Moving urban trips from cars to bicycles: impact on health and emissions

Abstract

Objective: To estimate the effects on health, air pollution and greenhouse gas emissions if short trips (≤7 km) were undertaken by bicycle rather than motor car.

Method: Existing data sources were used to model effects, in the urban setting in New Zealand, of varying the proportion of vehicle kilometres travelled by bicycle instead of light motor vehicle.

Results: Shifting 5% of vehicle kilometres to cycling would reduce vehicle travel by approximately 223 million kilometres each year, save about 22 million litres of fuel and reduce transport-related greenhouse emissions by 0.4%. The health effects would include about 116 deaths avoided annually as a result of increased physical activity, six fewer deaths due to local air pollution from vehicle emissions, and an additional five cyclist fatalities from road crashes. In economic terms, including only fatalities and using the NZ Ministry of Transport Value of a Statistical Life, the health effects of a 5% shift represent net savings of about $200 million per year.

Conclusion: The health benefits of moving from cars to bikes heavily outweigh the costs of injury from road crashes.

Implications: Transport policies that encourage bicycle use will help to reduce air pollution and greenhouse emissions and improve public health.

Key words: Air pollution, bicycles, climate change, environmental health, greenhouse gases, injury, mortality, physical activity, transport.

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Climate change has been described as the biggest global health threat of the 21st Century.[1] The potential health effects are numerous and include changing ranges of vector-borne diseases, malnutrition and increased diarrhoeal diseases.[2] Rising global temperatures are expected to bring increases in extreme events such as heat waves, drought and storms.[3]

Stabilising the world's climate will require deep cuts in greenhouse emissions.[3-6] How these cuts are made will be very important for human health. Effects may be negative (such as hunger resulting from substituting biofuels for food crops), or positive (for example, less disease due to air pollution if energy generation shifts from coal to cleaner technologies). A key challenge in the future is to meet the basic health and wellbeing needs of the large section of populations in developing countries that are currently living in 'energy poverty' while protecting the environment and human health.[7,8]

In high income countries like New Zealand, a 'wedge' approach, including reductions in emissions from all sectors, from multiple sources, will be required to make a fair and effective contribution to managing the risk of destructive climate change.[9] High levels of consumption are a key factor in driving New Zealand's very high per capita emissions.[10] The challenge is to change the nature of the goods and services we consume and the activities we undertake.

Transport is one area where change is possible and provides a good example of the opportunities for positive synergies between the environment and health. This sector is one of the fastest growing greenhouse emitters in many countries, including New Zealand,[11] and transport policies affect health in many ways.[12]

We describe here an assessment of the health and emissions effects of a transport mode shift that favours active transport over car trips. In New Zealand, bicycles are now seldom used for utility purposes such as commuting. Overall, bicycling made up about 1% of all trips in this country in 2003-07[13] compared to 3.6% in 1989/90.[14] In contrast, some northern European countries have rates of 20-30%.[15,16] Around 1.9% of New Zealanders cycled to work in 2006, about a third the level seen 20 years ago.[17]

In an urban setting, the distances travelled by drivers and passengers in light vehicles are generally relatively short and potentially amenable to be transitioned to other modes of travel. According to urban adult (ages 18-64) data from the 2003-06 New Zealand Household Travel Survey (NZHTS), 27% of vehicle trips were 2 km or less, 59% 5 km or less and 70% 7 km or less (authors' analysis).[18]

This paper presents the impact of increasing the proportion of urban kilometres travelled by bicycle instead of private motor vehicle on health and other parameters: vehicle air pollutants, greenhouse gas emissions and fuel consumption; vehicle-related air pollution deaths and morbidity; deaths and non-fatal injuries experienced by cyclists as a result of road crashes; and mortality benefits attributable to increased levels of physical activity. In addition, the potential energy expenditure associated with increased levels of cycling was estimated. In order to undertake these analyses, a number of modeling tools were drawn on. Assumptions and limitations of our approach will be discussed as well as policy implications.

