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Costs and Benefits of Bicycling Investments in Portland, Oregon

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Background: Promoting bicycling has great potential to increase overall physical activity; however, significant uncertainty exists with regard to the amount and effectiveness of investment needed for infrastructure. The objective of this study is to assess how costs of Portland's past and planned investments in bicycling relate to health and other benefits. ***Methods:*** Costs of investment plans are compared with 2 types of monetized health benefits, health care cost savings and value of statistical life savings. Levels of bicycling are estimated using past trends, future mode share goals, and a traffic demand model. ***Results:*** By 2040, investments in the range of $138 to $605 million will result in health care cost savings of $388 to $594 million, fuel savings of $143 to $218 million, and savings in value of statistical lives of $7 to $12 billion. The benefit-cost ratios for health care and fuel savings are between 3.8 and 1.2 to 1, and an order of magnitude larger when value of statistical lives is used. ***Conclusions:*** This first of its kind cost-benefit analysis of investments in bicycling in a US city shows that such efforts are cost-effective, even when only a limited selection of benefits is considered.

Keywords: return on investment, Health Economic Assessment Tool, infrastructure, promotion, physical activity, monetization

Recently, bicycling has received increased attention as part of comprehensive and sustainable health, transportation, and environmental policies.[1–3] Benefits of bicycling—such as the gain in physical activity and emission-free transportation—are generally understood, at least in broad, qualitative terms, and undisputed. Nonetheless, spending money on bicycle infrastructure is often a low priority compared with investments in roads, public transportation, and other government expenditure. Although traditionally debated within the framework of transportation policies, more recently the idea of considering investments in walking and bicycling as a measure of disease prevention has gained traction.[4] For example, investments in bicycle infrastructure have been proposed as a health prevention measure during the debate on health care reform in the US.[5] A better understanding of the cost-benefit relationships of bicycling investments would be helpful to justify such initiatives.

Cavill and colleagues have reviewed 16 cost-benefit analyses on health effects of transportation policies that included data on walking and cycling, all of which except for one were located in Europe.[6] Benefit-cost ratios varied widely across studies with a median ratio of 5:1, and only one study reporting a ratio smaller than 1.[7] Comparability of the studies was limited by the lack of transparent and standardized methodologies, and only 3 studies were considered to be of high quality.[6] Wang et al present the only cost-benefit analysis available for US bicycle facilities. For 5 trails in Nebraska they calculated a ratio of 2.94 between health benefits from trail use and costs associated with trail construction and use.

This paper compares past and future costs of investments in bicycling in Portland, Oregon, with health benefits from increased bicycling. The city of Portland has a population of 582,000 (metropolitan area 2.2 million). The topography is fairly flat for the most part. The city is intersected by the Willamette River, which is crossed by 4 bike accessible bridges. Portland enjoys a moderate, although fairly wet climate, with on average 155 rain days per year. Current bicycle mode share is the highest in the US, with 6.4% of commute trips taken by bicycle.[8]

This paper provides the first cost-benefit analysis for an urban bicycling network in the US. The analysis is made possible not only by almost 20 years of investments and growth in bicycling, but also by the availability of long term data unique for a US city which document the impacts of investments (Figure 1). Despite the extraordinary data availability, substantial uncertainties remain when assessing costs and benefits of bicycling, foremost for long-term projections. To date, there is no quantitative methodology available to predict future developments in bicycling. Assumptions on future investments in this analysis are based on 3 different bicycle plans by the city of Portland, and resulting increases in bicycling are projected based on stated goals and a few European precedents. While these plans are considered realistic, albeit ambitious, it is not the intention of this analysis to assess their appropriateness. Instead, the

