces the average speed on a portion of I-395 North during the peak from 39 miles per hour to 33 miles per hour. Overall, we estimate drivers save about 45.9 million hours per year in travel time thanks to the existence of a transit system.

The simulation results shed light on the distribution of benefits among income groups from the transit system. Table 3 shows the benefits of the transit system normalized by total trips (car, transit, and other) for each income group. In contrast to conventional wisdom, we find wealthy travelers receive by far the largest per trip benefit, approximately 10 times larger than the benefits received by the lowest-income group.

Table 3: Distribution of Benefits from the Washington Transit System

Income group	*Per trip benefits (¢2000)*	*Change in average car trip time (min.)*	*Value of time ($/hr.)*
1	9.6	–0.273	2.70
2	30.5	–0.439	5.64
3	40.3	–0.594	9.01
4	97.1	–0.908	18.80

Two factors drive this result. First, the model assigns different values of time[6] to travelers in different income groups. Under this assumption, reductions in travel times are valued more highly by wealthier travelers, and even a policy that produces equal travel time reductions across income classes will generate more benefits to the wealthy.

Even ignoring time valuation differences, however, time savings break down differently across the income groups, as Table 3 shows. Savings in terms of minutes per trip accrue disproportionately to the upper-income groups. This could be because wealthier individuals take more and longer trips along congested corridors than do lower-income individuals. Overall, benefits per capita are significantly lower for the lowest-income group compared with the others, as shown in Table 4, but the overall pattern differs between bus and rail. For rail (and for both modes), the group with highest benefits relative to income is group 2, the second-lowest group. For rail, however, benefits are strictly increasing in income. This is not a totally surprising result,

[6] Value of time is 40 percent of the wage rate for the majority of the travel times modeled. Exceptions include times associated with parking and waiting for public transit, valued at the full wage rate.

considering that the rail system was designed primarily to improve access from suburban areas (especially wealthy ones) to the downtown core.

Table 4: Benefits Per Capita ($ Per Year) and Percentage of Annual Income

Income group	*Both*		*Bus*		*Rail*	
1	106	1.12%	41	0.43%	41	0.43%
2	438	1.57%	204	0.73%	138	0.49%
3	750	1.45%	354	0.69%	264	0.51%
4	1714	1.42%	599	0.50%	663	0.55%

Finally, we are able to estimate the geographic distribution of benefits. Figure 4 shows the expected result: those who benefit from transit travel within the core and inner suburbs. The differentials in the benefits are striking. Per trip traveler welfare gain from the transit system is more than $1 for trips beginning in the downtown core, and less than 5 cents for trips originating in the distant suburbs. Basically, benefits accrue to zones with a large transit presence and congested roadways.