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Methods

The morbidity, mortality, vehicle pollutant and greenhouse gas emission effects of changing trips from cars to bicycles are not comprehensively covered by a single modelling instrument, therefore we have used a number of existing tools to capture these effects. We sought models that are relevant to the New Zealand setting and could be readily populated with local data. The New Zealand Household Travel Survey[18] was the starting dataset and this enabled light vehicle kilometres travelled in urban areas to be calculated and converted to cycling kilometres. Data from other models expressed on a per kilometre basis enabled the potential health and emission effects from moving light vehicle kilometres to cycling to be calculated. Economic values are in New Zealand dollars ($NZ). The data sources and methods for assessing the impacts of the transition from vehicles to cycling are outlined below:

New Zealand Household Travel Survey (NZHTS)

The 2003-06 NZHTS data[18] on light vehicle driver/passenger vehicle kilometres travelled (VKT) were restricted to adults aged 18-64 years; "urban areas" (population centres with populations ≥10,000); and short distance trips (defined as those 7 km or less). The NZHTS provided information on trip purpose, distance and average speeds. Recreational cycling and trips for employer purposes were excluded from this analysis. The distance of 7 km was chosen as this is approximately the distance that can be covered in 30 minutes at the average cycling speed indicated in the NZHTS data, and the majority of car trips for adults in the NZHTS were 7 km or less.

Vehicle emission and greenhouse gas calculations

Data from the VEPM (Vehicle Emissions Prediction Model) version 2.3[19] were used to calculate average light vehicle emissions per km for carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), volatile organic compounds (VOC), exhaust particulate matter ≤10 μm (PM_{10}), brake and tyre PM_{10}, and fuel consumption.

As the VEPM model did not produce data for methane and nitrous oxide (N_2O), two potent greenhouse gases that are present in motor vehicle exhausts, emission factors[20] were applied to the fuel consumption to calculate the total greenhouse gas load. Greenhouse gas emissions were converted to CO_2 equivalents (CO_2eq) using recognised conversion factors.[21]

Application of Health and Pollution in New Zealand (HAPiNZ) study vehicle air pollution findings

The HAPiNZ study is the most comprehensive analysis of air pollution that has been conducted in New Zealand.[22] HAPiNZ estimated the morbidity, mortality and health costs associated with domestic, road vehicle and industrial emissions for people aged 30 years and over living in 67 urban areas in 2001. The study areas covered 2.7 million people or 73% of the New Zealand population (as of the 2001 Census).

HAPiNZ estimated that vehicle-related air pollution caused about 500 deaths annually, as well as several hundred admissions to hospital and almost 700,000 restricted-activity days, with conservative cost estimates at approximately $500 million annually. The dose-response relationships of air pollutants used in the HAPiNZ study were based on the international literature and have been used by many other countries (see study for details). The authors noted that these relationships may be conservative. Vehicle kilometres travelled per square kilometre was found to be the best predictor of air pollution and used as the key component in the HAPiNZ study regression analyses. We considered it valid to assume that the number of health events and costs of vehicle emissions are related in a linear fashion to motor vehicle kilometers travelled (personal communication with Simon Hales, a HAPiNZ principal author). On this assumption, we converted the reported HAPiNZ health events and costs to a per kilometre basis (based on the estimated 19,792,242,010 vehicle kilometres travelled across the urban areas studied in the HAPiNZ model).

WHO HEAT (Health Economic Assessment Tool) for Cycling

HEAT was developed by the World Health Organization to estimate the reductions in mortality and resulting economic savings from increases in the prevalence of cycle commuting.[23] This Excel-based tool includes a relative risk of 0.72 for all-cause mortality for regular adult commuter cyclists, based on the findings of a large Danish prospective study[24] which controlled for age, gender, smoking, education, leisure time physical activity, Body Mass Index and other risk factors for chronic disease. Assumptions (based on the literature and expert consensus) in the HEAT model include a linear dose-response relationship between physical activity and mortality with no threshold for effect.[25]

The HEAT relative-risk of death calculations for cyclists are based on the local estimated level of cycling compared to that seen in the Danish study (3 hours per week for an estimated 36 weeks/year at an estimated speed of 14 kph).[26] HEAT was populated with New Zealand mortality rates;[27] average cycling speed and trip distance from the NZHTS; estimated trip frequency; and the Ministry of Transport's 2008 Value of Statistical Life ($3.35m),[28] to obtain estimates of reduced mortality and economic savings.