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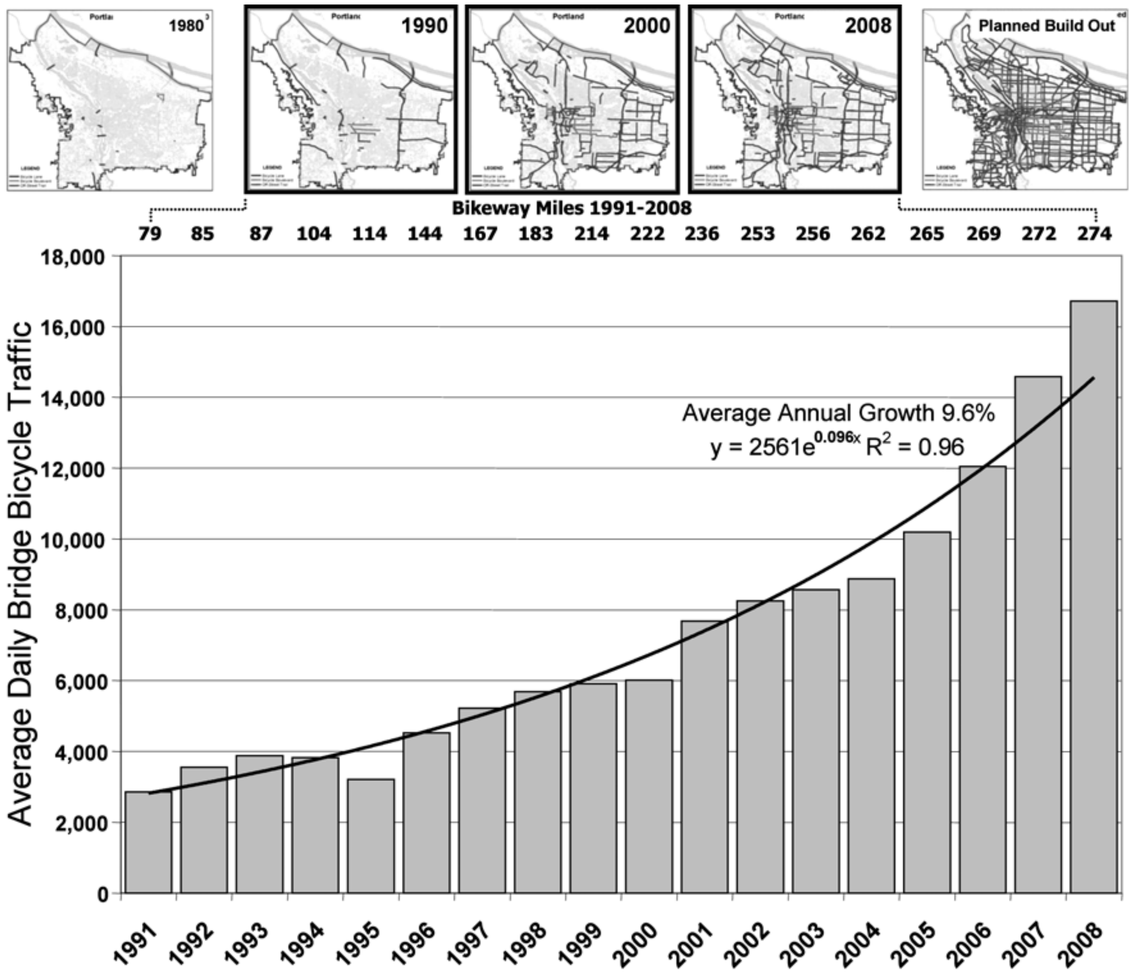

Figure 1 — Portland bikeway network development and growth in daily bicycle traffic across 4 bridges over the Willamette River from 1991 to 2008.

analysis evaluates health related economic aspects of past and planned developments of bicycling based on a transparently presented set of assumptions. As such, this analysis serves 3 main purposes: 1) presentation of empirical findings, 2) economic evaluation of existing planning scenarios, and 3) discussion of methodological issues that come with the comparison of investment costs to health benefits of bicycling.

Methods

Costs of bicycle investments in the past and under 3 future plans are compared with 2 types of monetized health benefits: health care cost savings and reduction in mortality, monetized as value of statistical lives.[9] In addition, fuel cost savings are assessed. Because the vast majority of investments fund infrastructure projects with long life spans, calculations are conducted over a 50-year period from 1991 to 2040.

The comparison of costs of investments to resulting benefits requires a number of steps, several of which require assumptions. Monetary figures reflect 2008 values. For future values, a discount rate of 3% is applied, reflecting an estimated long term average rate of US treasury bonds.[10]

The chain of calculations is sketched out in Figure 2, and includes the following steps: 1) compilation of past costs and plans for future investments, 2) extrapolation of future trends in bicycling based on past counts and goals for the future, 3) conversion of bicycle counts to miles biked, 4) calculation of physical activity from cycling, and 5) monetization of health benefits from physical activity.

Investment Costs

In 2008, the city of Portland estimated the hypothetical cost of rebuilding its entire 274-mile bikeway network at $57 million. In 2003, the city also initiated the Smart Trips program which encourages bicycling, walking, and

