Spinning the Wheels and Rolling the Dice: Life-Cycle Costs and Benefits of Bicycle Commuting in the U.S.

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Abstract

Objective. We assess average net longevity benefits of bicycle commuting in the U.S.

Methods. We construct age-specific fatality rates per distance bicycled or driven using denominators from the 2009 National Household Travel Survey and numerators from official fatality statistics. We model the impact on the life table of switching from car to bicycle commuting.

Results. Bicycling fatality rates in the U.S. are an order of magnitude higher than in Europe. These costs follow an age pattern that punishes both young and old, while the health benefits guard against causes of mortality that rise rapidly with age. Although the protective effects of bicycling appear significant, it may be optimal for individuals to wait until later ages to initiate regular bicycle commuting or avoid it in the current U.S. risk environment, especially if individuals discount future life years.

Conclusions. The lifetime health benefits of bicycle commuting appear to outweigh the costs in the U.S., but individuals who sufficiently discount or disbelieve the health benefits may delay or avoid bicycling. Bicycling in middle age avoids much fatality risk while capturing health benefits. Significant cross-state variation in bicycling mortality risks suggest that safety

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improvements in the built environment might spur changes in transit mode.

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Introduction

Many studies suggest that physical activity improves cardiovascular and other dimensions of health and thus longevity (Berlin and Colditz, 1990; Paffenbarger, Jr. et al., 1993; Blair et al., 1995; Lee et al., 1995; Lee and Paffenbarger, Jr., 2000; Warburton et al., 2006), and there is interest in encouraging health through active transport (Edwards, 2008; de Hartog et al., 2010; Oja et al., 2011; Fraser and Lock, 2011; Rabl and de Nazelle, 2012; Stipdonk and Reurings, 2012; Rutter et al., 2013; Dill et al., 2013). Two prospective cohort studies show that bicycling is associated with significantly reduced mortality (Andersen et al., 2000; Matthews et al., 2007), while two others are inconclusive (Tanasescu et al., 2002; Besson et al., 2008). The World Health Organization has embedded the estimates of Andersen et al. (2000) in its Health Economic Assessment Tool (HEAT), and recent years have brought bicycle sharing plans to several world cities (Rojas-Rueda et al., 2011), including most recently New York City, where the plan was partially motivated by the health benefits (NYC Dept. City Planning, 2009).

Bicycling involves greater exposure to traffic fatalities, and how these costs compare to the benefits is unclear. An earlier study quantified the net effect of bicycling on longevity using Dutch statistics, and it found the benefits significantly outweighed the costs (de Hartog et al., 2010). But traffic fatality rates for both bicyclists and drivers tend to vary with geography. Here we compare costs versus benefits of bicycle commuting in the U.S., and we reassess the decision-making framework that is standard in this literature. Behaviors that maximize period life expectancy may be optimal for public health or well-being in one sense, but individuals might maximize the present discounted value of their future well-being. Because bicyclists must accept elevated risk of early death via traffic fatality in exchange for the promise of improved health and reduced mortality in later years, young commuters especially may decide the risks are not worth it. A secondary goal is to present and examine geographic patterns in U.S. bicycle fatality rates in order to provide context.

Methods

We construct death rates by mode per distance traveled by combining numerators from data supplied by the National Highway Traffic Safety Administration (NHTSA) with denominators of person miles biked or driven estimated from the 2009 National Household Travel Survey (NHTS) of 26,000 U.S. households. Our state-level analysis of fatality rates are weighted using midyear state population estimates for 2009 from the U.S. Census Bureau. We estimate the protective effects of bicycling on mortality using the results of previous studies.

Traffic fatalities

Our numerators are annual traffic fatalities by type, age, and state drawn from the 2009 microdata distributed through NHTSA. We omit pedestrian fatalities and focus on occupants of motor vehicles, including motorcycles, and on bicyclists. Fatality statistics from a single year can be noisy for a mode as rare as bicycling, but we found no differences when averaging multiple years.

Person miles traveled

Our denominators are annual person miles traveled either by bicycle or by person occupied vehicle, omitting public transit. Defining exposure as a person trip produced similar results. We extracted representative statistics for person miles traveled by mode, age, and state of residence from the 2009 NHTS. In our state-level analysis we weight by population. In our national analysis, we smooth the data on miles bicycled by age with a kernel density estimator, holding total miles ridden constant. Smoothing did not substantially affect results.

