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Urban Densities and Transit: A Multi-dimensional Perspective

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*Abstract***— It is broadly accepted that fairly dense urban development is an essential feature of a successful public transit system. However going beyond this generality to specific guidelines on where, when, and by how much to increase urban densities is never easy.**

This paper investigates the relationship between transit and urban densities in the United States from multiple perspectives. While empirical evidence suggests that recent-generation rail investments in the U.S. have in many instances conferred net social benefits, considerable skepticism remains, particularly among the more vocal critics of American transit policy. All sides agree that increasing urban densities will place public transit on firmer financial footing. Our analysis suggests that light-rail systems need around 30 people per gross acre around stations and heavy rail systems need 50 percent higher densities than this to place them in the top one-quarter of cost-effective rail investments in the U.S. The ridership gains from such increases, our research showed, would be substantial, especially when jobs are concentrated within ¼ mile of a station and housing within a half mile. For smaller cities, such densities are likely politically unacceptable, however, as suggested by the reactions of stakeholders in Stockton, California to photo-simulations of higher densities along proposed BRT corridors.

Keywords: urban rail; transit-supportive density; transit-oriented development; rail costs and benefits; rail investment

I. INTRODUCTION

It is broadly accepted that fairly dense urban development is an essential feature of a successful public transit system. However going beyond this generality to specific guidelines on where, when, and by how much to increase urban densities is never easy.

This paper investigates the relationship between transit and urban densities in the United States from multiple perspectives. First, the paper summarizes the cost and benefits of recent rail transit investments in the U.S., including external benefits like air quality improvements and congestion savings. Net benefits are compared to a counterfactual—what might have been expected if the investment were not made. This is followed by section three which posits that urban densities are the most critical factor in determining whether investments in fixed guideway transit systems are cost-effective. Minimum population and employment densities that are likely needed to ensure a proposed investment ends up as one of the top-performing systems in the U.S. are presented. Section 4 extends the analysis by exploring the relationship between urban densities and transit ridership at the station-level. How this relationship varies by the size of a rail stop's walkshed is also examined. The final section of the paper addresses the thorny topic of how lay citizens react to the prospect of higher densities for expanded transit services. The reactions of a small sample of residents of Stockton, California to visual images of expanded Bus Rapid Transit (BRT) services matched by a combination of higher urban densities and public amenities are documented.

II. THE COSTS AND BENEFITS OF URBAN RAIL TRANSIT

There is a contentious debate over the costs and benefits of rail transit in the United States. Some opponents appear against all transit all the time (Cox, 2002; O'Toole, 2010) while others seem to support it no matter how much it costs or how few people ride it (Litman, 2006, 2009). As with most polemical debates, the truth probably lies somewhere in the middle. Some rail transit systems justify their high costs, while others do not. Looking at the costs of 24 urban rail systems in the United States, we find that the user benefits of two systems likely outweigh their total costs without accounting for any externalities. The user benefits of another eleven systems outweigh net operating costs without accounting for externalities. When we establish a counterfactual, in which 25% of rail trips are diverted to cars and 75% to buses, the benefits of rail outweigh the operating and capital costs in 14 of the 24 systems examined.

A. *Costs and Benefits*

Researchers have long criticized rail projects for failing to attract enough riders to justify the investment costs. Just four years after BART's opening, Webber (1976) declared that it failed to deliver on every one of its objectives—particularly in regards to strengthening the core city, giving order to the suburbs, and eliminating auto congestion. A flurry of studies in the 1990s equated urban rail investments in the U.S. to pork-barrel politics. Perhaps most notable was the work of Pickrell (1990, 1992). Looking at 10 transit investments from the 1980s, Pickrell found that projections systematically overestimated ridership (9 out of the 10 did not achieve 50% of projected ridership) while systematically underestimating capital cost (only 2 projects cost within 20% of forecasts). Widely cited, the Pickrell report came to symbolize the exaggerated benefits and understated costs of rail transit projects.

Although several recent papers have attempted to assess the costs and benefits of transit in the United States, there remains little consensus. Harford (2006) finds that of 81 urbanized areas in the United with transit, only 21 have higher benefits than costs. Since these are the largest areas with the most riders, however, the overall benefits of transit exceed costs by 34%. User benefits are derived from consumer surplus estimates—the area of the triangle formed by fare, quantity, and a linear demand curve with an assumed elasticity of -0.30 at the observed fare and ridership.

By contrast, Winston and Maheshri (2007) find that only one rail system out of twenty-five in the United States has benefits that exceed costs. A major difference in findings comes from the estimation of user benefits. Although both estimate consumer surplus based on elasticity and a linear demand curve, Winston and Maheshri find transit fare elasticities that range from -0.97 to -5.4 – far more elastic than documented in the literature (McCollum & Pratt, 2004). This leads to much lower estimates of user benefits than Harford, who assumes a fare elasticity that ranges from -0.15 to -0.45. The two studies also used different methodologies to estimate costs. Harford assumes that costs are proportional to operating costs whereas Winston and Maheshri look at annual capital expenditures.

Parry and Small (2009) find that the large current transit subsidies are more than justified in Los Angeles and Washington, D.C. and that reducing fares will generally improve social welfare. They conclude that the optimal transit subsidy is over 90% of operating costs during peak hours and between 88% and 89% during the off-peak. However, they also estimate that the marginal capital cost to attract a new rider to

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rail in Washington, D.C. is approximately $2.00. Thus, they find that while increasing operating subsidies is an attractive way to boost ridership, constructing new lines is not.

Combining fare and operating cost from the NTD with annualized capital cost figures and assuming linear demand curves for transit, Guerra (2011) makes back-of-the-envelope estimates of how large external costs and benefits would have to be in order to achieve higher social benefits than costs for 24 light and heavy rail systems in the United States and Puerto Rico. Using a commonly applied elasticity estimate of -0.30 (McCollum & Pratt, 2004) the 24 systems generate approximately $6.5 billion in consumer benefits. The New York subway and Bay Area Rapid Transit System generate $100 million and $25 million in social surplus without accounting for any externalities. Eleven other systems have consumer benefits that would outweigh costs with external transit benefits equal to about 50 cents per passenger mile. Pittsburgh, Buffalo, San Jose, and San Juan would need external benefits exceeding $2 per passenger mile to break even. With a fare elasticity of -0.60, none of the systems have monetized benefits that exceed costs.

Table I shows the estimated costs and rider benefits of the 24 systems, given different assumptions about fare elasticity. Table II presents the same figures, normalized by total passenger miles traveled.