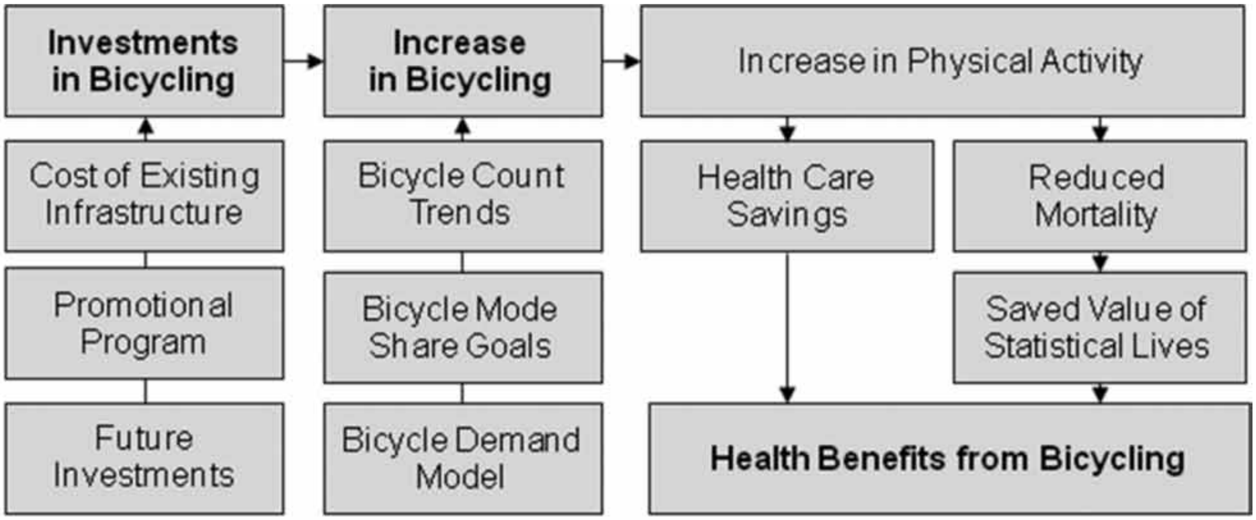

Figure 2 — Conceptual framework of the cost-benefit analysis (not including benefits of fuel savings).

use of public transportation, at an estimated cumulative cost through 2012 of $7.2 million.[11]

Estimates for future investments are based on 3 different plans by the city of Portland: a "basic" $100 million plan proposed in the context of the renewal of the federal transportation bill due in 2009;[12] an "80% plan" over $329 million to put 80% of all residents within a quarter mile of a developed, low-stress bikeway, and a "world class" plan with a price tag of $773 million. The latter 2 plans are part of the recently adopted 2030 bike master plan for Portland.[13] Among others, these plans foresee investments in crucial trail sections, bicycle boulevards (traffic calmed streets which limit motorized through-traffic and specifically accommodate bicycles), cycle tracks (bicycle lanes physically separated from traffic), bicycle and pedestrian bridges, various improvements and maintenance of existing infrastructure, the continuation of Smart Trips, and several additional projects.

User-side costs for bicycle purchase and maintenance, as well as opportunity costs are not included (see Discussion).

Levels of Bicycling

To estimate benefits of bicycling it is necessary to assess bicycling as total miles traveled, a particular challenge since bicycling is typically measured either through on-street counts, or as percent of all trips (mode share.)

Observed trends can inform expectations for the future to some extent, but projections require assumptions on long term levels of bicycling. Based on the past growth in bicycling of 10% annually (see Figure 1) and Portland's goal of a 25% future bicycle mode share,[12] this analysis assumes bicycle mode shares by 2030 of 15, 20, and 25%, for the basic, 80%, and world class plan, respectively. These mode share goals are roughly equivalent to a 3-, 4-, and 5-fold increase in bicycling over current levels by 2030, respectively. Based on these considerations, 50-year bicycle count series were constructed for each plan, consisting of the observed annual bridge bicycle counts of 2900 cyclists in 1991 to the 16,700 in 2008, a linear interpolation between 2008 levels and 2030 goals (3, 4, and 5-fold of current levels), and a plateau between 2030 and 2040 (see Figure 3.)

To convert bridge bicycle counts to miles, Portland's metropolitan traffic model is used.[14] This discrete mode choice model estimates miles bicycled in Portland in 2005, based on trip cost, trip time, socioeconomic factors and urban form. The ratio between modeled bicycle miles and bicycle counts in 2005 is then multiplied with the interpolated bike count data to derive a projection of future miles biked (Figure 3.) For this calculation bicycle miles for trips 3 miles or less were used. Longer trips were excluded based on a conservative assumption that the type of urban bicycle infrastructure, which is the subject of this analysis, primarily caters to shorter trips of utilitarian nature, and that future growth in bicycling will predominantly occur in the segment of relatively short routine trips for transportation, rather than recreational purposes.

Health Benefits

Miles of bicycling are converted into minutes of physical activity assuming an average speed of 10 mph.[15] To monetize the benefits from physical activity 2 different approaches are used.