Reduced mortality through improved health

Much research associates physical activity with improved health and reduced mortality (Berlin and Colditz, 1990; Lee et al., 1995; Lee and Paffenbarger, Jr., 2000; Kahn et al., 2002; Warburton et al., 2006). Four longitudinal cohorts studies consider bicycling: Andersen et al. (2000), Tanasescu et al. (2002), Matthews et al. (2007), and Besson et al. (2008). Of these, the first and third find statistically significant protective effects. All are observational in nature and unable to control for unobservables that might jointly determine health and bicycling.

Andersen et al. (2000) estimate the relative risk for all-cause mortality among commuting bicyclists at 0.72, and that is the most widely cited result, incorporated by WHO into its HEAT tool for example. We view the evidence as supportive of such an effect only on mortality at older ages, and not at younger ages when external causes are far more important. In the Andersen et al. study, the empirical relationship was not statistically significant for women aged 20–44, and it was not robust among men of those ages. Physical activity is protective against cardiovascular disease, ischemic stroke, type-2 diabetes, colon cancer, osteoporosis, depression, and fall-related injuries (Kahn et al., 2002), and few to none of these are major causes of death at younger ages. Table 1 lists shares of deaths by major underlying cause between ages 20–64 in the U.S. in 2009. More than half of young deaths are attributable to accidents or homicides, which exercise cannot plausibly reduce. There is an abrupt shift in causes at age 45 when cancer and heart disease begin to account for the majority of deaths. Thus we believe any protective effects of bicycling on mortality under age 45 are negligible, and in our preferred scenario we model reductions in all-cause mortality by 28% starting at age 45.

Table 1: Major causes of death in the U.S. in 2009

	Percent of deaths due to:				Heart	
Age	Accidents	Homicides	Suicides	Cancer	disease	Other
20–24	40.5	15.6	14.3	5.2	3.7	20.7
25–34	33.1	9.9	12.5	8.6	7.5	28.4
35–44	20.2	3.7	8.9	16.8	14.8	35.5
45–54	10.6	1.1	4.6	27.0	19.7	37.0
55–64	4.3	0.3	1.9	35.2	22.2	36.1

Notes: Data are deaths by underlying cause for both sexes combined reported by Heron (2012) and augmented with the CDC WONDER online database.

Results

Fatality rates by age

Table 2, which we present for comparison to Table 4 in de Hartog et al. (2010), lists fatality rates by age and travel mode per billion passenger kilometer traveled in the U.S. in 2009 and their ratios. Traffic fatalities are more prevalent in the U.S. overall, and the added risk associated with bicycling rather than driving is much higher in the U.S., especially at ages under 50. The ratio of the bicycling fatality rate to the driving fatality rate never dips below 2.9 at ages 25–29, when auto fatalities are near their peak. At older working ages, that ratio rises above 10. In the Dutch data, bicycling is *safer* than driving between ages 15 and 30, and only after age 60 does the relative risk approach the levels we see here. Although the ratios of fatality risks at older ages appear to converge across countries somewhat, the absolute fatality risk associated with bicycling in the U.S. remains consistently higher by an order of magnitude. Dutch bicyclists in their 30s suffer 3.9 deaths per billion km according to de Hartog et al., while their U.S. counterparts face between 25.1 and 32.8 here.

Fatality rates across states

These data also reveal much geographic variation in distance bicycled and in fatality rates, and a familiar correlation between the two that provides additional context. In Figure 1 we plot the logarithm of bicycle fatality rates per billion km for all ages by state against the log of annual bicycle km per capita. There is a significant downward slope elasticity equal to -0.86 (t-stat of -8.33), and the R^2 is 0.62. This elasticity is near the high end of the spectrum of previous estimates (Elvik, 2009), and this relationship has sometimes been cited as evidence of "safety in numbers," albeit controversially (Jacobsen, 2003; Stipdonk and Reurings, 2012; Wegman et al., 2012). There is also a positive and statistically significant relationship between bicycle and automobile fatality rates. This relationship is depicted in Figure 2 where the elasticity is 1.33 (t-stat of 3.77). Although the model fit is not strong (R^2 = 0.25), it suggests common causes for both fatality rates: the climate, the built environment, speed limits, prevalence of drunk driving, or other characteristics. Although unrelated to our nationwide average estimates of the costs of bicycle commuting, these patterns reveal how and potentially why the costs and the decisions vary across space.

