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The cost-effectiveness of competing congestion pricing plans in New York city

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ABSTRACT

Objectives: As nations urbanize, novel ways are needed to manage increasing automobile traffic in city centers. One innovative and efficient way of reducing traffic congestion is to charge automobiles when they enter congested areas of a city, a strategy referred to as congestion pricing. A number of cities worldwide have adopted congestion pricing with great success. To varying degrees, congestion pricing has lowered congestion, increased revenue for public transportation systems, reduced pollution, and increased residents' levels of physical activity. New York City is also adopting congestion pricing, and considered a large number of models for doing so.

Methods: We compare the costs and health benefits of two competing congestion pricing plans, Fix NYC (a higher-cost but geographically-focused proposal) and Move NY (a lower-cost city-wide proposal focused on equality), that were considered by the municipal and state governments. We use a Markov model to estimate the effects of these two congestion pricing plans in 2019 over a period of 10 years.

Results: We find Fix NYC's and Move NY plans produce similar cost savings and gains in life relative to the status quo. Fix NYC would save about $24,805 and Move NY would save about $24,777 per capita. Each would result in a gain of 0.10 QALYs per capita, with the only differences notable at 4 decimal points of rounding error.

Conclusions: Implementing congestion pricing in New York City would save both money and lives. Both of the plans we evaluate are roughly equal in value, and this is likely true of the plans that fall in-between these two plans in design. These findings suggest that congestion pricing is highly cost-effective, but that the program components do not matter much from a health standpoint.

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1. Introduction

The widespread use of privately-owned automobiles has ushered in an era of great convenience, providing individual autonomy and possibilities for economic development that were unthinkable at the end of the 19th century. However, it has also helped create four of the greatest challenges confronting humankind: global warming, obesity, traffic injuries, and air pollution (Xu et al., 2010; Anas and Lindsey, 2011; Durand et al., 2011; Rojas-Rueda et al., 2011; Heilig, 2012).

In most cities worldwide, the population is growing, leading to automobile congestion. Therefore, even as automobiles originally enhanced economic productivity by opening up global commerce, they now sap productivity as people idly sit in traffic and develop debilitating illnesses arising from obesity, air pollution, and injury (Farber and P Ez, 2011). Congestion pricing can reduce the negative consequences of automobiles by reducing the time people spend in traffic while enhancing their benefits.

Congestion pricing has produced positive impacts to health and society. London, Stockholm, and Milan realized significant reductions in air pollution, including the most dangerous form—particulate matter (PM) 2.5. (Transport for London Impacts Monitoring Group, 2008). These reductions ranged from small changes to as much as 20% (Anas and Lindsey, 2011; Anderson et al., 2018). Using alternative forms of transportation has further benefits of reducing obesity, heart disease, and cancer (Button and Verhoef, 1998). Where congestion pricing has been implemented, it has not only reduced congestion and air pollution but also encouraged the use of more active forms of transportation, such as walking, cycling, and public transportation(Suryo et al., 2007).

Congestion pricing plans all work by charging automobiles for entering areas with high vehicle concentrations, but differ in the form that they take. In Milan, residents in the city center are given partial fee exemptions, and incentivizes vehicle operators to use alternative fuels. In London, the pricing scheme introduced in 2003 underwent changes in fits and starts. More recently, London instituted a “toxicity charge” to discourage use of older vehicles which are found to pollute more than their modern counterparts (Anderson et al., 2018). In Stockholm and Singapore, a cordon system dictates pricing according to the time of day, with rush hour trips more costly than off-peak trips (Suryo et al., 2007). Thus, congestion pricing offers policymakers with a toolkit that allows them to design plans that meet local needs, such as placing additional charges on diesel or fine-tuning the mix of vehicles in a given area.

Based partially on its demonstrated success where implemented, congestion pricing is being considered in many cities around the world, including Beijing, and Sao Paulo. It will soon be implemented in New York City. Congestion pricing is understandably politically unpopular among drivers. It also comes with substantial implementation costs—devising ways of charging drivers for entering specific areas of a city is no small task. Finally, it comes with ongoing “transfer” costs—processing the payments and then distributing the proceeds to other government programs.

New York has considered congestion pricing in the past. A congestion pricing proposal was rejected in 2007. Michael Bloomberg, then the mayor of New York City, argued congestion pricing was necessary to accommodate the city's growing population. Much of the proceeds from congestion pricing were to be used to expand bus lines and improve means of public transportation to accommodate more users. Since then, two critical factors led to a reconsideration of congestion pricing. One was dramatic declines in service on New York City's subways; public transportation has moved to the top of the list of concerns and financing priorities for New Yorkers (Dot, 2018). The other was a shift in the composition of the New York State legislature.