The following HEAT default assumptions were applied – a 1-year buildup of cycling levels, 5-year buildup of health benefits, benefits are averaged over 10 years, and a 5% discount rate is applied to future savings.

A phased approach was used to translate kilometres travelled by bicycle (instead of by car) into the proportion of the population fitting the HEAT criteria of 'cycle commuters'. Further details on this aspect of the analysis can be obtained from the authors.

HEAT was also used to compare the ethnic-specific mortality benefits for every 1,000 additional regular cyclists using Māori, Pacific peoples and all-New Zealand mortality rates.[27,29,30]

Cycling injury/death data and 'safety in numbers' calculations

One limitation of HEAT is that it does not include a 'safety in numbers' factor in its calculations. The literature on 'safety in numbers' concludes that cycling becomes relatively safer as the overall levels of cycling increase and, conversely, becomes less safe as levels decline.[31,32] For example, if a community doubles the level of cycling it is likely the total number of injuries to cyclists caused by collisions with motor vehicles will increase; however, the number will not double since the risk per cyclist reduces. Comparisons between countries and between cities suggest that a doubling in the prevalence of cycling is associated with approximately a 34% reduction in the death rate per km cycled.[31]

In the present study, motor vehicle versus cyclist mortality data and public hospital discharge injury data were obtained from the National Injury Query System.[33]

Incorporating the 'safety in numbers' estimate of a 34% reduction in fatal injury rate for a doubling of cycle usage, we calculated the effects on cycling injury/death numbers and rates per kilometre travelled with increased levels of cycling in the urban setting.

Estimating the energy expenditure with varying proportions of vehicle trips transitioned to commuter cycling

We explored a range of scenarios with regards to cycling speed and energy expenditure[34] for a typical weight New Zealand adult (aged 18-64 years).[35] Caloric intake was assumed to be unchanged. Increases in energy expenditure due to cycling were also expressed in terms of the equivalent amount of adipose tissue. Although some studies have failed to show an association between exercise and weight loss, a Cochrane review concluded that exercise alone resulted in a small but statistically significant decrease in weight.[36] The review also commented that a number of large studies have shown that physical activity may have a preventative role as activity is associated with reduced weight gain. Energy expenditure was also expressed as the equivalent number of items of common foods and beverages (not shown in this paper but available from the authors on request).

Results

We estimated the effects on health of using bicycles instead of light vehicles for varying proportions of short trips (≤7 km) for adults in urban settings in New Zealand (Table 1).

The health benefits heavily outweigh the costs of injury from road crashes, at all levels of substitution. Due to the effect of 'safety in numbers', the benefit:cost ratio tips even further in favour of cycling as the proportion of trips made by bicycle increases. For fatalities, in economic terms and using WHO HEAT present value of mean benefit, the benefit:cost ratio is 3:1 for 1% substitution, and over 40:1 when 30% of trips are substituted.

Table 1: Effects on health of moving short urban car trips (≤7 km) to cycling (annual): from 1% to 30% of vehicle km.

Parameter	1%	5%	10%	30%
Air pollution health benefits (based on HAPiNZ data)				
Reduced deaths	1.1	5.6	11.3	33.9
Reduced restricted-activity days	1,515	7,574	15,148	45,443
Reduced acute cardiac and respiratory admissions	0.6	2.8	5.6	16.7
Cost savings[a]	$1,116,500	$5,582,250	$11,164,500	$33,493,500
Motor vehicle versus cyclist injuries and fatalities (incorporating 'safety in numbers' concept)				
Hospital discharge rate per million km cycled	0.48	0.29	0.21	0.12
Discharges annually (number)	77.5	108.9	135.1	200.1
Cyclist fatalities per 100m km cycled	2.19	1.32	0.95	0.53
Cyclist fatalities annually (number)	3.5	5.0	6.1	9.1
Cost of fatalities (at VOSL of $3.35m)[b]	$11,813,500	$16,589,000	$20,587,000	$30,494,500
Mortality reductions from regular commuter cycling (WHO HEAT for Cycling estimates)[b]				
Annual reduction in deaths	20.5	116.5	165.3	716.2
Maximum annual benefit at steady state	$68,240,000	$390,640,000	$553,410,000	$2,399,590,000
Mean annual benefit	$51,250,000	$290,690,000	$389,400,000	$1,787,160,000
Present value of mean annual benefit (5% discount rate)	$36,780,000	$212,150,000	$300,360,000	$1,301,160,000
Energy expenditure[c]				
Total kilojoules expended over baseline resting metabolic rate (billion, rounded)	3.8	19.1	38.2	114.7
Body fat equivalent (kg, rounded)	101,000	506,000	1,013,000	3,040,000