B. *External Costs and Benefits*

No cost benefit analysis is complete without considering the alternatives. We apply Parry and Small's (2009) external car cost estimates, which include pollution and congestion, to 25% of passenger miles from our previous estimates. The other 75% of passenger miles switch to bus. Based on calculations of the percent of subway, elevated, and trolley passenger miles travelled during the peak hours from the 2008 National Household Travel Survey, we assign 44% percent of passenger miles to the peak when estimating costs. We then net out the external costs of rail travel from the car and bus estimates. To assess the costs of providing bus service, we use the NTD's 2008 estimates of revenues, operating costs, and passenger miles for each city served by rail. Where rail-passenger miles are significantly higher than bus-passenger miles, we estimate the cost of providing service as the existing average cost. Where it is significantly lower, we use marginal cost, assumed to be 67% percent of average cost, the difference between marginal and average costs in Parry and Small's estimates. Where bus ridership is within 50% of rail in either direction, we average marginal and average operating costs. In cities that would have to massively expand bus service to accommodate new patrons, we expect costs to draw nearer to the average than the margin, due to congestion, bunching, and the need for new overhead. Capital costs for new buses and equipment are estimated at 50% of operating costs, well below the 1.2 adjustment adapted by Harford (2006).

We estimate the cost of additional bus service and bus and car externalities at $19 billion. Approximately 6% of this difference can be accounted for by the external costs of bus trips and driving. The rest relates to the costs of providing bus service for 75% of the former rail riders. If we assume that bus service is also eliminated, than the congestion and pollution impacts of eliminating rail service will also rise. Furthermore, if bus is no longer an option, the price elasticity for rail service will change since the next best option for 75% of riders will also be eliminated.

Table III presents the total costs and benefits of the 24 rail systems, after accounting for the established counterfactual. The net benefit of the 24 rail projects is $13 to $17 billion annually. Even assuming no capital costs for additional bus service, the benefit of providing rail service is around $6 to $8 billion annually. Nevertheless, 10 rail systems fail to produce net positive benefits under the scenario. Charlotte, Buffalo, New Jersey Transit, Pittsburgh, and San Jose perform particularly badly. These systems do not have enough riders to produce the economies of scale that make transit provision by rail significantly less expensive than bus. For additional tables and costs and benefits per passenger mile, see Cervero and Guerra (2011).

TABLE I. Total Costs and Benefits of Transit Systems without External Benefits (in Millions)

City	Agency	Unlinked Passenger Trips	Passenger Miles	Fare Revenues	Operating Expenses	Fare as Percent of OE	Capital Costs	Elasticity -0.3	Net Gain	Elasticity -0.6	Net Gain
Atlanta	Metropolitan Atlanta Rapid Transit Authority	82.984	593.419	$49.242	($158.545)	31%	($239.874)	$82.071	($267.105)	$41.035	($308.141)
Baltimore	Maryland Transit Administration	21.810	120.898	$19.176	($92.433)	21%	($94.194)	$31.960	($135.492)	$15.980	($151.472)
Boston	Massachusetts Bay Transportation Authority	222.430	736.938	$230.793	($397.975)	58%	($266.901)	$384.655	($49.429)	$192.327	($241.757)
Buffalo	Niagara Frontier Transportation Authority	5.681	14.623	$4.244	($23.440)	18%	($31.538)	$7.073	($43.661)	$3.537	($47.197)
Charlotte	Charlotte Area Transit System	2.263	13.065	$1.623	($9.495)	17%	($14.214)	$2.705	($19.382)	$1.352	($20.734)
Chicago	Chicago Transit Authority	198.137	1183.981	$203.810	($439.881)	46%	($433.735)	$339.683	($330.124)	$169.841	($499.965)
Dallas	Dallas Area Rapid Transit	19.438	151.755	$13.823	($89.218)	15%	($59.686)	$23.038	($112.043)	$11.519	($123.562)
Denver	Denver Regional Transportation District	20.635	134.036	$21.946	($41.677)	53%	($47.604)	$36.577	($30.759)	$18.288	($49.047)
Los Angeles	Los Angeles County Metropolitan Transportation Authority	86.707	524.813	$61.532	($249.196)	25%	($350.159)	$102.554	($435.269)	$51.277	($486.546)
Miami	Miami-Dade Transit	18.539	142.152	$13.247	($82.382)	16%	($82.226)	$22.078	($129.284)	$11.039	($140.323)
Minneapolis	Metro Transit	10.222	61.059	$8.990	($23.698)	38%	($15.078)	$14.983	($14.802)	$7.492	($22.294)
Newark/Jersey City/Trenton	New Jersey Transit Corporation	21.331	97.029	$20.976	($114.560)	18%	($132.790)	$34.961	($191.414)	$17.480	($208.894)
New York	MTA New York City Transit	2428.309	9998.115	$2,176.131	($3,250.031)	67%	($2,446.748)	$3,626.885	$106.238	$1,813.443	($1,707.205)
Philadelphia	Southeastern Pennsylvania Transportation Authority	121.562	484.989	$106.007	($211.127)	50%	($257.056)	$176.678	($185.499)	$88.339	($273.838)
Pittsburgh	Port Authority of Allegheny County	7.142	33.256	$7.054	($44.345)	16%	($51.127)	$11.757	($76.661)	$5.879	($82.539)
Portland	Tri-County Metropolitan Transportation District of Oregon	38.932	193.574	$31.495	($84.120)	37%	($76.891)	$52.492	($77.023)	$26.246	($103.270)
Sacramento	Sacramento Regional Transit District	15.485	85.807	$14.032	($51.830)	27%	($29.969)	$23.387	($44.379)	$11.694	($56.073)
Salt Lake City	Utah Transit Authority	14.753	71.121	$9.797	($27.383)	36%	($24.614)	$16.328	($25.872)	$8.164	($34.036)
San Diego	San Diego Metropolitan Transit System	37.621	206.924	$31.120	($55.949)	56%	($71.009)	$51.867	($43.971)	$25.933	($69.905)
San Francisco	San Francisco Bay Area Rapid Transit District	115.228	1448.529	$308.852	($478.987)	64%	($321.281)	$514.754	$23.338	$257.377	($234.039)
San Francisco	San Francisco Municipal Railway	122.707	239.057	$68.723	($278.018)	25%	($142.617)	$114.539	($237.374)	$57.269	($294.643)
San Jose	Santa Clara Valley Transportation Authority	10.451	54.475	$8.598	($55.544)	15%	($82.582)	$14.329	($115.199)	$7.165	($122.364)
San Juan	Puerto Rico Highway and Transportation Authority	8.700	44.784	$10.466	($57.500)	18%	($76.147)	$17.443	($105.738)	$8.722	($114.459)
Washington, DC	Washington Metropolitan Area Transit Authority	288.040	1639.629	$458.305	($755.747)	61%	($693.685)	$763.842	($227.286)	$381.921	($609.207)

