Transit in Washington DC: Current Benefits and Optimal Level of Provision

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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% 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% in 1960 to 4.7% 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, suburban areas (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 a reasonable question is how dramatically current levels of transit investment differ from the efficient ones. One can take this a step

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[1] For example, expenditures on transit account for 60% of total spending in the regional transportation plan for Washington, DC and over 81% in San Francisco.

further and ask whether any investment at all is warranted; in other words, does the transit system as a whole produce benefits in excess of its costs?

Of course, the answers to these questions will depend greatly on the setting. Studies that have looked at the factors explaining transit ridership have found that key 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 present simulation results from the Washington-START model, an integrated transportation model of the metropolitan Washington, DC region. We first estimate 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. We also identify the optimal level of transit provision for the area. Finally, we compare the relative cost-effectiveness of investments in bus and rail.

Section 2 is an overview of the arguments for and against significant public investment in transit as well a survey of some of the relevant research. Section 3 provides background on Washington, DC's transportation system. Section 4 describes the model, data sources and general approach used for the analysis. Sections 5 and 6 present the results from the simulations. The final section concludes and discusses model limitations.

2. Arguments for subsidizing transit and relevant literature

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 autodependent 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, Quigley, and Raphael 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 effect (1972)). As 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 main 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.

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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.

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. 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% decline for bus and a 60% 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.

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% in the off-peak, while supply rises 13% and 54% 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, while they fall for bus and increase for rail in the off-peak. For London, they find 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. The studies 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 U.S. 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 VMT 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. Washington, DC Transportation System

Washington, DC 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 intra-regional 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, DC metropolitan area remains a comparatively dense region, with population densities comparable to those of other East Coast metropolitan areas like 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) is the area's main transit operator and runs the Metrobus and Metrorail systems. WMATA is the fourth-largest transit system in the U.S. in terms of annual trips and the rail system is second only to MTA in New York in terms of ridership. During rush hour, 18% of all person trips in WMATA's service area use transit, the second highest percentage in the country. Over 40% 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 and VRE, as well as various local jurisdictional bus systems.

WMATA's rail system recovers over 60% 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 26%, a relatively low figure, although this is partly because bus is priced to be a feeder into rail. For comparison, the nations's top perfomer, New York City's MTA, had cost recovery factors of 67.3% and 40.9%, and the average cost recovery factor across all transit systems nationwide was 39% in 2000 (FTA 2000). WMATA's total operating budget for weekday service in 2000 was $642 million, with subsidies for rail and bus at $95 million and $170 million respectively.

WMATA's long-run funding 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, I-270, 95, and US-50 in Maryland and I-66, I-

[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.

95, and US-267 in Northern Virginia, connect the outer suburbs to the central region within the circular Beltway, I-495/I-95, as shown in Figure 1. Existing HOV lanes on these freeways at peak period are taken into account.[4]

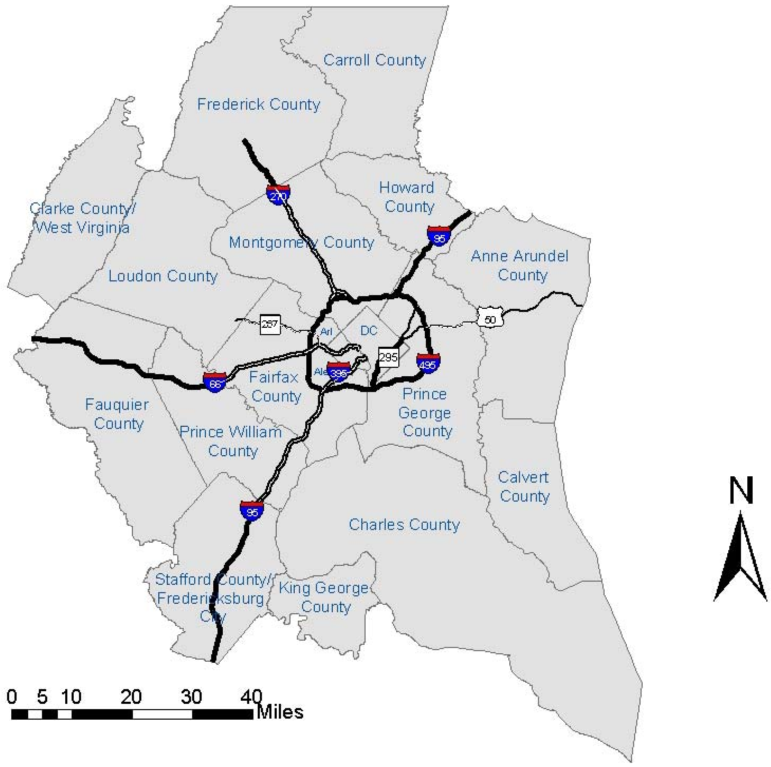

Figure 1: Washington-START Zones and Special Links

4.1 Public Transit

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

4.1.1 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 are made up of a succession of links along a path of zones leading from origin to destination, and were

[4] The only exception is US-50, which operates a 24-hour HOV lane; this route is modeled off-peak as well.