Notes:

a) *Cost savings are based on the costs per health event used in the HAPiNZ study[22] and are savings to the New Zealand health system and economy. Cost savings are likely to be conservative as personal cost savings were not included in the HAPiNZ study. Indirect costs such as extra doctor visits and use of medication associated with air pollution events were not included. Also, some effects were not studied, or explicitly costed. For example, asthma cases; short-term effects and toxic effects; lower-level effects such as drowsiness, headaches, loss of attention and quality of life may not be included in the HAPiNZ restricted-activity day analysis.*

b) *VOSL = Value of Statistical Life (New Zealand Ministry of Transport's June 2008 value of NZ$3.35 million).[28] Cost of cycling fatalities and WHO HEAT for Cycling mortality savings calculated using this value.*

c) *Energy expenditure based on 4.0 MET scenario[34] for an average weight person aged 18-64 years (79.3 kg based on NZ Health Survey data)[35] and a 14 kph mean cycling speed (from NZHTS dataset).[18] One MET is the energy expenditure of a person while at complete rest. 1.0 MET was then subtracted to estimate energy expenditure over baseline. This resulted in an estimated 71 KJ / 17 kcal energy expenditure (equivalent to 1.9 gm potential fat loss per km cycled). Caloric intake was assumed to be unchanged. 1 kcal = 4.184 kJ; 1 MET = 1 kcal/kg/h = 4.184 kJ/kg/h. 37.7 KJ per gram of fat. The MET or metabolic equivalent is defined as the ratio of a person's working metabolic rate relative to the resting metabolic rate.*

The effects of a 5% shift in light vehicle kilometres travelled to cycling

The results of shifting 5% of vehicle kilometres in short trips to cycling are detailed here for illustrative purposes. A 5% shift would be consistent with the goal for walking and cycling in the current New Zealand Transport Strategy (30% of urban trips by walking and cycling by 2040),[37] and would return cycling to the levels seen in this country in the 1980s.

Each year, such a move would reduce vehicle travel by approximately 223 million kilometres and save about 22 million litres of fuel and $37 million in fuel bills (Table 2); 50,000 tonnes of CO_2 (about 0.4% of the total domestic road transport greenhouse emissions in 2007);[11] as well as reduction in other pollutants such as PM_{10} and volatile organic compounds.

Annually, the health effects (Table 1) would include 116 deaths avoided as a result of increased physical activity, 5.6 fewer deaths due to local air pollution from vehicle emissions, and an additional five cyclist fatalities from road crashes. In economic terms, and including only fatalities, the health effects would amount to net savings of approximately $200 million per year.

Increased use of bicycles could potentially play an important role in reducing the health effects of dietary energy excess – a 5% shift in short trips from cars to cycles would expend about 19 billion kilojoules, equivalent to around 500,000 kg of adipose tissue.

HAPiNZ vehicle-related mortality/morbidity/costs on a per km basis

We used data on the number of events and the distance travelled in the HAPiNZ study to calculate the number of vehicle air pollution health events on a per kilometre basis (Table 3).

The KNT or Kilometres Needed to Travel (analogous to the Numbers Needed to Harm concept) for one vehicle air pollution event was approximately 30,000 kilometres.

For every 100 million kilometres of vehicle travel there were an estimated 2.5 deaths due to vehicle-related pollution; 3,395 morbidity events, the large majority of which were restricted-activity days; and $2.5 million in associated health costs.