TABLE II. COSTS AND BENEFITS OF TRANSIT BY PASSENGER MILE WITHOUT EXTERNAL BENEFITS

City	Agency	Fare	Operating Expenses	Fare as Percent of OE	Capital Costs	Elasticity -0.3	Net Gain	Elasticity -0.6	Net Gain
Atlanta	Metropolitan Atlanta Rapid Transit Authority	$0.08	($0.27)	31%	($0.40)	$0.14	($0.45)	$0.07	($0.52)
Baltimore	Maryland Transit Administration	$0.16	($0.76)	21%	($0.78)	$0.26	($1.12)	$0.13	($1.25)
Boston	Massachusetts Bay Transportation Authority	$0.31	($0.54)	58%	($0.36)	$0.52	($0.07)	$0.26	($0.33)
Buffalo	Niagara Frontier Transportation Authority	$0.29	($1.60)	18%	($2.16)	$0.48	($2.99)	$0.24	($3.23)
Charlotte	Charlotte Area Transit System	$0.12	($0.73)	17%	($1.09)	$0.21	($1.48)	$0.10	($1.59)
Chicago	Chicago Transit Authority	$0.17	($0.37)	46%	($0.37)	$0.29	($0.28)	$0.14	($0.42)
Dallas	Dallas Area Rapid Transit	$0.09	($0.59)	15%	($0.39)	$0.15	($0.74)	$0.08	($0.81)
Denver	Denver Regional Transportation District	$0.16	($0.31)	53%	($0.36)	$0.27	($0.23)	$0.14	($0.37)
Los Angeles	Los Angeles County Metropolitan Transportation Authority	$0.12	($0.47)	25%	($0.67)	$0.20	($0.83)	$0.10	($0.93)
Miami	Miami-Dade Transit	$0.09	($0.58)	16%	($0.58)	$0.16	($0.91)	$0.08	($0.99)
Minneapolis	Metro Transit	$0.15	($0.39)	38%	($0.25)	$0.25	($0.24)	$0.12	($0.37)
Newark/Jersey City/Trenton	New Jersey Transit Corporation	$0.22	($1.18)	18%	($1.37)	$0.36	($1.97)	$0.18	($2.15)
New York	MTA New York City Transit	$0.22	($0.33)	67%	($0.24)	$0.36	$0.01	$0.18	($0.17)
Philadelphia	Southeastern Pennsylvania Transportation Authority	$0.22	($0.44)	50%	($0.53)	$0.36	($0.38)	$0.18	($0.56)
Pittsburgh	Port Authority of Allegheny County	$0.21	($1.33)	16%	($1.54)	$0.35	($2.31)	$0.18	($2.48)
Portland	Tri-County Metropolitan Transportation District of Oregon	$0.16	($0.43)	37%	($0.40)	$0.27	($0.40)	$0.14	($0.53)
Sacramento	Sacramento Regional Transit District	$0.16	($0.60)	27%	($0.35)	$0.27	($0.52)	$0.14	($0.65)
Salt Lake City	Utah Transit Authority	$0.14	($0.39)	36%	($0.35)	$0.23	($0.36)	$0.11	($0.48)
San Diego	San Diego Metropolitan Transit System	$0.15	($0.27)	56%	($0.34)	$0.25	($0.21)	$0.13	($0.34)
San Francisco	San Francisco Bay Area Rapid Transit District	$0.21	($0.33)	64%	($0.22)	$0.36	$0.02	$0.18	($0.16)
San Francisco	San Francisco Municipal Railway	$0.29	($1.16)	25%	($0.60)	$0.48	($0.99)	$0.24	($1.23)
San Jose	Santa Clara Valley Transportation Authority	$0.16	($1.02)	15%	($1.52)	$0.26	($2.11)	$0.13	($2.25)
San Juan	Puerto Rico Highway and Transportation Authority	$0.23	($1.28)	18%	($1.70)	$0.39	($2.36)	$0.19	($2.56)
Washington, DC	Washington Metropolitan Area Transit Authority	$0.28	($0.46)	61%	($0.42)	$0.47	($0.14)	$0.23	($0.37)

TABLE III. Costs of Counterfactual Scenario (Totals in Millions)

City	Agency	Bus: Average Operating Expense	Bus: Marginal Operating Cost	Average Fare	Bus: Net Operating Costs Total	Bus: Net External Costs (Pollution and Congestion)	Bus: Net Capital Costs	Car: Net External Costs (Pollution and Congestion)	Total Costs of Counterfactual
Atlanta	Metropolitan Atlanta Rapid Transit Authority	($0.33)	($0.22)	$0.09	($106.837)	($23.161)	($53.42)	($19.189)	($95.768)
Baltimore	Maryland Transit Administration	($0.75)	($0.50)	$0.19	($50.893)	($4.719)	($25.45)	($3.909)	($34.075)
Boston	Massachusetts Bay Transportation Authority	($1.15)	($0.77)	$0.27	($485.678)	($28.763)	($242.84)	($23.829)	($295.431)
Buffalo	Niagara Frontier Transportation Authority	($1.18)	($0.79)	$0.29	($9.694)	($0.571)	($4.85)	($0.473)	($5.891)
Charlotte	Charlotte Area Transit System	($0.85)	($0.57)	$0.14	($6.911)	($0.510)	($3.46)	($0.422)	($4.388)
Chicago	Chicago Transit Authority	($0.96)	($0.65)	$0.35	($548.824)	($46.211)	($274.41)	($38.285)	($358.908)
Dallas	Dallas Area Rapid Transit	($1.28)	($0.86)	$0.17	($126.801)	($5.923)	($63.40)	($4.907)	($74.231)
Denver	Denver Regional Transportation District	($0.74)	($0.50)	$0.17	($58.096)	($5.231)	($29.05)	($4.334)	($38.614)
Los Angeles	Los Angeles County Metropolitan Transportation Authority	($0.64)	($0.43)	$0.18	($179.688)	($20.484)	($89.84)	($16.970)	($127.298)
Miami	Miami-Dade Transit	($0.79)	($0.53)	$0.17	($66.552)	($5.548)	($33.28)	($4.597)	($43.421)
Minneapolis	Metro Transit	($0.72)	($0.48)	$0.23	($22.352)	($2.383)	($11.18)	($1.974)	($15.534)
Newark/Jersey City/Trenton	New Jersey Transit Corporation	($0.71)	($0.48)	$0.30	($30.194)	($3.787)	($15.10)	($3.138)	($22.022)
New York	MTA New York City Transit	($1.30)	($0.87)	$0.44	($6,442.378)	($390.230)	($3,221.19)	($323.295)	($3,934.720)
Philadelphia	Southeastern Pennsylvania Transportation Authority	($0.91)	($0.61)	$0.30	($225.165)	($18.929)	($112.58)	($15.682)	($147.194)
Pittsburgh	Port Authority of Allegheny County	($1.02)	($0.69)	$0.25	($19.390)	($1.298)	($9.70)	($1.075)	($12.069)
Portland	Tri-County Metropolitan Transportation District of Oregon	($1.00)	($0.67)	$0.21	($114.559)	($7.555)	($57.28)	($6.259)	($71.094)
Sacramento	Sacramento Regional Transit District	($1.51)	($1.01)	$0.28	($79.570)	($3.349)	($39.78)	($2.775)	($45.909)
Salt Lake City	Utah Transit Authority	($0.61)	($0.41)	$0.10	($27.353)	($2.776)	($13.68)	($2.300)	($18.752)
San Diego	San Diego Metropolitan Transit System	($0.75)	($0.50)	$0.25	($77.440)	($8.076)	($38.72)	($6.691)	($53.487)
San Francisco	San Francisco Bay Area Rapid Transit District	($2.03)	($1.36)	$0.21	($1,979.568)	($56.537)	($989.78)	($46.839)	($1,093.161)
San Francisco	San Francisco Municipal Railway	($1.29)	($0.86)	$0.31	($175.080)	($9.330)	($87.54)	($7.730)	($104.601)
San Jose	Santa Clara Valley Transportation Authority	($1.39)	($0.93)	$0.19	($49.062)	($2.126)	($24.53)	($1.761)	($28.419)
San Juan	Puerto Rico Highway and Transportation Authority	($1.65)	($1.10)	$0.25	($46.875)	($1.748)	($23.44)	($1.448)	($26.633)
Washington, DC	Washington Metropolitan Area Transit Authority	($1.15)	($0.77)	$0.24	($1,113.205)	($63.995)	($556.60)	($53.018)	($673.617)