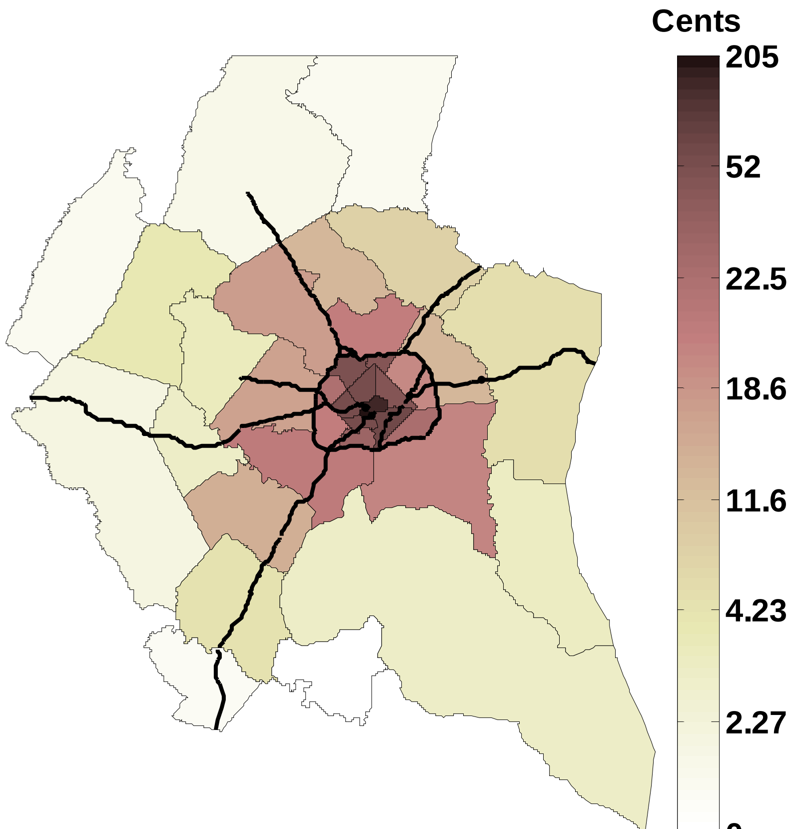

Figure 4: Per Trip Traveler Benefits by Trip Origin

6. The Optimal Level of Transit

Although estimating the total benefits of the existing transit system is an interesting academic and political question, it is something of a moot point practically. Most of the costs are sunk, and there is little prospect that the system will be disassembled. Of more practical significance is whether the current scale of service is close to the optimum. In this calculation we hold routes and fares constant and scale bus miles and/or rail miles by adjusting capacity and frequency simultaneously on the existing network links. For example, to obtain a bus network that is 1.1025 times larger than the existing one, we adjust frequencies by a factor of 1.05 and capacities by a factor of 1.05.

Results are presented in Table 5. After netting out operating costs, we find that the optimal level of provision is 14 percent above the current amount of daily bus and rail vehicle miles. Increasing the supply of transit by this amount increases the overall operating subsidy by $78 million annually and increases traveler welfare by $82 million. The net improvement from moving to the optimum is only $4.5 million dollars per year, or roughly 2 percent of the current operating subsidy. It appears that the marginal social benefit from increased transit in Washington is very much in line with the marginal cost, if the operating subsidy is the only cost considered.

Table 5: Optimal Provision Compared with Base Case (Ignoring Capital Expenditures)

	Bus	*Rail*	*Both modes*
Change in supply	16.6%	14.5%	14.5%
Traveler welfare (millions)	$51.22	$37.84	$82.25
Operating subsidy (millions)	$48.79	$35.06	$77.73
Capital expenditure	$10.25	$32.24	$41.16
Net welfare (millions)	$2.44	$2.78	$4.52

As noted above, from an efficiency perspective, capital costs should be considered as well. Accounting for capital costs is difficult because of their nonlinear nature. However, WMATA’s estimates of the capital costs associated with expanding service are publicly available in WMATA’s annual financial reports. With a simplified assumption (in reality the capital stock would depreciate with use) that the capital cost savings from reducing system size are symmetrical to the capital costs of increasing system size, we find the optimal supply in terms of capacity and frequency is about 25 percent lower than current levels. The potential gain from moving to this optimum is only about $20 million a year, or about 1 percent of the total net benefits of the transit system. Figure 5 illustrates how flat the net benefit curve is near the optimum.

In addition, we test the relative attractiveness of bus and rail investment by changing the level of one while holding the other constant. When ignoring capital costs, we find that both bus and rail are underprovided. Bus should be increased by 16.6 percent if rail is held fixed. Holding bus fixed, we find that rail should be increased by more than 14 percent. The two modes differ greatly in the composition of their net benefits, however. Increasing bus supply alone brings more marginal benefits to travelers and higher marginal costs to the transit agency than do changes in rail alone. This is intuitive; bus is subsidized almost twice as much as rail per passenger, and trains arrive very frequently during the rush hour in Washington (every 2.5 to 3 minutes versus 5 to 10 minutes for buses), so the time benefits of additional rail frequency are proportionately lower than additional bus frequency.