Seeing opportunity, public and private agencies began drafting a number of plans for implementing congestion pricing in New York City. These proposals can be roughly reduced into two major conceptual approaches, ‘Move NY Fair (Move NY)’ and ‘Fix NYC.’ The Move NY flat toll plan proposes a cordon system with bridge tolls for the four East River bridges (Queensboro, Williamsburg, Manhattan, and Brooklyn bridges) and is bounded by 60th street in Manhattan's Central Business District (CBD). Under this plan, all vehicles would be charged a toll of $5.76 in both directions at all times without consideration of the time of day (The Nurture Nature Foundation, 2018; Fair, 2015). Higher tolls would be assessed in areas where public transportation options are more available, but existing tolls would be reduced in areas lacking such alternatives and in lower-income areas. Specifically, the Move NY plan would reduce tolls for New York Metropolitan Transportation Authority's (MTA's) seven “major” bridges as well as for the three “minor” bridges. Tolls would be collected electronically without vehicles having to reduce their speeds (Fair, 2015). Additional consideration is being given for the type of vehicle mix in order to maximize fairness along with traffic flow. Vehicles going into or out of Manhattan below 60th street or using one of the East River bridges would have tolls capped at one round trip each day regardless of the number of trips, as long as the vehicle uses an electronic system which would register the exemption. Trucks would be subject to a per axle toll (Fair, 2015). The Move NY proposal includes a congestion toll exemption for city-approved metered taxis and all for-hire vehicles within the cordon, but these vehicles would still be subjected to various surcharges (Fig. 1). The common and different features of the two plans were summarized in Supplementary Table 1.

The Fix NYC plan is a three-phase plan designed around investing in public transportation infrastructure (Nyc, 2018). It differs from the Move NY plan in that it monitors traffic within the congestion pricing zones rather than just on the perimeter (Fig. 1). This allows for more nuanced pricing schemes because vehicles that never leave the congestion pricing zone can be treated differently from those that enter it. It would introduce a zone pricing scheme in the CBD below 60th street in various phases (Nyc, 2018). In Phase One, the plan introduces six components: i) identifying and investing in public transportation alternatives; ii) further enforcing existing traffic laws and regulation; iii) creating a review board to evaluate all government issued parking placards; iv) reviewing the use of commuter, charter, tour and other buses creating congestion in the CBD; v) reviewing the current class categorization of for hire vehicles; and vi) beginning planning, design, and construction of infrastructure (Nyc, 2018). Phase Two includes implementing a surcharge for taxi and other for hire vehicles for trips entering or starting within the CBD. Phase Three consists of congestion pricing zone implementation but with pricing exemption on the FDR Drive from Brooklyn Bridge to 60th street, thus allowing some vehicles to bypass the congestion pricing zone if they do not intend to enter the CBD. Once the pricing zone is established, a trial period in which only trucks would be charged would be used to identify and correct any potential issues. After this trial period, all vehicles

Fig. 1. Proposed changes in fees within New York City associated with the FIX NYC congestion pricing plan (White Text) and the Move NY Fair congestion pricing plan (black text). While Fix NYC focuses on pricing changes in lower Manhattan, Move NY Fair add new tolls for high congestion, high income areas (Lower Manhattan) and reduces tolls in lower income areas elsewhere in the city. (1 = Manhattan, 2 = Brooklyn, 3 = Queens, 4 = Bronx, and 5 = Statin Island.)

would be charged accordingly. The three phase Fix NYC plan proposes a number of different permutations. We evaluated a "higher range" scenario, in which charges were higher and the plan details were more complex, but also more heavily evaluated. The Fix NYC higher-range plan includes a full two-way toll of $11.52 on weekdays from 6 a.m. to 8 p.m. and on weekends from noon to 10 p.m. on inbound trips only (The Nurture Nature Foundation, 2018). We chose this higher cost, more complex version of Fix NYC in order to maximize the differentiation between the Fix NYC plan and the Move NY plan. While the Move NY plan attempts to fix regressive elements of existing tolls in the city, the main distinguishing feature between the plans is that Fix NYC conducts extensive monitoring of vehicles within the congestion pricing zone and Move NY simply charges vehicles on the perimeter. Fix NYC is therefore more expensive, but also more versatile.

This paper explores the cost-effectiveness of the Move NY and Fix NYC congestion pricing plans as a health investment in New York City (NYC). Officials at the Regional Planning Association collaborated with the core research team in developing the details of each scenario in our models. These two plans represent the range of possible pricing schemes across the city, from a very simple, inexpensive, but non-specific scheme to one that provides policymakers with state-of-the-art controls and evaluations. The two plans blend the implementation aspects and lessons learned from previous congestion pricing schemes in Singapore, London, Stockholm, and Milan. By contrasting these different models, we hope to provide insights for future cities that might be considering adopting congestion pricing.