Of course any rough estimates, such as these, need be viewed with caution and perhaps even some skepticism. The analysis tends to favor systems with high transit fares relative to bus fares and with high operating costs for bus. Regardless of the assumptions used in the analysis, it is clear that there is significant variation in the economic performance of the different rail systems. The best systems significantly outperform the worst. In the following sections, we turn our attention to how high concentrations of jobs and people around rail stations contribute to transit cost-effectiveness by increasing ridership.

III. DENSITY AND TRANSIT INVESTMENT COST-EFFECTIVENESS

As Meyer, Kain, and Wohl (1965) put it almost a half-century ago, –nothing is so conducive to the relative economy of rail transit as high volumes and population density. High population density increases the costs of all urban transportation systems, but substantially less for rail than for other modes” (p. 246). Using a unique panel constructed from data on 59 American transit investments since 1970 and the operating characteristics of 23 light- and heavy-rail systems, we find a strong positive relationship between costs, ridership, and job and population densities. Ridership and capital costs typically rise with job and population densities, but increased ridership more than offsets increased costs.

A. *Transit Cost-Effectiveness Thresholds*

Early evaluations of the cost-effectiveness of different transit modes focused on the average cost of providing trips on a corridor by different modes. Researchers have consistently found that rail, with its high up-front capital costs and increasing economies of scale, needs to attain a threshold density of trips in order to cost less than providing the same trips by car or bus (Keeler, Small, & Associates, 1975; Meyer et al., 1965; Pickrell, 1985; Pushkarev, Zupan, & Cumella, 1982).

Since rail transit needs high passenger volumes to be cost-effective, it also needs high concentrations of people and jobs around stations. In high-density cities, Meyer et al. (1965) found that rail was more cost-effective than bus at all passenger volumes and corridor lengths, while private cars were generally the least expensive transportation technology in low-density cities. Pushkarev and Zupan (1977) estimated land use thresholds for different types of transit. Under the right circumstances—downtowns with substantial office and commercial floor space and linear travel corridors of densely developed multi-family or attached housing—they hypothesized that rail would improve mobility, save energy, and conserve land. According to their calculations, the high costs of a heavy-rail investment would require a net-residential corridor density of at least 12 households per acre leading to a minimum 50-million non-residential square-foot CBD. A minimal light-rail investment, by comparison, would require 9 households per acre to a CBD of 20 to 50 million non-residential square feet.

B. *Methodology*

We collected data on 59 capital transit investment projects in 19 metropolitan areas in the U.S. The 59 investments range from 2 to over 30 stations per project. Thirty-three of the projects are light-rail investments; twenty-three, heavy-rail; and four, bus rapid transit. Collectively, they include 768 transit stations and 740 bidirectional route miles of fixed-guideway service (i.e., half the number of track miles, given consistent double tracking), and were built at a total 2009-adjusted cost of $68 billion. We combined the investment data with data on fare revenues, operating costs, and passenger trips to construct a panel dataset. Jobs and population around the station catchment areas change in two ways. First, they change naturally over time. Second, they change as a system expands and incorporates new station catchment areas. Figure 1 shows the expansion of Sacramento's light-rail system in 2005 and 2006. Five stations opening to the northeast in 2005 added nearly 2,500 acres to the station catchment area. The two stations that opened in 2006 added little to the catchment area since they are close to existing stations in the northwest. For additional details on the dataset, model estimation procedures, and results see Guerra and Cervero (2011).

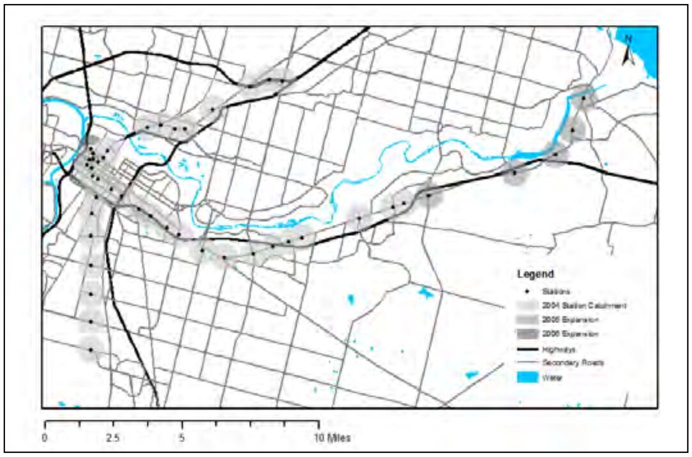

Figure 1. Expansion of Sacramento light rail system from 2004 to 2006.

C. *Findings*

Based on our analysis, we present several findings as well as threshold densities for cost-effective transit.

1) *Wide Variation*

First, as with system-level cost-benefit analysis, there is wide variation in the costs per passenger mile of recent transit investments. In order to compare capital costs, operating costs and fares, we annualized capital costs and attributed annual passenger miles to each project by assuming that a project is responsible for the same proportion of annual passenger miles as average weekday ridership. Adding the average operating costs net of fare revenues per passenger mile by agency in 2008, we estimated the cost of each passenger mile of transit service for the investments. The average net cost per passenger mile is $1.35 with a standard deviation of $1.55. The median project cost $0.93 cents per passenger mile. Figure 2 graphs the cumulative percentage of systems that cost between $0 and $5 per passenger mile. We excluded the 2006 Newark light-rail extension from Penn Station to Broad Street, which cost a staggering $10.43 per passenger mile in 2008, from the graph. The best performing project cost approximately $0.22 per passenger mile. As with system-level costs per passenger, there is wide variation in the best- and worst-performing investments.

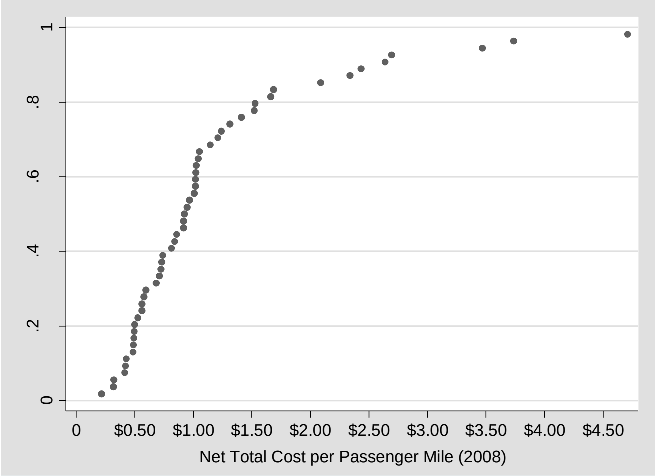

Figure 2. Cumulative distribution of projects by net total cost per passenger mile in 2008.