The annual costs of vehicle-related air pollution were approximately $500 m or $25 per 1,000 kilometres travelled.

Estimated mortality and economic benefits per 1,000 additional adult commuter cyclists in New Zealand using the Health Economic Assessment Tool for Cycling

The WHO HEAT for Cycling was run using its default values to estimate the mortality reduction and resulting economic benefit for every additional 1,000 regular commuter cyclists aged 20-64 years in New Zealand (Table 4).

The mean annual economic benefit to society from reduced mortality ranged from $1.05 to 1.81 million per 1,000 cyclists. The maximum annual benefit at steady state ranged from $1.50 to $2.69 per km cycled for each cyclist and $1,410 to $2,441 annually per cyclist.

The potential benefits for Māori were almost double that of the overall population, reflecting the significantly higher Māori baseline mortality rates. The benefits for Pacific peoples are in between all-NZ and Māori, which reflects the intermediate baseline mortality rates for Pacific peoples.

Discussion and conclusions

We find there are potentially substantial co-benefits, both health and environmental, if the bicycle replaces the car for short trips in urban settings in New Zealand. Health gains from regular cycling are greater for Māori and Pacific peoples, reflecting the higher baseline mortality rates in these groups. Reduction in air pollutants, greenhouse gases, vehicle travel and fuel savings are considerable.

The assumptions inherent in the modelling tools available mean that we can be fairly confident that the benefits of replacing car trips with cycling outweigh the harms. However, the size of the effects should be treated with caution, and we discuss some of the main limitations in the modelling below.

The estimates presented here are highly sensitive to the relative

Table 2: Fuel and vehicle emission annual savings from moving short urban car trips (≤7 km) to cycling: from 1% to 30% of vehicle km.

Parameter	1%	5%	10%	30%
Reduction in light vehicle km driven (million)	44.7	223.4	446.8	1,340.4
Fuel savings (litres)[a]	4,413,000	22,065,000	44,129,000	132,388,000
Fuel savings ($NZ)[b]	$7,413,000	$37,069,000	$74,137,000	$222,412,000
CO_2 (tonnes)[a]	10,033	50,167	100,334	301,001
CO_2eq (tonnes)[c]	10,735	53,676	107,351	322,054
Carbon monoxide (tonnes)[a]	290	1,449	2,898	8,695
NOx (tonnes)[a]	32	161	321	964
PM10 exhaust (tonnes)[a]	1.9	9.3	18.7	56.0
PM10 brake, tyre (tonnes)[a]	0.6	2.9	5.8	17.3
Volatile organic compounds (tonnes)[a]	19	95	189	568
Methane (tonnes)[d]	2.8	13.9	27.9	83.6
Nitrous oxide (tonnes)[d]	0.3	1.4	2.7	8.2

Notes:

a) VEPM 2.3 model light vehicle data used to calculate fuel, CO2, CO, NOx, PM10 and volatile organic compound emissions.[19]

b) Based on average price of petrol (91 octane, $1.75/L) and diesel ($1.12/L) for quarter 1, 2010;[49] and proportion of light vehicles that were petrol and diesel.[19]

c) CO2eq = Carbon dioxide equivalents. Calculated using the IPCC 2007 100-year Global Warming Potential factors (methane has 25, nitrous oxide 298, and carbon monoxide 1.9 times the warming compared of CO2).[21]

d) Methane and nitrous oxide calculations based on fuel emission factors for these gases.[50]

risk co-efficients for mortality and economic values associated with cycle commuting. It is possible that the 'safety in numbers' factor that we applied overestimated cycling injuries and deaths. For example, cycling levels in greater London increased by almost 110% from 2000 to 2008, yet the absolute number of cycle casualties was essentially unchanged over this period.[38]

The WHO HEAT for Cycling model applies a 28% reduction in deaths from all causes for regular commuter cyclists, based on a single study from Copenhagen, Denmark.[24] While physical environments differ between countries, it is likely that effects on mortality of achieving the levels of cycling seen in this study are realistic and generalisable across countries.[26] The level of all-cause mortality reduction seen in this study are consistent with the other large prospective study of commuter cycling (women commuter cyclists in Shanghai, China);[39] observational studies of the health effects of moderate physical activity of all types (20-30% reduction in mortality);[40-44] and a recent large systematic review and meta-analysis of physical activity that calculated that physical activity reduced all-cause mortality by 33% (95% CI 28-37%).[45]