The first approach assesses savings in health care costs from achieving a sufficient level of physical activity, based on the recommendation of the Centers for Disease Control and Prevention of 30 minutes of moderate physical activity on almost every day.[16] Several studies have compared health care expenditures between active and inactive individuals using various definitions for activity

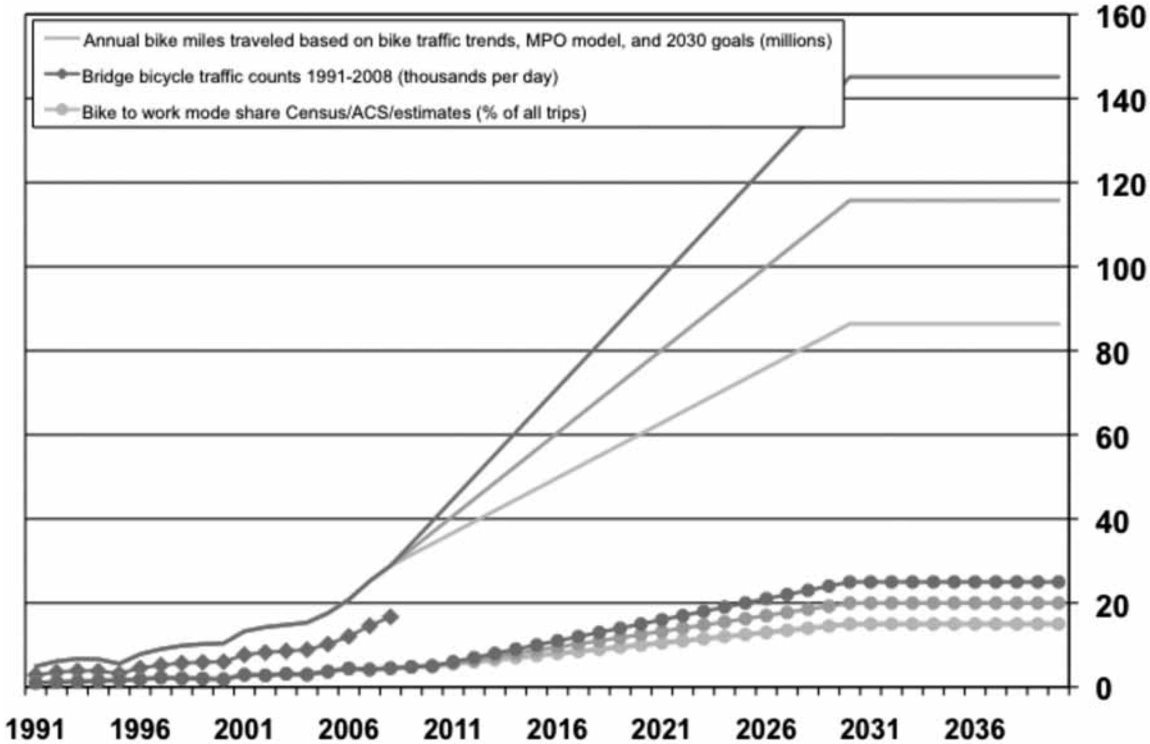

Figure 3 — Observed bicycle bridge traffic from1991 to 2008 (diamonds), and observed and projected bicycle mode share (dots) and extrapolated annual miles bicycled (solid lines) for 3 investment plans in Portland from 1991 to 2040.

and types of expenditures.[17] For this analysis, 3 studies were considered suited and of sufficient quality to derive an average estimate of health care costs from inactivity, per person.

Colditz et al reviewed the scientific literature and estimated that in 1995 in the US, the lack of physical activity (defined as absence of leisure time activity) cost $24 billion in treatments of morbidities, such as coronary heart disease, hypertension, Type II diabetes, colon cancer, depression and anxiety, and osteoporotic hip fractures.[18]

Linking 1996 Medical Expenditure Panel Survey to the 1995 National Health Interview Survey, Wang et al estimate the national health care costs from cardiovascular disease attributable to inactivity to be $23.7 billion in 2001.[19]

To estimate the health care cost per inactive person, the total estimates provided by Wang et al and Colditz et al are divided by the total US population of the year of the estimate, divided by 0.75 to adjust for the proportion of adults, and divided by 0.48 to adjust for the proportion of inactive people. Although the original studies apply different definitions in their calculations, using the same definition for the adjustment of prevalence of inactivity (ie, 48%) reduces the variation between these estimates and leads to more conservative per capita estimates. The resulting per capita health care costs attributable to inactivity are $257 in 1996, based on the study by Colditz et al,[18] and $231 in 2001, based on the study by Wang et al.[19] The third study by Pratt et al provides direct per capita estimates of $330 in 1987 attributable to inactivity.[20] All 3 estimates are inflated to 2008 dollars using the consumer price index for medical care (www.bls.gov) with an annual average increase of 4.2% between 1991 and 2008. The inflation-adjusted estimates are then averaged to derive the final estimate of $544.

To apply this dichotomous estimate to physical activity from bicycling, the underlying difference in activity between active and inactive people needs to be known (measured in minutes). To the best of the author's knowledge, this information has not been published, and therefore was derived based on the following assumptions. The studies which estimate costs of inactivity define it as lack of leisure time activity, not considering other sources of activity, but for lack of better alternatives, types of physical activity are not distinguished for this analysis and the current recommendation for physical activity levels, namely 30 minutes per day, is used as the cut-off between inactive and active people. People below this cut-off are assumed to get on average 15 minutes of physical activity a day—clearly not enough to meet the 30 minutes cut-off, but also clearly more than no activity at all. People above the cut-off are assumed to get on average 45 minutes in physical activity—the vast majority of them somewhere between 30 and 60 minutes—per day. Under these assumptions, it takes on average 30 minutes of physical activity for an inactive person to become active. Thirty minutes of daily bicycling are therefore credited with $544 in health care savings annually.