2) *Cost per Mile and Cost per Rider*

Rail capital costs are often normalized and compared on a per-mile basis (Altshuler & Luberoff, 2003; Booz Allen Hamilton, 2003; GAO, 2001; Pickrell, 1992). Low costs, however, are often offset by low ridership. Heavy-rail projects, although more than four times as expensive as light rail on average, are less expensive per rider and per passenger mile on average. Thus capital cost per guideway mile is an effective metric for normalizing costs across projects, but fails to account for the strong positive relationship between capital costs and ridership. Projects in Los Angeles, for example, tended to have high costs per mile but below-average costs per rider, while projects in San Jose had low costs per mile, but among the highest costs per rider. That said, the most cost-effective projects had lower capital costs on average, and reducing costs is an important way to increase cost-effectiveness.

3) *Jobs Matter*

Transit planners often aim to increase ridership by investing in new corridors on existing systems. The marginal cost of attracting new riders is highly dependent on the cost and design of the expansion and its surrounding land uses. We found that capital expansions into residential neighborhoods tended to be a more expensive way to increase passenger miles than either fare reductions or service increases. To increase cost-effectiveness, residential extensions need to be coordinated with concurrent increases in jobs around existing system stations. Without increasing jobs in the catchment area, a $200 million per mile heavy-rail system in the average city needs population densities that are twice as high as Washington, DC's to achieve high cost-effectiveness.

4) *Mass Transit Needs Mass*

While escalating costs are often emphasized when discussing rail transit success, we found that insufficient densities play a larger role. Pushkarev and Zupan's (1977) estimates of rail transit costs were not for from the mark, after adjusting for inflation. By contrast, many recent investments in heavy-rail and light-rail have lacked the prescribed densities to support them. Assuming an average gross-to-net density ratio of 67%, the average rail investment of the past four decades has fewer households around stations than Pushkarev and Zupan's recommended minimum. Just 26% of heavy-rail and 19% of light-rail station-areas surpass the recommended minimum. Figure 4 plots a histogram of the average gross residential density in 2000 of the 526 light-rail and 261 heavy-rail stations used in our study that have opened since 1972.

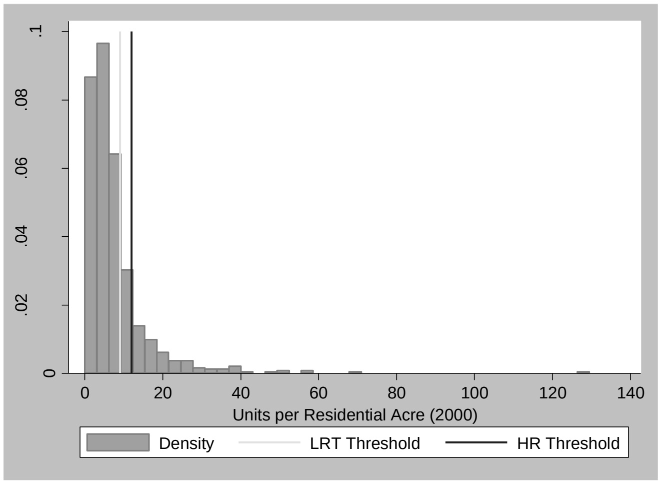

Figure 3. Histogram of units per residential acre around light and heavy rail stations opened since 1972. *Thresholds from Pushkarev and Zupan (1977)

5) *Updated Cost-Effectiveness Thresholdsobs*

Table IV presents the minimum threshold population density that an average light-rail and heavy-rail city need in order to achieve a high cost-effectiveness rating at different capital costs per passenger mile. We defined high cost-effectiveness as projects that cost less than $0.58 per passenger mile. Although somewhat arbitrary, this threshold represents the average estimated marginal cost of increasing passenger miles through fare reductions, and it is just above the cutoff for the top quartile of investments. Each 1% increase in the population corresponds with a 0.37% increase in passenger miles at a marginal cost of $0.26 per passenger mile. The light-rail city has an estimated 100,000 jobs in the station catchment area, while the average heavy-rail system has 350,000.

Since capital costs tend to rise with density, we also modeled the variation in cost per passenger mile while adjusting capital costs, based on increasing densities. We then varied the number of jobs and population around stations by 1%. The results, graphed in Figure 5, suggest that, on average, light rail is more cost-effective than heavy rail up to approximately 28 people and jobs per gross acre. With system-area densities near or below 20 people and jobs per acre, Atlanta, Miami, and Baltimore appear better suited for light than heavy rail. While costs also rise with density, the increased ridership more than offsets these costs per passenger mile.

TABLE IV. POPULATION DENSITY THRESHOLDS FOR TOP QUARTILE COST-EFFECTIVENESS AT A RANGE OF CAPITAL COSTS FOR AVERAGE LIGHT- AND HEAVY-RAIL CITIES.

Large city (HR) job catchment of 350,000		Medium city (LRT) job catchment of 100,000	
Capital Cost[a]	PPA[b]	Capital Cost[a]	PPA[b]
$100	9	$25	14
$150	22	$50	32
$200	36	$75	50
$250	50	$100	67
$500	119	-	-

Notes: a. Average capital cost per mile in millions (2009).
b. Population per gross acre.

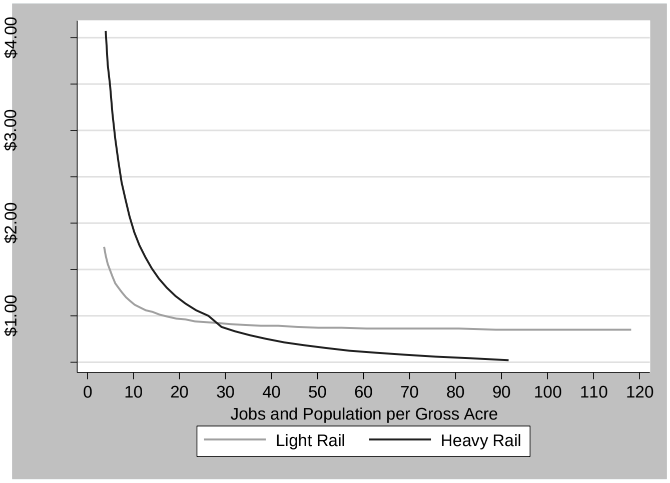

Figure 5. Net cost per passenger mile by jobs and population in average light- and heavy-rail cities.