We know of no relevant trials of different forms of commuting that confirm or otherwise the findings from observational studies. As observational studies are susceptible to uncontrolled confounding and bias, effect sizes tend to be over-stated.[46] In particular, selection bias is likely to exaggerate the observed differences between groups in the studies described. For example, early uptake of active transport interventions is likely to be by those who are thinner, fitter and younger than the general population.

The effects of air pollution on morbidity and mortality were limited by the HAPiNZ modelling to adults. However, the improvements in air quality of changing transport patterns would have potentially greater impacts on the respiratory morbidity and mortality of children, which have not been included. Our estimates of the benefit of improving air quality in this analysis are therefore likely to underestimate the true benefits.

Methods for placing a monetary value on human life and morbidity are contentious and complex. The 'value of a statistical life' approach was used in our study as this is frequently applied in the transport sector in New Zealand to guide priorities for investment in roading and other infrastructure projects. Other techniques could be used to quantify the economic impacts. Our results did not take into account potential years of life lost. The average age at death from bicycle crashes is less than the average age at death from cardiovascular disease and diabetes. If greater weight was given to deaths at young ages, then this would reduce

Table 3: HAPiNZ vehicle air pollution mortality, morbidity and costs recalculated on a per km basis.

Event	Number vehicle-related air pollution events[a]	KNT for one event[b]	Events per 100m km	HAPiNZ costs per event[c]	Annual costs	Cost per 100m km	Cost per 1,000 km
Mortality (for PM_{10}, NO_2)	414	47,807,348	2.1	$750,000	$310,500,000	$1,568,797	$15.69
Mortality (CO)	86	230,142,349	0.4	$750,000	$64,500,000	$325,885	$3.26
Bronchitis and related events	541	36,584,551	2.7	$75,000	$40,575,000	$205,005	$2.05
Acute respiratory admissions	163	121,424,798	0.8	$2,700	$440,100	$2,224	$0.02
Acute cardiac admissions	83	238,460,747	0.4	$3,675	$305,025	$1,541	$0.02
Cancer	22	899,647,364	0.1	$750,000	$16,500,000	$83,366	$0.83
Restricted-activity days	671,000	29,497	3390.2	$92	$61,732,000	$311,900	$3.12
Total	**672,309**	**29,439**	**3396.8**	**N/A**	**$494,552,125**	**$2,498,717**	**$24.99**

Notes:

a) *HAPiNZ vehicle-related air pollution annual events are for the 2001 population aged 30+ covered in the 67 urban areas in the HAPiNZ study.[22]*

b) *KNT = Kilometres Needed to Travel (analogous to Numbers Needed to Harm concept). Based on an estimated 19,792,242,010 vehicle kilometres travelled across the 67 urban areas studied in the HAPiNZ model.*

c) *Costs per event as used in HAPiNZ. The HAPiNZ authors argue that as the population in the centres studied has increased by 17% over the period 2001 to 2006, it can be reasonably expected that the number of events and therefore overall costs in 2006 were 17% greater than in 2001.*

Table 4: Mortality reduction resulting from increased levels of commuter cycling using the WHO HEAT for Cycling. Results presented per 1,000 commuter cyclists (aged 20-64 years), year, by ethnicity.