Longevity effects of bicycle commuting

Increased fatality risk

We model bicycle commuting as the substitution of a 6-mile (10km) daily round-trip bicycle commute during 5 days each week over 50 workweeks for an equivalent set of commutes by auto. Using number of trips in place of

Table 2: Rates of traffic deaths per billion person kilometer in the U.S., 2009

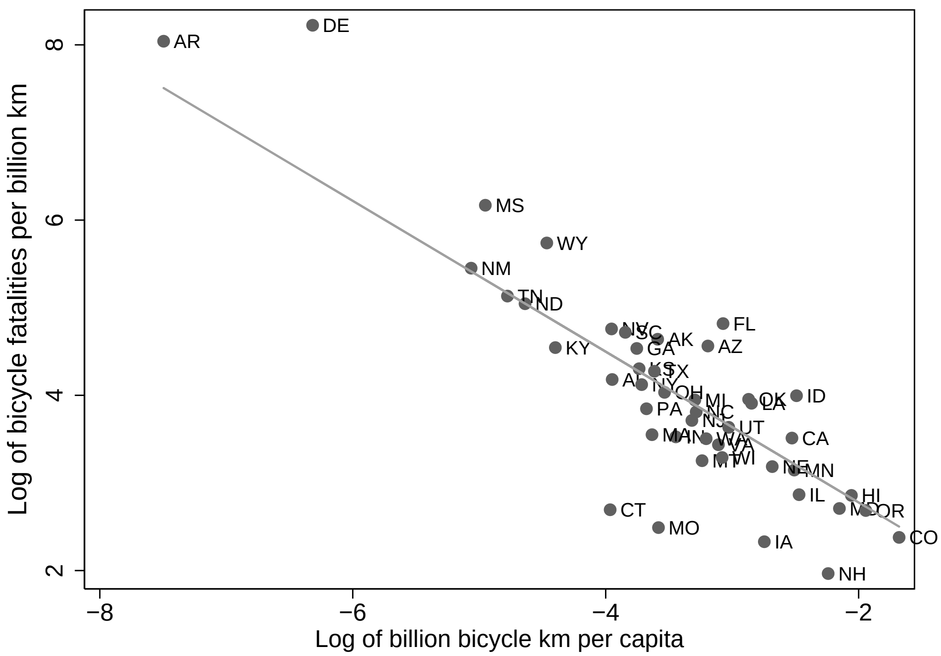
Age	Bicycle	Auto	Ratio
5–9	19.0	1.3	14.5
10–14	47.6	1.4	32.9
15–19	41.1	7.9	5.2
20–24	33.5	11.3	3.0
25–29	32.2	11.2	2.9
30–34	25.1	5.3	4.7
35–39	32.8	3.9	8.3
40–44	43.5	3.0	14.3
45–49	55.1	5.0	11.0
50–54	52.9	4.5	11.7
55–59	60.5	3.8	15.8
60–64	76.7	4.1	18.9
65–69	97.5	5.0	19.4
70–74	80.9	6.6	12.3
75–79	165.9	8.3	19.9
80–84	357.9	15.8	22.6
ages 5+	44.7	5.5	8.2
ages 20–64	43.0	5.2	8.2

Notes: Statistics are for both sexes combined. Numerators are drawn from NHTSA fatality statistics for 2009. Denominators are converted from annual million person miles traveled by mode in the 2009 NHTS, smoothed over single years of age as described in the text.

distance did not significantly alter the results. While 6 miles (10km) is a relatively short commute by American standards, 25% of commutes in the 2009 NHTS were shorter.

Table 3 shows the net effects of this bicycle commuting regimen on age-specific mortality rates due to traffic fatalities. This part of the exchange is always prima facie unfavorable because bicycling is more hazardous than driving, but it is particularly disadvantageous for younger commuters. At younger ages, the absolute increase in mortality associated with bicycling is higher relative to baseline mortality because the latter is much lower than at older ages. Commuters in their 20s face an increase in their mortality rates

Figure 1: Log bicycle fatality rate as a function of log bicycle km per capita, U.S. states in 2009