High-cost systems need higher density levels. At the observed average cost of $231 million and $53 million per mile, the average heavy-rail and light-rail systems in the average heavy- and light-rail cities need around 45 and 30 people per gross acre around stations to achieve a high cost-effectiveness rating. Only New York has higher average population densities. In order to begin to improve transit investment cost-effectiveness, it is necessary—but not sufficient—to increase development around existing stations. Cities also need to increase jobs around transit, reduce operating costs, and keep capital expenses down. Increasing the number of jobs around stations, in particular, appears to have a stronger impact on ridership than increasing population, particularly when comparing figures across systems. Since jobs tend to be concentrated around existing downtown stations, however, system expansions are unlikely to capture significant job concentrations. Rather, residential expansions need to be coordinated with pro-active policies to facilitate job growth in other areas.

IV. STATION-LEVEL TRANSIT RIDERSHIP AND CATCHMENT AREAS

Job and population densities matter within as well as across transit systems. Using station-level variables from 1,449 high-capacity American transit stations in 21 cities, we test this relationship and aim to measure the influence of jobs and population on transit ridership using different catchment areas. For the purposes of predicting station-level transit ridership, we find that different catchment areas have little influence on a model's predictive power. This suggests that transit agencies should use the easiest and most readily available data when estimating direct demand models. For prescribing land-use policy, by contrast, the evidence is less clear. Nevertheless, we find some support for using a quarter-mile catchment area for jobs around transit and a half-mile catchment for population. While these distances will likely vary from place to place and depending on the study purpose, they are a good starting point for considering transit-oriented policy or collecting labor-intensive data, such as surveys, about transit-adjacent firms or households.

A. *Transit Station Catchment Areas*

The distance of origins and destinations from transit stations has a strong influence on whether people use transit to get to and from them (Cervero, 1994, 2007; Ewing & Cervero, 2010). Both stated preference surveys and observed behavior indicate that time spent walking is significantly more onerous than time spent in a car or transit vehicle (Small 1993, Wardman 2001). Thus reducing average walk times to transit can help increase transit ridership. Transit catchment areas are broadly based on an understanding of how far people are willing to walk to take transit. In addition to supporting the half-mile radius, the same general explanation has also been used to justify using quarter-mile (Zhao, Chow, Li, Ubaka, & Gan, 2003) and two-fifths-of-a-mile (Calthorpe, 1993) (0.40 and 0.64 kilometers). Looking at 17 transit agencies with light rail service, O'Sullivan and Morral (1996) found transit walking distance guidelines that ranged from 300 to 900 meters (0.19 to 0.56 miles).

B. *Methodology*

We collected data on 832 heavy rail, 589 light rail, and 36 bus rapid transit stations and their surroundings from twenty American transit agencies. We then estimated several dozen station-level direct demand models of transit ridership. Using direct demand models—essentially a statistical regression based on observed ridership—is a simple alternative to full-blown travel models to predict transit ridership on transit stations, corridors, and systems (Cervero, 2006). Guerra, Cervero, and Tischler (2011) provide a full description of the dataset and estimation procedures.

C. *Transit Catchment Areas*

Our first set of models test the predictive power of direct demand models using different radial catchment areas. Each increment increases in one quarter mile bands and excludes geographic areas that are closer to another transit station. Each

TABLE V. Ordinary Least Squares Regressions of the Influence of Catchment- Area Population on the Average of Weekday Boardings and Alightings[A]

	(1)	(2)	(3)	(4)	(5)	(6)
Population within 0.25 miles	0.338*** (6.02)					
Population within 0.50 miles		0.249*** (4.62)				
Population within 0.75 miles			0.183** (3.52)			
Population within 1.00 miles				0.146** (3.00)		
Population within 1.25 miles					0.122* (2.67)	
Population within 1.50 miles						0.104* (2.38)
Observations	1449	1449	1449	1449	1449	1449
Adjusted R-squared	0.7402	0.7463	0.7463	0.7454	0.7445	0.7436

Notes: (a) For a list of the included control variables, see Table VII, Model 1. The regression also includes six job count variables in quarter-mile bands out to 1.5 miles.
(b)Robust clustered t statistics in parentheses; (c) * p<0.05, ** p<0.01, *** p<0.001

TABLE VI. Ordinary Least Squares Regressions of the Influence of Catchment-Area Jobs on the Average of Weekday Boardings and Alightings[A]

	(1)	(2)	(3)	(4)	(5)	(6)
Jobs within 0.25 miles	0.685*** (4.25)					
Jobs within 0.50 miles		0.421*** (4.88)				
Jobs within 0.75 miles			0.342*** (4.80)			
Jobs within 1.00 miles				0.317*** (4.29)		
Jobs within 1.25 miles					0.301*** (3.89)	
Jobs within 1.50 miles						0.287** (3.55)
Observations	1449	1449	1449	1449	1449	1449
Adjusted R-squared	0.7448	0.7405	0.7333	0.7287	0.7255	0.7225

Notes: (a) For a list of the included control variables, see Table VII, Model 1. The regression also includes six population count variables in quarter-mile bands out to 1.5 miles.
(b)Robust clustered t statistics in parentheses; (c) * p<0.05, ** p<0.01, *** p<0.001

model also includes the full list of station controls from the final regression (model 1 from Table VII). Table V, which models different radii population counts, includes a full range job counts in quarter-mile-catchment bands out to 1.5 miles (2.4 kilometers). Table VI reverses the jobs and population counts to see if the best predictive catchment area differs for jobs and population counts. We ran both sets of models using ordinary least squares regressions with standard errors clustered by city.

The chosen station catchment area has little to no influence on the predictive power of the models. For the six radii catchment areas, the adjusted r-square ranges from 0.742 to 0.746 for population and from 0.723 to 0.745 for jobs. This suggests that, for the purposes of direct demand modeling, discussions about the appropriate walking distance or type of catchment area (radial, diamond, or network) are largely irrelevant. Nevertheless, the best fitting models are the half-mile and three-quarter-mile radii for population counts and, more noticeably, the quarter-mile radius for job counts. The declining parameter estimates with increasing radius distance follow expectations. An additional person within a quarter mile of a station correlates with 0.338 more average weekday trips; within one half-mile, 0.249 more.

D. Density and Station-Level Ridership

To test the robustness of our estimates and provide additional evidence for the large and growing literature on the influence of job and population concentrations around transit, we ran several model specifications. Table VII provides parameter estimates of the influence of jobs and population around transit, ranging respectively from 0.20 to 0.47 and 0.09 to 0.345. Model 1 includes variables on transit technology and service frequency. While these factors likely generate transit ridership, they are also influenced by demand. Service variables, as shown in models 1 and 2, appear to exert a strong and statistically significant influence on station-level transit ridership. At an elasticity of over 0.80, our estimates of the influence of service levels on ridership are within the range of previous estimates, but higher than average (Evans, 2004).

Agencies, however, only build high capacity subway or run frequent service where demand is high. Removing these endogenous variables nearly doubles the estimated impact of jobs and population on transit ridership. The true elasticity likely lies within the bounds of the parameter estimates from models 1 and 3. Since coefficients of log-log models represent elasticities, the results also show that ridership is more strongly influenced by jobs within ¼ mile than population within ½ mile. While TOD planning tends to focus on residences, these results reinforce the findings of others that non-residential development can have an even bigger impact on transit ridership (Cervero, 2002; Cervero, 2007; Kolko 2011). This confirms our investment-level analysis and suggests that transit-oriented development policies focus on jobs, in addition to housing.