In the second approach the World Health Organization's Health Economic Assessment Tool (HEAT) for cycling is applied.[21] The tool uses a relative risk estimate for all cause mortality of 0.72 for 3 hours of bicycling to work per week, from a large Danish cohort study, adjusted for other forms of physical activity.[22] Based on input of an annual number of bicycle trips and their average length, the tool calculates the number and value of statistical lives saved due to bicycling. The default parameters are adjusted to the US using a mortality rate of 0.0034 and a statistical value of life of $5.8 million, as suggested by the US Department of Transportation,[9] and to reflect the settings of this analysis (see online supplements).

Fuel Savings

For the purpose of calculating fuel savings bicycle trips of 3 miles or less are assumed to be utilitarian in nature, in other words replacing driving (the substitution of transit trips is assumed to be negligible). Fuel savings are calculated assuming a fuel economy of 20.2 miles per gallon between 1991 and 2006, which thereafter increases to 35 miles per gallon by 2030. Actual national average fuel prices are used for past years, and average predictions by the Energy Information Administration (www.eia.gov) are used for future years.

Results

Since 1991, Portland conducts annual counts of cyclists crossing bridges across the Willamette River. From 1991 through 2008 the number increased 5-fold at an exponential rate of 9.6% per year (R^2 for exponential trend line: 0.96). From 2006 to 2007 and from 2007 to 2008 growth was 22% and 14%, respectively (Figure 1).[23] The same trend is reflected in mode share figures, which increased from 1.8% in 1996% to 6.4% in 2008 (American Community Survey).[8] (The City of Portland provides somewhat higher figures based on its own survey showing a 3% mode share in 1997 and a recent spike to 8% in 2008.)[24]

This calculation is based on projected 3-, 4-, and 5-fold increases in miles bicycled by 2030, under 3 different investment plans, respectively.[12,13] The projections eventually plateau at 86, 116, and 145 million annual miles in 2030, respectively, as shown in Figure 3. By 2040 these will accumulate 2.2, 2.8, and 3.4 billion miles of bicycling, respectively, attributable to Portland's investments since 1991.

Developments of investment costs, health benefits, and net benefits (including fuel savings) are shown in Figure 4. Results of the analysis are summarized in Table 1.

Total values of investments in 2008 dollars of $138, $296, and $605 million are included in the calculation for the 3 plans, respectively, including $57 million in