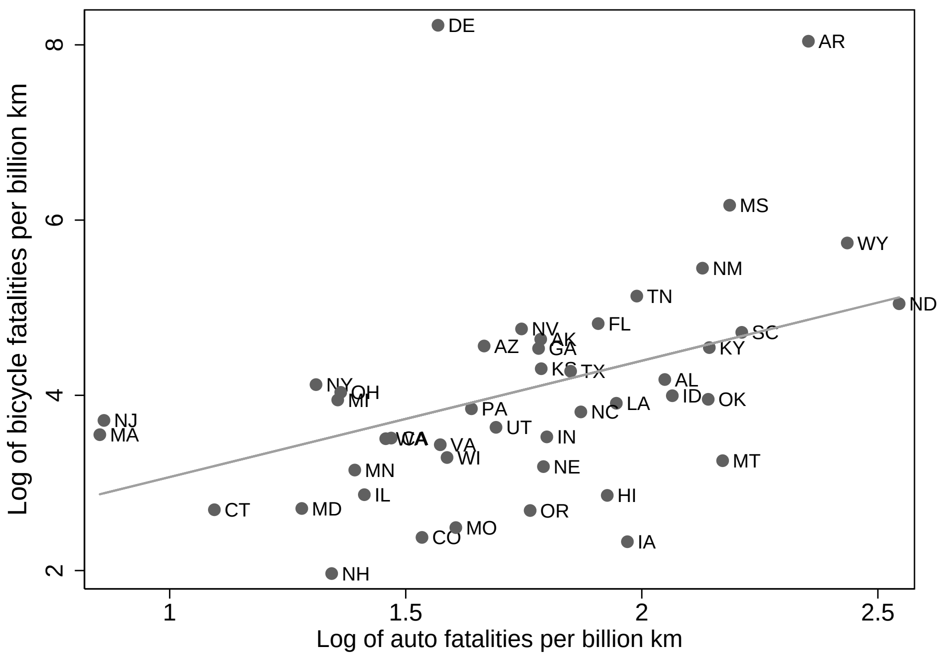
Notes: See notes to Table 2. The regression line shown is estimated by weighted least squares using state populations as weights.

by 5–6% if they switch to bicycling, while older commuters face increases of more like 3–4%.

Net effects on the life table

Because the protective effects of exercise on mortality rates are proportional, their approximate impacts on life years lived can be additively separated from the underlying effects of increased fatality risk (Vaupel and Canudas-Romo, 2003) and are depicted across the columns of Table 4. The first column shows life years lived by age interval at baseline. The sum of this column, shown at bottom, is period life expectancy at birth. The second column depicts reductions in life years associated with increased traffic fa-

Figure 2: Log bicycle fatality rate as a function of log auto fatality rate, U.S. states in 2009



Notes: See notes to Table 2. The regression line shown is estimated by weighted least squares using state populations as weights.

talities, and the sum of this column is the gross reduction in life expectancy. The third column displays gains in life years associated with a relative risk of 0.72 in all-cause mortality starting at age 45, and as an addendum, the fourth column shows the additional life years gained if the protective effects also operated between ages 20 and 44.

Table 4 reveals that the excess fatality hazard associated with bicycling reduces life expectancy by 0.138 year or 50 days, an order of magnitude larger than the reductions estimated by de Hartog et al. (2010). This result is unsurprising given relative rates of traffic fatalities. It is noteworthy that the negative impacts of elevated fatality risk on life years lived are persistent through age even though the fatality risk itself is not, because present and

Table 3: Net effect of commuting mode switch on 2009 U.S. fatality rates per 100,000

Age	Bicycle commuting	No auto commuting	Sum	Baseline death rate	Percent change
20–24	8.1	−2.7	5.4	88.0	6.1
25–29	7.8	−2.7	5.1	98.0	5.2
30–34	6.1	−1.3	4.8	111.0	4.3
35–39	7.9	−0.9	7.0	144.0	4.8
40–44	10.5	−0.7	9.8	214.0	4.6
45–49	13.3	−1.2	12.1	335.0	3.6
50–54	12.8	−1.1	11.7	506.0	2.3
55–59	14.6	−0.9	13.7	716.0	1.9
60–64	18.5	−1.0	17.5	1,035.0	1.7

Notes: Rates are for both sexes combined. As described in the text, we assume a 6-mile (10km) round-trip commute, 5 days per week for 50 weeks. The baseline mortality rate is for all causes of death and is provided by the Human Mortality Database (2013).

future life years cannot be lived by the dead.

Our preferred estimate of the health benefits associated with bicycling is 0.847 life year, shown at the bottom of the third column in Table 4. If the relative risk of 0.72 were to apply starting at age 20 rather than 45, which we view as implausible, then the additional life years shown in the fourth column, which sum to 0.415, would bring the total benefit to 1.262 life years, closer to other estimates in the literature.