Parameter[a]	All-NZ	Māori	Pacific
Mean proportion of population aged 20-64 who die each year[b]	0.002410	0.004173	0.002987
Expected deaths per 1000 people aged 20-64 per year	2.4	4.2	3.0
Lives saved per year from regular commuter cycling	0.42	0.73	0.52
% reduction in mortality	17.5%	17.5%	17.5%
Mean annual benefit[c]	$1,050,000	$1,818,000	$1,302,000
Present value of mean annual benefit (5% discount rate)[c]	$765,000	$1,324,000	$948,000
Maximum annual benefit once in steady state[c]	$1,410,000	$2,441,000	$1,747,000
*Savings per km cycled per individual cyclist	$1.50	$2.59	$1.85
*Savings per individual cyclist per year	$1,410	$2,441	$1,747
*Savings per trip	$6.25	$10.82	$7.75

Notes:

a) *HEAT for Cycling defaults used: 4 km one-way trip, 14 kph mean speed, 124 days cycling per year, 90% return rate (i.e. 90% of cycling trips resulted in a return cycling journey)[23]*

b *Mortality rate calculated from mortality data (2002 to 2005 inclusive)[27,29,30] and estimated resident population data.[51]*

c) *Based on the Ministry of Transport's Value of Statistical Life, June 2008 value of $3.35m per life.[28]*

the size of the benefit resulting from the shift from cars to bikes.

Would commuter cyclists need to continue to ride into their 60s and 70s to experience the benefits reported here? Probably not, in our view – a longer history of cycling may be associated with steeper risk reductions, but in the Copenhagen cohorts (average age about 50 years), the 28% reduction in mortality applied to all individuals who recorded at baseline they were commuter cyclists. It is not reported how many maintained their cycling through the period of follow-up (mean 14.5 years), but it seems likely there was some attrition with time.

Future research

The modelling exercise we have undertaken raises a number of important research questions. Some of the assumptions and limitations relate to factors inherent in the datasets used, and others are a result of a need for further research. The following areas are suggested to address these limitations:

1. Expanding the modelling of mortality and morbidity in the HAPiNZ study to all age groups would enhance our ability to estimate the benefits to communities of improved air quality.
2. In order to gain a more complete picture of the health impacts, addition of other health conditions that may be influenced by cycling[47] and changing modes of transport are recommended. Physical activity is associated with decreased prevalence and severity of depression, for instance.[48]
3. The analysis undertaken in this research is easily transferable to an analysis of changing very short car trips (less than 2 km) to walking trips.
4. Research that examines the risk profiles of those who respond to policies to encourage cycling for utility purposes would improve the assumptions made about the health benefits of increasing transport cycling. In addition, such research would identify the effects of such policies on health inequities, and encourage the design of policies which reduced such inequities.
5. Expanding the focus of epidemiological study into the broader social and micro-economic benefits of cycling to transport would enable these effects to be counted in analyses such as these. Impacts should include those on social connection and community severance, accessibility to goods and services, impacts on household transport costs and the ability to manage family responsibilities.

Implications for policymakers

The benefits of a transport mode shift from cars to bicycles outweigh the harms, and our findings are likely to be conservative.

We have chosen an indicative 5% shift in mode of travel. Given the considerable likely co-benefits of reducing car travel and increasing physical activity, further work might estimate, based on the results of research conducted to date, what policy-makers could reasonably expect to achieve as a result of interventions such as fuel taxes, congestion charges, parking restrictions, education programs and infrastructure development. Incorporating benefits as well as harms of different transport modes into decision-making processes will be important.

How the move from cars to bicycles might occur was not the focus of our paper, but we will give some comment as this is an important issue for policy decisions. It is worthwhile noting that the Netherlands is often hailed as a 'cycling nation', but it has not always been so. They had a dramatic decline in bicycle use from the 1950s until the mid 1970s and over this time, cycling became less safe.[15] As a response to this, there was a deliberate, massive investment in cycling infrastructure and restrictions on car use. Cycling levels have recovered somewhat since then but are still not back at levels seen in the 1950s. Cycling is now significantly safer and it is likely that increased safety was a central factor in promoting more cycling.

The effects of transport policies on health inequalities have not been closely examined, but warrant attention. If those who move most readily from cars to bikes come from relatively privileged groups, compared with citizens who for various reasons have fewer degrees of freedom in their transport choices, health differentials by ethnicity and socio-economic position will potentially widen.

Finally, with refinement, the methods used in this study could be applied to greenhouse gas reduction policies in other sectors than transport, such as energy, housing, food and agriculture, and the health sector itself, where considerable opportunity exists for reducing emissions, increasing sustainability and achieving health co-benefits.

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