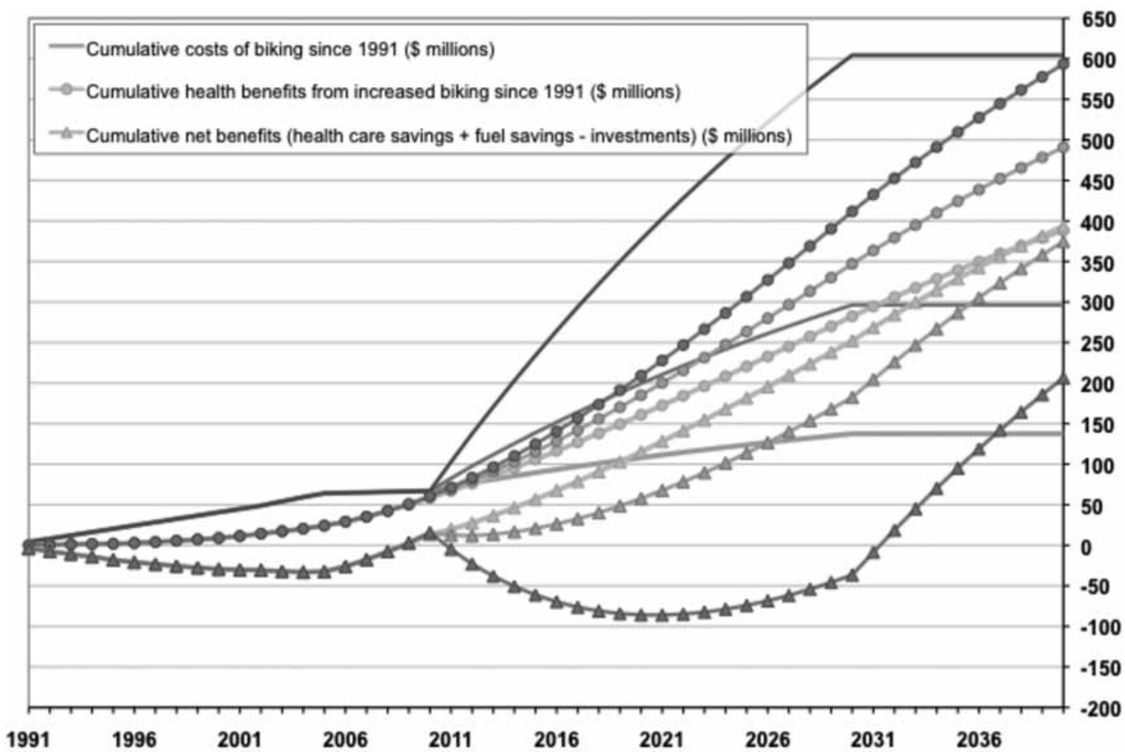

Figure 4 — Cumulative costs (solid lines), health care savings (dots), and net benefits including fuel savings (triangles) of 3 bicycle investment plans in Portland, 1991 to 2040.

Table 1 Key Figures and Results for 3 Investment Plans for Bicycling in Portland (Dollar Figures are in Millions of 2008 Dollars)

	Basic	80%	World Class
Investment costs (after discounting; incl. past)	$138	$296	$605
Projected mode share by 2030	15%	20%	25%
Max. annual bike miles (2030–2040)	86M	116M	145M
Max. daily bike trips (3km trip length)	60,000	80,000	100,000
Cumulative bike miles 1991–2040	2200M	2800M	3400M
Cumulative health care savings 1991–2040	$388	$491	$594
Cumulative fuel savings 1991–2040	$143	$180	$218
Cumulative net benefits 1991–2040	$394	$375	$207
Year to break even	2015	2015	2032
Annual lives saved (1991–2040 average)	42	55	68
Annual value of statistical lives saved (1991–2040 average)	$147	$196	$245
Cumulative value of statistical lives saved (1991–2040)	$7350	$9800	$12,250
Benefit-cost ratio for health care + fuel savings	3.8	2.3	1.3
Benefit-cost ratio for value of statistical lives saved	53.3	33.1	20.2

past infrastructure investments and $7.2 million in promotional efforts.

By 2008, cyclists have accumulated 109 million miles over the baseline level of 1991, equivalent to $42 million in health care savings and $16 million in fuel savings, or a net cost of $7.8 million.

By 2015, the investment costs and benefits will break even for the 2 cheaper plans. For the world class plan this will be the case in 2032.

By 2040, the miles bicycled for the 3 plans convert to a total of $388, $491, and $594 million in health care cost savings, respectively, as shown in Figure 4. Fuel savings amount to $143, $180, and $218 million, respectively (not shown.) Adding up health care savings, fuel savings, and investment costs, the net benefits will be $394, $375, and $207 million, respectively.

The increase in bicycling between 1991 and 2040 is equivalent to an average of approximately 60,000, 80,000, and 100,000 daily trips of 3km in length, for the 3 plans respectively, which using HEAT results is 42, 55, and 68 lives saved per year, respectively.

Benefit-cost ratios based on health care and fuel savings are 3.8, 2.3, and 1.3 for the basic, 80%, and world class plan, respectively. Using value of statistical lives saved, the benefit-cost ratios are 53, 33, and 20, respectively.

Discussion and Conclusions

The presented analysis shows that investments in bicycling are cost-effective, even for a limited selection of benefits. Crucial data, such as bicycle counts and modeled miles of bicycling, render a cost-benefit analysis for Portland's bicycle investments feasible, albeit with a number of uncertainties. Besides assumptions on investment costs and resulting levels of bicycling, the choice of method to quantify health benefits is particularly influential for the benefit-cost relationship.

The more relevant issues are discussed in the following sections.

Estimating Investment Costs

Building transportation networks is characterized by a nonlinear S-shaped return-on-investment curve, where early investments yield little, midway investments yield maximum, and later investments again yield less return per invested dollar.[25] The assumptions in this analysis suggest that the basic plan will benefit most strongly from earlier investments that built the base for a functioning network of bicycle facilities, yielding roughly 4 times the amount of bicycle miles traveled per invested dollar, compared with past investments. The 80% plan yields about twice as much, and the world class plan about the same, reflecting that the more expensive plans achieve levels of cycling where attracting even more people to bicycling comes at a steeper price. As such, these assumptions reflect an expected pattern, however, there is no method available to further substantiate the quantitative aspects of these assumptions.

Opportunity costs, typically assessed as the time needed to take advantage of the new opportunity, are not straightforward for bicycling. Although typical bicycling trips can be expected to take somewhat longer than driving trips they replace, one could argue that utilitarian bicycling saves time over exercising otherwise (eg, through sports). This analysis assumes that increases in bicycling stem from trips for which overall opportunity costs are close to 0.