It is helpful to identify the minimum health benefit associated with bicycling that would make the choice to commute by bicycle worthwhile in terms of expected life years. We find that a 5% reduction in mortality starting from age 45 is sufficient to offset the negative effect on life expectancy caused by bicycle commuting, which is below the lower bound reported by de Hartog et al. (2010) in their review of the literature.

Effects of discounting

Figure 3 graphs the percent gain in discounted life years and the discount rate under four different assumptions about the timing and intensity of the protective effects of bicycle commuting. Three of the four trajectories are

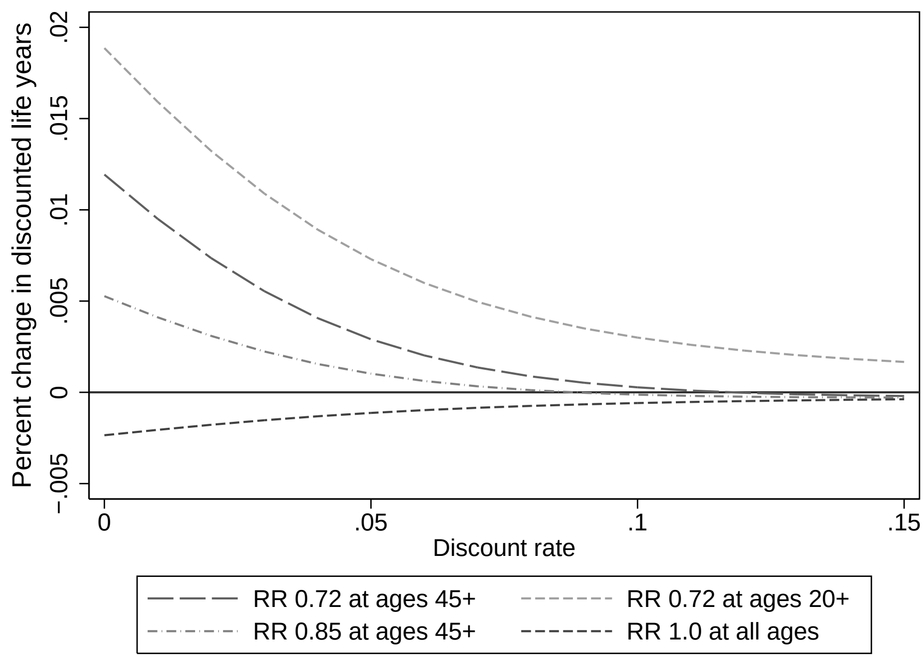
Table 4: Effects of bicycle commuting on the 2009 U.S. life table

Age	Life years lived at baseline	Change in life years due to: Excess bicycling mortality	Health benefits from 45	Health benefits 20–44
0–1	0.994	0.000	0.000	0.000
1–4	3.971	0.000	0.000	0.000
5–9	4.960	0.000	0.000	0.000
10–14	4.957	0.000	0.000	0.000
15–19	4.950	0.000	0.000	0.000
20–24	4.932	−0.001	0.000	0.003
25–29	4.909	−0.002	0.000	0.009
30–34	4.883	−0.003	0.000	0.016
35–39	4.853	−0.004	0.000	0.025
40–44	4.810	−0.006	0.000	0.037
45–49	4.746	−0.009	0.010	0.044
50–54	4.648	−0.011	0.037	0.043
55–59	4.509	−0.014	0.075	0.042
60–64	4.319	−0.017	0.125	0.041
65–69	4.051	−0.018	0.150	0.039
70–74	3.681	−0.016	0.136	0.035
75–79	3.167	−0.014	0.117	0.030
80–84	2.487	−0.011	0.092	0.024
85–89	1.658	−0.007	0.061	0.016
90–94	0.828	−0.004	0.031	0.008
95–99	0.264	−0.001	0.010	0.003
100–104	0.046	0.000	0.002	0.000
105–109	0.004	0.000	0.000	0.000
110+	0.000	0.000	0.000	0.000
sum	78.628	−0.138	0.847	0.415

Notes: Statistics are for both sexes combined. As described in the text, we assume a 6-mile (10km) round-trip commute, 5 days per week for 50 weeks. Person years lived in the baseline are provided by the Human Mortality Database (2013). Excess bicycling mortality is depicted in Table 3. The health benefits of cycling is a 28 percent reduction in the all-cause mortality rate, a relative risk factor of 0.72 per Andersen et al. (2000). We apply the relative risk starting at age 45 in the third column. In the fourth column, we present the additional life years lived had the relative risk been applied starting at age 20 concomitant with bicycling.

downward sloping; an increase in the discount rate typically reduces the attractiveness of bicycling because gains further in the future are worth less. The fourth trajectory, in which there are no health benefits of bicycling, is upward sloping but never positive because bicycling is never good.