2. Material and methods

2.1. Overview

We conducted a simulation using a traditional stochastic, time-varying Markov chain model using TreeAge Pro 2016. The model includes the two aforementioned congestion pricing schemes and their respective costs and health benefits to New York residents over their lifetime. This model was primarily built using data obtained from the Regional Plan Association, the Balanced Transportation Analyzer (BTA), and the scientific literature.

We set 10 years as the time horizon of the analysis under the assumption that the infrastructure would be updated roughly on a 10-year cycle. The model follows a hypothetical cohort of New Yorkers with a median age of 36 (the median age in NYC) over this 10-year cycle (Census, 2019; City, 2019). To simplify the results, we present cumulative data for this single cohort after considering variability in the cohort composition, random error, and non-random error in the model (Census, 2019). Those interested in sub-analyses pertinent to other groups in other geographic locations should contact the authors. Baseline mortality rates with age were obtained from US life tables provided by the Centers for Disease Control and Prevention (CDC) (Arias et al., 2014).

The health outcome measured was the quality-adjusted life year (QALY), indicating the quality and the quantity of life lived. One QALY equates to a year of living in 'perfect' health. If an individual lives a year in a state of less than perfect health or live in perfect health for less than a year, this year is worth less than one QALY. Death is assigned a value of 0 QALYs. Cost-effectiveness outcomes were measured using the incremental cost-effectiveness ratio (ICER), which is the change in costs divided by the change in QALYs when the congestion pricing program is in place. A willing-to-pay (WTP) threshold is the maximum price that society is willing to forego to gain an additional QALY. While the Panel on Cost-Effectiveness in Health and Medicine recommends against setting a WTP for a QALY, the use of a threshold helps provide a reference range around which ICER values can be compared in order to provide policymakers with a sense of how likely it is that the model will fall below or above this threshold after considering model error. A WTP threshold of $50,000 per QALY gained was used as the lower bound of acceptable ICER values (Grosse, 2008; Organization, 2014). A 3% discount rate was used for considering future costs and health outcomes in accordance with the recommendations of the Panel on Cost-effectiveness in Health and Medicine (Neumann et al., 2016).

2.2. Model structure

The Markov model has three major health states: healthy, unhealthy, and dead. The hypothetical cohort begins in the healthy state. It is then exposed to the risk of non-fatal injury and fatal injury. Non-fatal injury is categorized as serious injury and minor injury. The cohort was also exposed to the age-specific risk of death, the effect of exposure to pm 2.5., the effect of traffic noise on health, and the health benefits associated with active transport. (See Table 1 for model inputs). If simulated participants were seriously injured, they would stay in that state (or die) and could not recover. If they only had minor injury or illness, participants could recover to a healthy state, while those not injured or sick would remain so unless circumstances caused a change to a different state.

The 'unhealthy' state refers to individuals who cannot recover from injury or disease and therefore will subsequently have a permanent change in health related quality of life (HRQL) over their remaining life course (Jiao et al., 2017). Our model has two arms: the congestion pricing arm and the status quo arm.

In our model changes induced by congestion pricing plan have both positive (e.g., increased exercise) and negative (e.g., increased injury) outcomes. In addition, with a change in transport modality, commuting, air pollution and traffic noise would be affected. Parameters and their values were determined according to the Move NY proposal and the Fix NYC higher-range plan, respectively. The time cycle of this model was one year. We conducted a series of one-way sensitivity analyses as well as a Monte Carlo simulation on all variables at once.

2.3. Model parameters

2.3.1. Probability

The probability parameters can be found in Table 1. The background mortality rate was obtained from life table data from the CDC (Arias et al., 2014). The injury rate, serious injury rate, and fatal injury rate associated with car commuting and active transport commuting before the congestion pricing plan were derived from 2014 crash data from the NY Department of Motor Vehicles and the Institute for Traffic Safety Management and Research (New York State Department Of Motor Vehicles, 2014; Institute For Traffic Safety Management And Research, 2014). These changes in these rates after implementing the congestion pricing plan were largely obtained from the London congestion pricing plan (Green et al., 2016). While London and New York have different baseline values, we used the London data only to estimate the expected change in the baseline parameter values for New York City. Among the 3.5% of people who shifted from commuting by car to means of active transport after the London congestion pricing program, 2.9% shifted to using bicycles, 5.7% to ferry, and 91.4% to subway use. The mix of transportation modalities in New York City and London are similar.