This analysis does not take into account presumably small individual costs of bicycle ownership and maintenance, which to a large part flow back into the local economy.[26]

Estimating Increase in Bicycling

Portland provides a quasi-natural experiment with a long-term data record unique for a US city. Given the low baseline level in 1991 and the large, 5-fold increase in bicycle counts until 2008 it is fair to assume that there is a causal relationship between investments and the observed exponential growth in bicycling. What remains unknown is how much investment is needed to maintain this growth and at what point it will begin to taper off. European cities can serve as references for what mode share goals may be reasonable. Some Dutch cities achieve bicycle mode shares of 30 to 40%.[27] In Copenhagen, bicycling increased 4-fold between 1975 and 2005, to now more than 35% mode share.[28] In the US, such developments are unprecedented, and long-term mode shift goals are primarily a political statement and not a firm quantitative prediction. Portland`s long term goal is to increase bicycling to a mode share of over 25%, with the expectation that the 80% plan will bring the city close to that goal.[13] These planning goals are comparable to patterns observed in several European cities, which saw similar growth trends since the late 1970s and currently have bike mode shares of over 20%.[27,29–32]

The model estimations also translate into reasonable travel distances for individual cyclists. For 2005, the model predicts that trips of 3 miles or less amount to 17.6 million miles, which is equivalent to 5% of Portland residents (pop. 582,000) riding 1.6 miles per day. The 2040 estimate of 145 million miles (World class plan) is equivalent to 20% of Portland residents (pop. 800,000) riding for 2.5 miles per day. In a study of cyclists in Portland, Dill et al observed an average of 1.6 trips per day and a median trip distance of 2.8 miles.[15,33]

Estimating Health Benefits

Both methods apply a linear dose-response effect. While there is strong evidence for a linear effect of physical activity on mortality,[34] effects for other endpoints, including health care costs may be modified by health status and level of activity. Because the presented analysis is not based on individual data, such nonlinear effects, should they exist, could not be considered.

Similarly, it is unknown whether people who bike would not be equally active, would they not have the opportunity to bike. This analysis assumes that any increase in bicycling translates directly into an equivalent increase in physical activity.

A common concern is that the risk of injury or fatality in traffic crashes may outweigh long-term health benefits from bicycling. Several studies have shown that increasing levels of bicycling reduces individuals' risk of a crash, a phenomenon commonly referred to as "safety in numbers."[35] This same pattern has been observed in Portland for reported crashes and fatalities, for which rates dropped by roughly 50% between 1991 and 2006 (Figure 5). For a cost-benefit comparison, however, absolute crash figures are relevant. Fatalities fluctuated between 0 and 5 without a clear trend over time, and reported crashes fluctuated between 150 and 200 per year, with a very weak upward

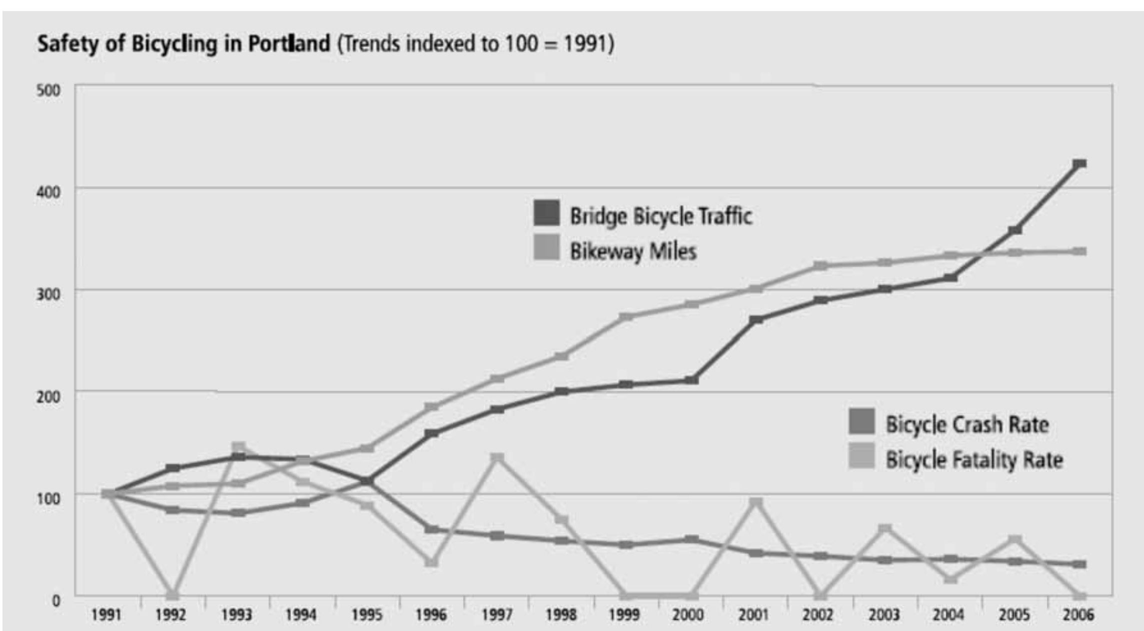

Figure 5 — Relative changes in bicycle traffic, bikeway miles, reported crashes, and cyclist fatalities in Portland from 1991 to 2006.

trend over time ($R^2 = .17$). Since no clear increase was observed over baseline levels, this calculation assumes that the absolute number of fatalities and crashes would not increase with investments in bicycling.