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 Metro- and commuter-rail lines in the DC 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 non-existent park and ride legs, while 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).

4.1.2 Bus

Bus routes, however, are much less tractable and buses are therefore assigned to routes already defined for the road network available to cars. For each time period, buses are assumed to travel the most frequently-used route from the origin to the destination, and use HOV lanes wherever possible. 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), when buses were modeled as if they operated on a distinct network of bus-lanes and bus travel times were unaffected by automobile congestion.

4.1.3 Trip Cost Calculation

Transit users face monetary costs as follows:

Bus:

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

Rail:

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

Where:

f denotes the transit fare.

v^* denotes value of time, set at 40% of the wage rate for all purposes except non-home-based work trips. For non-home-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, as 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 to 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/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 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 of one's parking category (reserved versus unreserved space), as well as of the physical details of the parking area, such as lot size.

$\tilde{e}$ denotes the time required to egress 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.

4.1.4 Crowding Curve

A crowding curve, established at four different 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, Cheung, and Lam 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).

4.2 Demand Side Data

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 non-home-based trips are distinguished between work-related and non-work 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).

Washington-START takes the distribution of households by demographic segment and residential location as given. Travel decision making is modeled as a nested logit tree; in successive nests, households choose whether or not 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. It should be noted that this elasticity value is not a model parameter, but the result obtained from model runs. Therefore, 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, Dargay, and Hanly 2003). See Table 1 for more model elasticities.

Table 1: Washington-START Computed Elasticities

Elasticity	**Washington-START**	**Compare To:**
PT Trips WRT Fuel Price	0.088	0.07 (Luk and Hepburn 1993)
Bus Trips WRT Bus Fare	-0.291	Compare at -0.28 short run, -.55 long run (Goodwin 1992)
Train Trips WRT Train Fare	-0.732	Compare at -0.65 short run, -1.08 long run (Goodwin 1992)

4.3 Supply Side Data

Data sources for the supply side of the Washington-START model are discussed more fully in Safirova et al (2004), and 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. Fares for the model were calibrated using WMATA data on average fare collections per mode, which the organization publishes on an annual basis. Since the Safirova et al (2004) study, the model has been recalibrated with more recent CTPP 2000 data.

5. The Level and Distribution of Benefits of Washington, DC's 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.

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 rough measure of the benefits of the existing system. This estimate is obviously imperfect; such an analysis ignores important 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 relative benefits of the system in existence today. Certainly, without a transit system, metropolitan DC's road network would look entirely different. Thus, the question we answer instead is: does the existence of WMATA benefit the DC metro area more than it costs it?

Table 2: Overall benefits of the weekday Washington, DC transit system ($2000)

	Bus	**Rail**	**Both Modes**
Ridership (000s)	515.2	646.2	1161.5
Traveler welfare per trip	$7.57	$5.16	$7.97
Traveler welfare (Millions)	$975	$833	$2313
Operating subsidy (Millions)	$169.4	$95.2	$264.6
Benefits net of regional subsidy	$806	$738	$2048

We test three scenarios: eliminating bus and rail separately and eliminating both modes together. In all cases, we find large net benefits in the current system. 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. 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, DC is a relatively hospitable setting for a large transit system undoubtedly explains a large part of the discrepancy.

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 the 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 DC metro system stretch back over 35 years. We take two approaches to including capital costs in the analysis. First, we look retrospectively at expenditures and estimate the current burden imposed on the government sector by previous capital outlays. We collect historical capital outlays (Siggerud 2005), and assume the money was borrowed at a 5% nominal interest rate and a 30-year payback period (see Figure 2). Under these assumptions, the expenditures on repaying debt from capital investment amount to payments of around $225 million in 2000. Adding this figure to the operating costs results in a total cost of around $490 million and an estimate of annual net benefits of the system of over $1.8 billion for the year 2000.

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[5] Figures 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.