Finally, we remove the city-level dummy variables. This significantly reduces the predictive power of the models and again increases the importance of jobs and population on ridership. This indicates that, in a national model of transit ridership, system-level variation is as important, or more important, than station-level variation. Some cities have developed driving or transit cultures over time, or have other attributes, such as more significant parking constraints, that lead to higher or lower ridership. It is important to note, however, that the signs and magnitudes of these effects are sensitive to which variables are included in the model. They absorb the average effects of all excluded but relevant predictor variables. For example, when modal dummy variables are included, Portland has higher ridership than would otherwise be expected. However, when not accounting for Portland's light rail technology, ridership levels are lower than otherwise expected. New Jersey Transit systems have lower ridership than otherwise predicted in all models, while Washington D.C. subway has higher than expected ridership. Contrary to what one might expect, high concentrations of jobs and people around transit do a good job of predicting New York City transit ridership; there does not appear to be some excluded variable that drives the city's high ridership. Although we tested several system-level attributes that influence ridership, these did not provide better fits than the city-level dummy variables.

V. PUBLIC REACTIONS TO EXPANDED BRT AND HIGHER DENSITIES IN STOCKTON, CA

Bus Rapid Transit (BRT) has gained attention as a potentially cost-effective form of high-capacity transit. This is particularly the case in small to medium-size cities that do not have high enough densities or serious enough peak-period traffic congestion to justify fairly expensive fixed-guideway transit investments.

This section summarizes research on how lay citizens react to the kinds of density increases needed to mount cost-effective BRT services, using Stockton, California (2010 population of 290,000) as a case context. Photo-simulations of three levels of higher densities matched by increased amenities (e.g., street trees, attractive landscaping, street furniture, improved building facades, bike lanes) along a BRT corridor were presented to a citizen's advisory group from Stockton. The analysis sought to gauge the reactions of local residents to the kinds of densities needed to attain cost-effective BRT services. Because citizen advisory committee members are well-positioned politically to block efforts to increase urban densities along BRT corridors, there is value in probing their views and opinions on the matter with an eye toward gaining insights into how to best overcome opposition.

Images of expanded BRT services matched by three levels of density were created for two parts of Stockton that currently have a low-end BRT service that would be expanded to a higher-end, exclusive lane service in two parts of Stockton. Three sets of images were presented, ranging from low to medium to high densities. As densities

TABLE VII. LOG-LOG ORDINARY LEAST SQUARES DIRECT MODELS OF U.S. TRANSIT RIDERSHIP

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Population within 0.50 miles	0.0922*	0.140**	0.137**	0.147**	0.345***
	(2.27)	(2.99)	(3.15)	(3.00)	(5.18)
Jobs within 0.25 miles	0.198***	0.257***	0.374**	0.370**	0.466***
	(3.88)	(3.89)	(3.73)	(3.78)	(4.61)
Park-and-ride spaces	0.0136***	0.0137***	0.0145**	-	-
	(4.20)	(4.06)	(3.09)		
Regional Rail Connection Dummy	0.296**	0.292*	0.446**	-	-
	(3.37)	(2.67)	(3.62)		
Bus lines servings station area	0.0375***	0.0401***	0.0479***	-	-
	(7.79)	(5.68)	(8.60)		
Terminal station dummy	0.340**	0.359***	0.322***	-	-
	(3.59)	(3.96)	(4.26)		
Airport station dummy	0.755***	0.788***	0.753**	-	-
	(3.98)	(3.90)	(3.31)		
Linear distance (yards) to central business district	-0.0204*	-0.0256*	-0.0343*	-	-
	(-2.74)	(-2.46)	(-2.16)		
Linear distance (yards) to nearest station	0.00971	0.0932*	0.0589	-	-
	(0.40)	(2.47)	(1.22)		
Frequency (trains during AM peak hour)	0.875***	0.817***	-	-	-
	(17.70)	(13.24)			
Light rail dummy (1=LRT)	-1.098***	-	-	-	-
	(-9.69)				
BRT dummy (1=BRT)	-1.876***	-	-	-	-
	(-13.13)				
City-level dummy variables					
Baltimore	-0.203*	-0.922***	-1.197***	-1.383***	-
Boston	-0.0115	-0.629***	-0.367***	-0.730***	-
Buffalo	0.388**	-0.689***	-1.044***	-1.191***	-
Chicago	-0.506***	-0.491***	-0.347***	-0.605***	-
Dallas	0.279*	-0.814***	-0.908***	-0.961***	-
Denver	-0.0396	-1.113***	-1.211***	-1.271***	-
Los Angeles	0.303**	-0.785***	-0.695***	-0.776***	-
Miami	-0.765***	-0.792***	-0.835***	-0.747***	-
Minneapolis	0.432**	-0.607***	-0.733***	-1.071***	-
New York	0.0935	-0.0107	0.289*	-0.106	-
Newark/Jersey City	-0.914***	-1.965***	-1.970***	-2.197***	-
Phoenix	-0.0278	-1.115***	-1.303***	-1.443***	-
Portland	0.327*	-0.675***	-0.702***	-1.066***	-
Sacramento	0.635***	-0.403***	-0.879***	-1.352***	-
San Diego	0.295*	-0.788***	-1.004***	-1.308***	-
San Francisco	0.0560	-0.0151	0.157*	0.330***	-
San Jose	-0.681***	-1.751***	-2.188***	-2.440***	-
St. Louis	0.557**	-0.481***	-0.737***	-0.879***	-
Trenton	-0.503**	-1.546***	-1.977***	-2.156***	-
Washington D.C.	0.459***	0.500***	1.026***	0.300***	-
Constant	3.907***	2.750**	4.606***	4.778***	1.812
Observations	1449	1449	1449	1449	1449
Adjusted R-squared	0.798	0.734	0.667	0.577	0.334

Notes: (a)Robust clustered t statistics in parentheses; (b) * $p<0.05$, ** $p<0.01$, *** $p<0.001$

increased, so did an amenity package (e.g., landscaping, street furniture, building articulations, multi-modal options such as bike lanes). Consistent with theories of urban design, the aim was to soften the perception of higher densities by layering in more amenities that improved the image and —feel” of the corridor. Community representatives were then asked to comment on the images. Images portrayed how development might look to a pedestrian on the street. The intent was to stimulate dialogue about the kinds of density envelopes that might be acceptable in light of improved aesthetics, urban-design qualities, and transit services.

A. BRT and Density Photo-Simulations

The first corridor studied was Miner Avenue in Downtown Stockton, which operates a bus (route #40) between a commuter-rail station and the city's downtown riverfront. The corridor averages 25 jobs plus residents per gross acre. The proposed density increases, shown in Figures 6, 7, and 8), would increase current densities by a factor of two (lowest range) and four (highest range), with the amount of urban amenities increasing in lockstep with higher densities.