A similar dynamic applies to air pollution. While bicycling reduces pollution emissions overall, cyclists are potentially exposed to higher doses of pollution, because physical activity increases ventilation rates.[36,37] Health effects of air pollution were not considered in this analysis. Well-designed bicycle facilities, such as Portland's bicycle boulevards and trails allow cyclists to avoid air pollution hot spots along busy roads. In addition, a recent study showed that health benefits from bicycling clearly outweighed the risks of increased air pollution exposure among Dutch cyclists.[38]

Conceptually, HEAT addresses the traffic and air pollution issues by using all-cause mortality, which accounts for the risk of dying in traffic or from air pollution.

A criticism of HEAT is that the relative risk estimate derived in Copenhagen may not translate to other locations (eg, with different traffic risk or air pollution levels.) However, Matthews et al report risk reductions for cycling among women in Shanghai of very similar magnitudes, providing assurance that this effect may be fairly location independent.[39]

Monetizing Health Benefits

Monetizing health benefits from bicycling, or physical activity for that matter is challenging. A report by Krizek et al reviewed estimates ranging from $19 to $1175 per capita (nominal values), although these estimates include different cost components (some only hospital bills, some loss in productivity).[17] For the purpose of this analysis, 3 studies were deemed best suited to describe the benefits from bicycling,[18–20] even though they are based on rather crude estimates of health care savings from physical activity in general. After adjustment for inflation their estimates for health care cost savings were $305, $421, and $907 for an active person, compared with an inactive one, providing a sense for the uncertainty of these measures.

The HEAT approach, on the other hand, uses the value of a statistical life to monetize the reduction in mortality resulting from bicycling. Value of statistical life figures are based on willingness-to-pay and occupational risk studies, and as such do not directly reflect actual expenses or savings. The figures are regularly updated,[9] and vary widely from country to country.[40] Value of statistical life is widely used in the assessment of transportation projects (eg, highway safety improvements,)[41] and should be interpreted as a relative measure with the primary purpose to make alternative projects comparable with regards to their effects on mortality.

As such, the 2 presented methods quantify fundamentally different aspects of health benefits and the substantial differences in results should not come as a surprise. The relevance of either findings strongly depends on the context the results are being used in.

In the past, health care costs have increased faster than other consumer goods. By assuming that health care costs will increase at a rate 3 percent higher than inflation, health care savings from bicycling would increase by $300 to $400 million by 2040.

Outside of the actual calculation, the major limitation of this analysis is the purely opportunistic selection of benefits, which does not include a number of other benefits attributable to bicycling. For example, by 2040, bicycling in Portland will have avoided between 540 and 830 million metric tons of CO_2. The millions of miles traveled by bike reduce road and parking capacity demand, which is much more costly to provide for cars than for bikes.[42] Several studies show increases in property values in the vicinity of bicycle facilities.[43–46] Bicycling is also an ideal access mode to transit,[47] and key to the success of smart growth or mixed-use development.[48]

In conclusion, even the narrow selection of health care cost savings and fuel savings over time alone justifies investments in bicycling infrastructure and promotion, yielding benefit-cost ratios between 3.8 and 1.2 to 1. Accounting for lives saved from a reduction in mortality using value of statistical life, as is commonly done for transportation projects, dramatically increases the benefits-cost ratio. Including additional, less easily monetizable benefits would further bolster the economic case for investments in bicycling.

Online Supplements

Parameters for the HEAT for Cycling calculation.

The Health Economic Assessment Tool for Cycling can be downloaded here: www.euro.who.int/HEAT.

The parameters used in this calculation are

Number of Trips per day (rounded; projected average annual miles of bicycling divided by 365 and a trip length of 3km):

- Basic Plan: 60,000
- 80% Plan: 80,000
- World Class Plan: 100,000.

Average trip distance: 3km.

Number of days cycled per year: 365 (the analysis is based on annual estimates).

Proportion of return trips: 0 (not applicable to the network wide estimates from the transportation model).

Proportion who would not otherwise cycle: 0. (The analysis subtracts the baseline level of bicycling as the proportion of people who do not cycle because of the investments, and assumes that all increase there after is attributable to the investments.)

Mortality rate for the US working population: 0.0034.

Value of life: 5,800,000 (ignoring currency).

Discount rate: 3%.

Present value of mean annual benefits (to derive benefit cost ratios these values are multiplied by 50 years):

- Basic Plan: $147,259,000
- 80% Plan: $196,346,000
- World Class Plan: $245,432,000

Number of lives saved per year:

- Basic Plan: 41
- 80% Plan: 55
- World Class Plan: 69

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