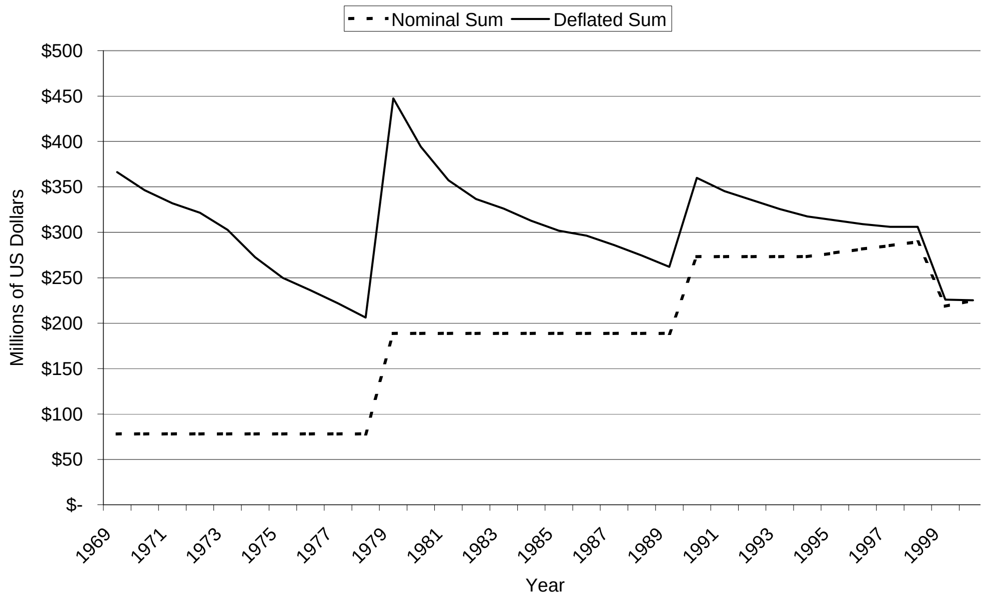

Figure 2: Hypothetical WMATA Capital Payment Stream

As an alternative, we use WMATA's own estimate of the capital replacement cost of the current system, $24 billion in 2000 dollars (Metro Funding Panel 2005)**,** and compare that to a present value of a 30-year stream of annual future benefits equal to the net benefits (traveler benefits-operating subsidy) in 2000. This calculation probably understates net benefits, because increasing real income in the metro area will likely result in higher values placed on time-savings in the future. Still, using this approach we find the current system produces net present benefits in excess of $10 billion given a 6% discount rate and $1 billion at an 8% discount rate

5.1 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 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 20.6 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 ten 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 ¢)	Mean Driver's time savings (min)	Value of Time ($/hr)
1	9.6	0.167	2.70
2	30.5	0.175	5.64
3	40.3	0.185	9.01
4	97.1	0.233	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 trips than lower-income individuals along congested corridors.

Finally, we are able to estimate the geographic distribution of benefits. Figure 3 shows the expected result: those that benefit from transit travel within the zones with a large transit presence, specifically the core and inner suburbs. The differentials in the benefits are striking. Annual traveler welfare gain from the transit system is over $500 million for trips beginning in the downtown core, and less than $5 million for trips originating in the distant suburbs.

[6] Value of time is 40% 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.

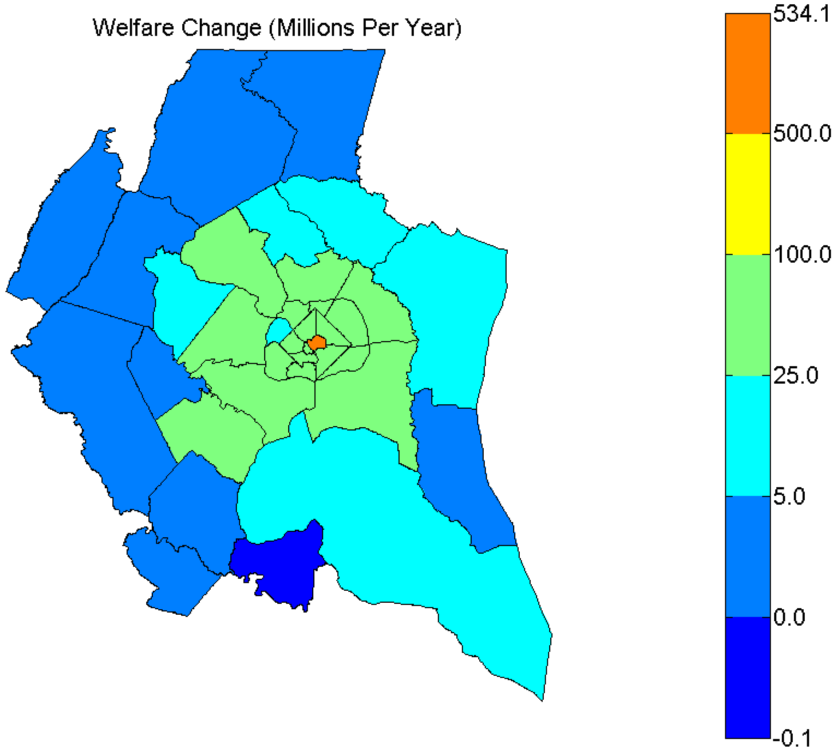

Figure 3: Regional Welfare Distribution (By Origin Of Trip)