Figure 3: Percent gain in discounted life years due to bicycle commuting as a function of the discount rate and parameters



Notes: Each trajectory shows the percent gain in discounted life years associated with a switch from auto to bicycle commuting at age 20 under various assumptions about the relative risk (RR) of all-cause mortality associated with bicycling and the age at which the protective effect begins.

Two trajectories cross the axis, at which point bicycling would not increase the sum of discounted life years. For our preferred scenario in which the relative risk is 0.72 from age 45, the break-even discount rate is 12%. If the relative risk is 0.85 starting at age 45, the break-even discount rate falls to 9%. On the other hand, if the relative risk is 0.72 and applies starting from age 20, there is no break-even discount rate; it is always optimal to bicycle because the protective effect dominates the increased fatality risk.

Discussion

The longevity effects of bicycle commuting are complex because costs and benefits vary by age. Costs weigh more heavily early in the life cycle, when accidents are the primary cause of death, while the benefits of increased exercise will be enjoyed later in life, when cardiovascular and other chronic diseases are most deadly. If individuals discount future life years, this complexity becomes particularly salient.

Bicycling is dangerous in the U.S., where fatality rates are an order of magnitude higher than in the Netherlands and other more bicycle-friendly countries. Driving is also more dangerous in the U.S., but the substitution of bicycling for driving still substantially elevates the risk of accident mortality across all adult ages.

If we believe that the protective effects of enhanced health due to bicycling are anywhere near those observed in prospective cohort studies, these positive effects on life expectancy will outweigh the negative effects of increased accident mortality risk. The catch is that the benefits are longer-term in nature than the costs, which are immediate. We argue that bicycling cannot substantially lower mortality rates before age 45, when deaths are primarily due to external causes, and the empirical evidence supports this.

Delayed receipt of the benefits until later in life could tip the scales away from bicycling especially for younger commuters. Under large but empirically reasonable rates of time discounting around 10% (Viscusi and Moore, 1989; Redelmeier and Heller, 1993), rational individuals may not be willing to trade away traffic safety now in exchange for improved health later, even if it raises the undiscounted sum of life years. This may be controversial in the public health domain, where a focus on undiscounted life expectancy is more typical. Health economists are interested in patterns of individual choice, which in the case of commuting mode may reflect time discounting or other tastes or perceptions.

In addition to the mechanical point that the benefits of bicycling are delayed in time, another issue is that they may be inherently uncertain. If they are, or if they are perceived that way, individuals may choose not to bicycle because of risk aversion in one form or another. As discussed by Edwards (2012), a positive rate of time discounting alone implies some degree of risk aversion over gambles in length of life. Switching from driving to bicycling is a gamble because it reduces probability-weighted life years at younger ages in exchange for increases at older ages. Bommier (2006) argues there is stronger risk aversion than implied by time discounting alone, which could tilt decisions further away from bicycling. However likely they may be perceived, the benefits are reductions in causes of mortality that are most relevant at older ages, and as such are the longest of long-run benefits that most individuals consider. It is easy to see how bicycle commuting may not be a popular choice early in the life cycle.

Our analysis suggests that waiting until older ages to commute by bicycle is a good strategy because the benefits rapidly eclipse the costs. This insight contrasts starkly with the recommendations of (Stipdonk and Reurings, 2012) based on Dutch data that younger individuals switch to bicycling. The difference may stem from a focus on the total number of fatalities in a geographic area rather than on the life table.

Our study has many limitations. We model the costs and benefits of bicycling without any acknowledgment that exercise and lifestyles may need to be habitual and longer-term in order to improve health. Bicycle-related traffic hazards and health benefits might differ for habitual cyclists. It could be riskier to initiate bicycle commuting at older ages.

State-level fatality hazards in the U.S. suggest room for improvement in reducing the risk of early death by bicycle or auto accident. Aggregate patterns in the cross section support the notion that there is a correlation between bicycle safety and "numbers," but we believe this reflects how individuals are more likely to choose bicycling when hazards are lower. It is striking that states with high auto fatality rates also suffer high bicycle fatality rates, a subject worthy of further investigation.

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The authors declare that there are no conflicts of interest.

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