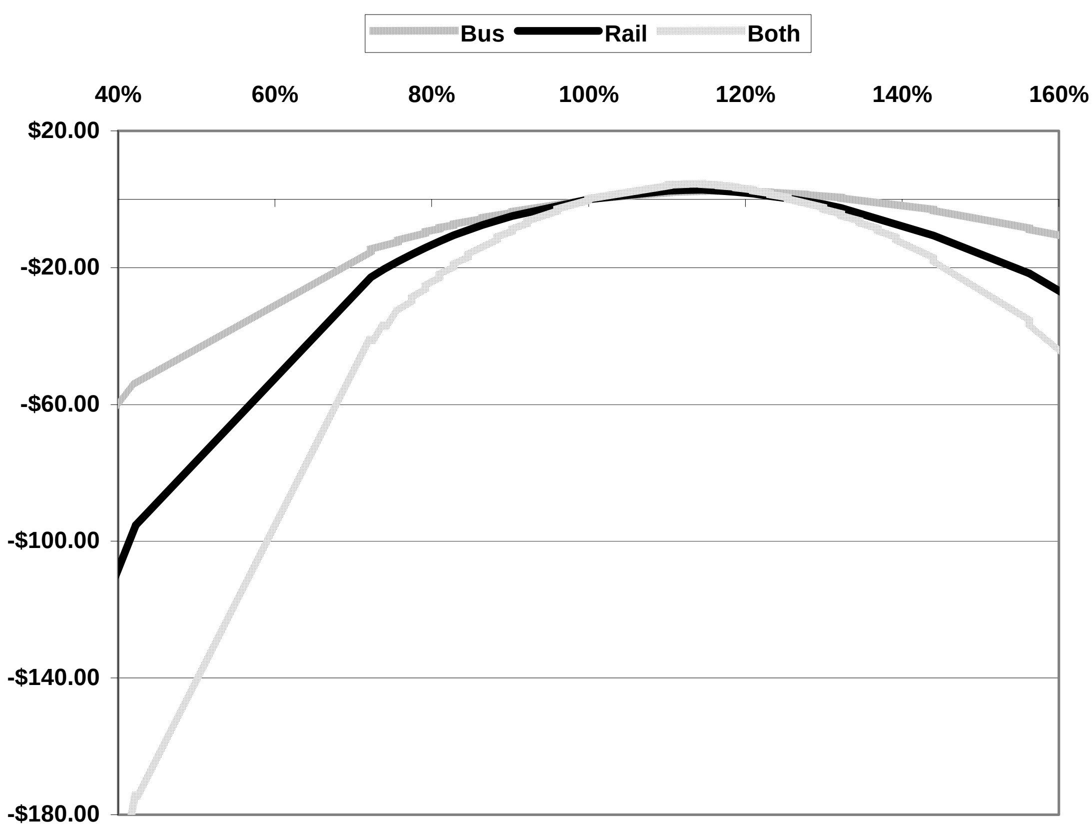

Figure 5: Optimal Transit Provision

7. Discussion

An obvious limitation of this study is that the results reflect specific features of the Washington metropolitan area, including the geography of income distribution, relative importance of public transit, level of carpooling, degree of utilization of HOV lanes, and the fixed central economic activity of the federal government. As Baum-Snow and Kahn (2000) argue, the D.C. region is one of the most promising settings for a major transit system in the country. The large benefits found here should not be taken as evidence in support of transit investment in dissimilar locations.

In addition, the decision to have a major transit system represents a nonmarginal choice about overall urban form. Without WMATA, Washington's economic geography of development patterns and road networks would look very different. Care should be taken in interpreting the overall benefit number because estimating the true benefit requires a very uncertain counterfactual speculation about the region's alternative development path. Still, this test can shed light on the benefits of the system across various income classes and geographic regions, under current conditions.

The test of optimal provision presented here shifted the level but not the spatial pattern of investment. There is reason to believe that the current geographic distribution of transportation services is inefficient, given that transit operates at low capacity levels in the outlying areas. If transit routes were rationalized, the optimal level of investment could be higher or lower than the current amount.

The benefits measured here include reduced congestion and increased travel options. Other benefits, such as reductions in air pollution and accidents, are ignored in the analysis. However, numerous studies show the benefits from reduced pollution are very small, especially compared with those from congestion reduction. The benefits from reduced accidents, on the other hand, are significant, and therefore the benefit numbers reported here are probably an understatement (Parry and Small 2005).

Finally, efficiency is but one of the rationales for transit investment; serving low-income communities is another. With the approach taken here, improved service to lower-income travelers will be weighted lower based on their assigned value of time. This may not be appropriate, given societal desires for ensuring access to employment, health care, and other goods. A related point is that people's value of time as they travel may not be as closely connected to household income levels as this study assumes.

Despite those caveats, several conclusions can be drawn. First, it is clear that under a wide range of assumptions, the transit system delivers large benefits to travelers—transit users and drivers alike. These benefits dwarf the region's operating subsidies and are still significantly large when capital outlays are taken into account.

Second, against conventional wisdom, the benefits of the D.C. transit system accrue disproportionately to wealthy travelers, both in terms of economic welfare measures and raw minutes saved while traveling. This observation lends support to the proposition that transit provision should be financed through progressive revenue instruments.

Third, although the current level of investment in transit in the Washington area is not optimal, it is reasonably close. Furthermore, although the value of the system as a whole is unquestionable, the net gains from moving from baseline to the optimum (assuming no other concurrent instruments, like road pricing) are trivial compared with the net benefits of the system. Similarly, moving from the optimum to a point of lower provision results in trivial losses. This large range of near-optimal transit provision suggests that transit provision levels can be shifted within the current road and transit network framework without a large negative effect on social welfare.

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