6. The optimal level of transit

While 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 of the system being disassembled. Of more practical significance is whether the current provision of service is close to the optimum. To find the optimum, we 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 4. After netting out operating costs, we find an optimal level of provision 14% 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% 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 4: Optimal provision compared to 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

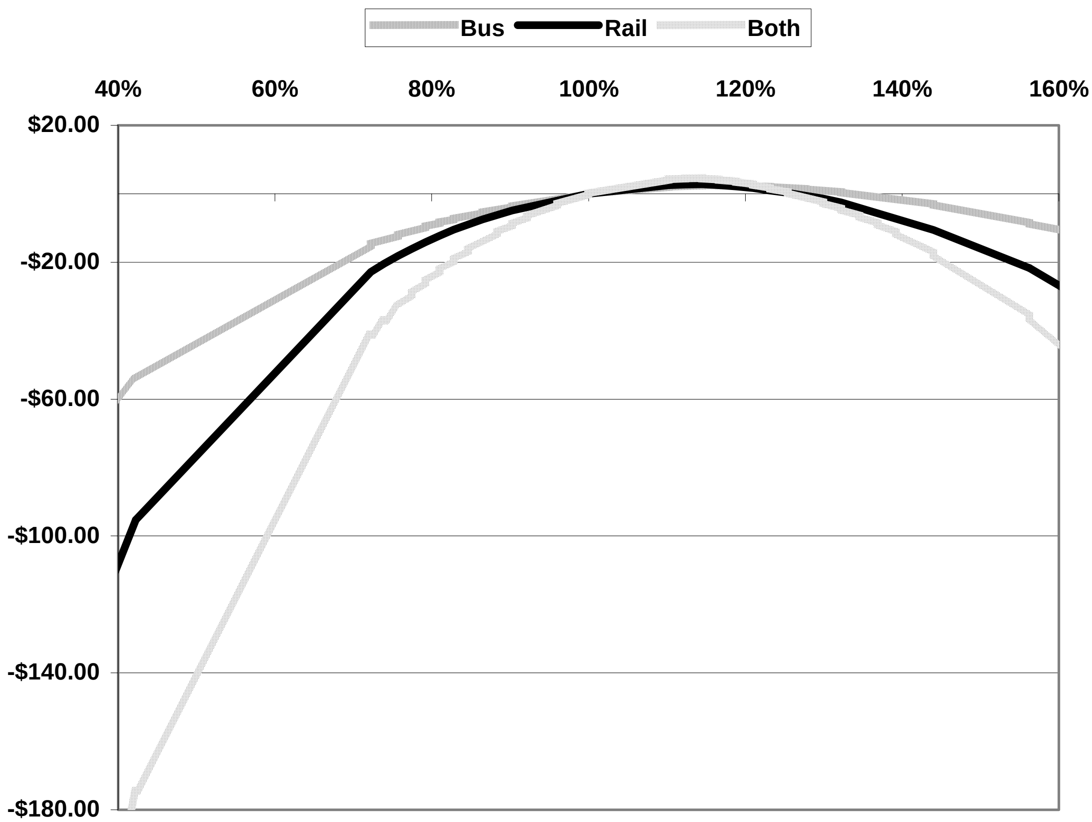

Figure 4: Optimal Transit Provision

As noted above, from an efficiency perspective, capital costs should be considered as well. Accounting for capital costs is difficult because of the nonlinear nature of capital costs. 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 one percent of the total net benefits of the transit system. Fig. 4 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% if rail is held fixed. Holding bus fixed, we find that rail should be increased by over 14%. The two modes differ much 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 rail trips are very frequent during the rush hour in Washington (every 2.5-3 minutes whereas busses run every 5-10 minutes), so the time benefits of additional rail frequency are proportionately lower than additional bus frequency.

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 Federal Government's placement as a fixed central economic activity. As Baum-Snow (2000) argues, the DC 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 an as evidence in support of transit investment in dissimilar locations.

In addition, the decision to have a major transit system represents a non-marginal choice about overall urban form. Without WMATA, DC'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.

Similarly, the test for transit's overall benefit assumed that no private party would step in and fill the gap. In actuality, market forces would probably create some transit provision along profitable routes.

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 reduced air pollution and accidents are ignored in the analysis. However, numerous studies show that the benefits from reduced pollution are insignificant, especially when compared to 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, while serving low-income communities is another. With the approach taken here, improved service to lower income travelers will be weighted less than improved service to higher income travelers because lower income travelers are assigned a lower 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.

In spite of these 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 significant when capital outlays are taken into account.

Second, contrary to conventional wisdom, the benefits of DC's 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 when compared to 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 political concerns can shift transit provision levels within the current road and transit network framework without largely negatively affecting social welfare.

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