Figure 6. Miner Ave - Scenario 1

The second set of photo-simulations was produced for a more traditional suburban environment, one made up of predominately single-family homes and strip commercial development, including big-box retailers. Transforming this corridor, called Pacific Avenue, into a more transit-supportive built environment is all the more challenging. The three photo simulations (Figures 9, 10, and 11) reveal a slightly lower density building profile than along the downtown corridor (Miner Avenue) in light of the surrounding neighborhood's single-family residential character.

B. Community Reactions

The photo-simulations and background information (mainly on likely investment costs) were presented to a group of stakeholder interests at Stockton's Climate Action Plan Advisory Committee in May, 2011. From the group discussions following the photo-simulation presentations, it was apparent that the proposed densities were too high in the minds of Stockton residents, even if a host of urban amenities were introduced and BRT services markedly improved. Sentiments expressed by the stakeholder participants that were generally agreed upon by all present were the following:

- There was general disapproval of a dedicated lane for BRT service. The feeling was that traffic congestion was not serious enough and the prospects of expropriating a lane for buses only would be controversial enough that it was premature to present this option. Support was expressed for increased transit service levels when it would not significantly reduce existing roadway capacity.

Figure 7. Miner Ave - Scenario 2

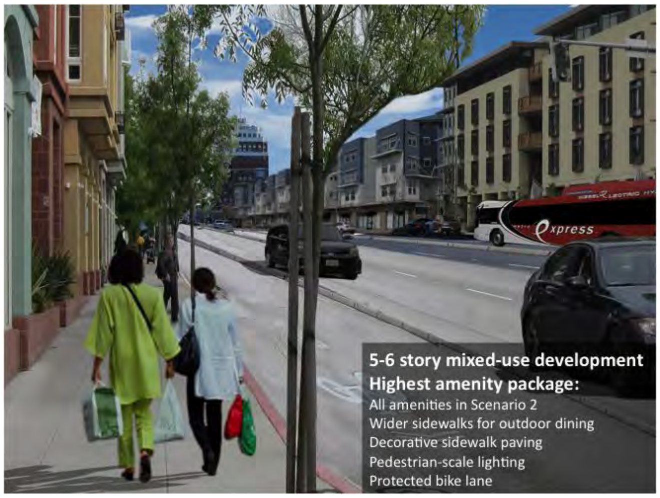

Figure 8. Miner Ave - Scenario 3

Implicitly this viewpoint favors —BRT lite”—e.g., introduction of signal prioritization schemes, far-side bus stops, passenger information systems, and other design

Figure 1. Pacific Ave - Scenario 1

Figure 2. Pacific Ave - Scenario 2

Figure 3. Pacific Ave - Scenario 3

treatments that mildly enhance the transit riding experience but fail to significantly increase average bus speeds.

- Most attendees like the greening of BRT corridors. The idea of planting street trees along the corridor, providing a shaded canopy to pedestrians and bus patrons, was welcomed by everyone in attendance.
- Several participants expressed concerns and skepticism about the estimated cost recovery rates and BRT service levels of scenarios that were presented for each photo-simulated image. Even with considerably higher densities, the prevalence of free parking and the absence of serious traffic congestion levels prompted some to question the estimated increases in transit ridership productivity. This likely reflects the limitation of single-image photo-simulations in the sense that participants did not associate higher urban densities with higher potential traffic densities and thus the possibility of increased traffic congestion and transit ridership.
- There was general agreement that the highest density scenario was simply too high for Stockton, both for the present and in the foreseeable future. This view held for downtown as well as the Pacific Avenue corridor. More acceptable for downtown were densities with 3-4 story buildings, and some vertical mixing of land uses, along the BRT corridor. By rejecting higher densities, implicitly the participants were also rejecting a high-end, dedicated-lane BRT investment.

What this research perhaps most clearly underscored is the disconnect that lies between transit and urbanism in the minds of many. Notably, there was a clear disconnect between the kind of high-quality transit services that would be needed to make a serious dent in Stockton’s current transit modal splits (i.e., high-end BRT) and the kinds of urban land-use and streetscape transformations that would be needed to support these radically improved transit services. Participants widely embraced integrated transportation and land-use planning and the goal of Stockton following a more sustainable pattern of urban development. They also generally liked the idea of improved transit services, including BRT, as long as it did not encroach on road space occupied by Stockton motorists (which no doubt included many of the participants themselves). However when it came to growing ―upwards instead of outwards” in the form of taller buildings, participants were generally uncomfortable, even when higher densities were matched by a richer package of urban amenities. More pedestrian-scale densities of 3 to 4 story buildings appeared to be the tallest building heights acceptable to participants. Yet unless such densities exist throughout a corridor, it is unlikely that the cost of a high-end BRT could be economically justified. Regardless of whether in Stockton or any other city, as the adage goes, mass transit needs ―mass”. Unless considerably higher densities are embraced and politically accepted, high-end transit services will remain a pipedream in settings like Stockton.

Perhaps a limitation of single-image photo-simulations is that they fail to reflect this dynamic. While they might provide feedback on specific elements that are liked or disliked by observers, they are hardly a platform for helping stakeholders sort through the kind of trade-offs needed to place a city like Stockton on a more sustainable pathway. In this sense, they are a single tool or snapshot, not a complete accounting of impacts or a panorama of possible urban futures. Their limitations must be weighed accordingly when engaging local residents and stakeholders in discussions about urban transformations.

VI. CLOSE

This paper has offered multiple perspectives on the challenges of increasing urban densities in order for historically pricey fixed-guideway transit investments to become cost-effective. While empirical evidence suggests that recent-generation rail investments in the U.S. have in many instances conferred net social benefits, considerable skepticism remains particularly among the more vocal critics of American transit policy. All sides agree that increasing urban densities will place public transit on firmer financial footing. Our analysis suggests that light-rail systems need around 30 people per gross acre around stations and heavy rail systems need 50 percent higher densities than this to place them in the top one-quarter of cost-effective rail investments in the U.S. The ridership gains from such increases, our research showed, would be substantial, especially when jobs are concentrated within ¼ mile of a station and housing within a half mile. For smaller cities, such densities are likely political unacceptable, however, as suggested by the reactions of stakeholders to photo-simulations of higher densities along proposed BRT corridor in Stockton, California.

It is unlikely that ―livability enhancements" like streetscape improvements and greening of transit corridors will be sufficient to offset the opposition to higher densities in traditionally more auto-oriented settings of the U.S. More than likely, external factors like higher motoring and parking costs will be more effective than well-intended urban design strategies at creating the kinds of urban densities needed for cost-effective transit services in the U.S. Recent simulations in Portland, Oregon suggest positive synergies between congestion pricing, urban densities, and transportation system performance (Guo Agrawal, & Dill, 2011).

Whether higher price signals are best achieved through market forces or regulatory fiat is itself a politically contentious matter. Regardless, more knowledge and best-case examples are needed that demonstrate how higher densities combined with other factors, like higher parking charges, might combine to create higher performing transit services.

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