Table 1
Markov model inputs for both the Fix NYC and Move NY plans including the baseline value used in the model, the form of the probability distribution, and the range or standard error.

Variable	Base	Distribution[a]	Range/Standard Error
Age at baseline	36	–	–
Utility			
Health utility decrement of serious injury (Muennig et al., 2014)	0.450	Triangular	low: 0.360; high: 0.530
Incremental health related quality of life due to active transport (Jia and Lubetkin, 2005)	0.011	Triangular	low: 0.008; high: 0.014
Probability			
Fatal injury rate of car commuting-status quo (New York State Department Of Motor Vehicles, 2014)	0.301	Triangular	low: 0.226; high: 0.376
Fatal injury rate of active transport commuting-status quo (New York State Department Of Motor Vehicles, 2014)	0.594	Triangular	low: 0.446; high: 0.743
Injury rate of car commuting-status quo (New York State Department Of Motor Vehicles, 2014)	0.047	Triangular	low: 0.035; high: 0.059
Injury rate of active transport commuting-status quo (New York State Department Of Motor Vehicles, 2014)	0.014	Triangular	low: 0.011; high: 0.018
Serious injury rate of car commuting-status quo	0.156	Triangular	low: 0.117; high: 0.195
Serious injury rate of active transport commuting-status quo	0.094	Triangular	low: 0.071; high: 0.118
Rate of active transport commuting-status quo (The Nurture Nature Foundation, 2018)	0.830	Triangular	low: 0.620; high: 1.000
Rate of active transport commuting-congestion pricing program (The Nurture Nature Foundation, 2018)	0.850	Triangular	low: 0.640; high: 1.000
Relative risk (RR)			
RR of mortality for active transport (Celis-Morales et al., 2017)	0.755	Triangular	low: 0.575; high: 0.995
RR of mortality for air pollution exposure (Rojas-Rueda et al., 2011)	1.002	Triangular	low: 1.000; high: 1.253
RR of mortality for traffic noise exposure (Halonen et al., 2015; Siemens, 2014)	1.010	Triangular	low: 1.000; high: 1.020
RR of fatal injury rate for congestion pricing	0.998	Triangular	low: 0.749; high: 1.000
RR of injury rate for congestion pricing	0.800	Triangular	low: 0.600; high: 1.000
RR of serious injury rate for congestion pricing	0.982	Triangular	low: 0.737; high: 1.000
Background mortality rate (Arias et al., 2014)	US life table	–	–
Cost (2017 USD)			
Medical costs of serious injury (Centers for Disease Control and Prevention, 2017)	38,857	Gamma	9,714
Productivity loss of serious injury (Centers for Disease Control and Prevention, 2017)	74,365	Gamma	18,591
Medical costs of fatal injury (Centers for Disease Control and Prevention, 2017)	18,794	Gamma	4,699
Productivity loss of fatal injury (Centers for Disease Control and Prevention, 2017)	1,349,212	Gamma	337,303
Incremental productivity due to congestion pricing program (Siemens, 2014; Texas A&M Transportation Institution, 2014)	371	Gamma	93
Incremental productivity of goods delivery due to congestion pricing program (Siemens, 2014; Texas A &M Transportation Institution, 2014)	47	Gamma	12
Start-up costs for congestion pricing program-Fix NYC higher-range plan (The Nurture Nature Foundation, 2018)	18	Gamma	4
Operating costs for congestion pricing program-Fix NYC higher-range plan (The Nurture Nature Foundation, 2018)	35	Gamma	9
Start-up costs for congestion pricing program- Move NY flat toll plan (The Nurture Nature Foundation, 2018)	19	Gamma	5
Operating costs for congestion pricing program- Move NY flat toll plan (The Nurture Nature Foundation, 2018)	38	Gamma	9

[a] For use in the Monte Carlo simulation.

2.3.2. Health utility

EuroQol 5D 5L (EQ5D-5L) is used to assess the impact of injury and death on victims' HRQL. HRQL is measured on a scale from 0 (death) to 1 (perfect health). The health utility decrement of serious injury was estimated from a published study by Muennig et al. (2014). The incremental HRQL due to active transport was calculated from a study by Jia and Lubertkin (Jia and Lubetkin, 2005).

2.3.3. Cost

The start-up costs for the congestion pricing programs were the costs for program implementation (e.g., installation costs and equipment costs), as well as related operating costs (e.g., administrative, amortization). The two analyzed congestion pricing plans contained different costs. All the costs in this study were estimated using the BTA (The Nurture Nature Foundation, 2018).

Medical and work-loss costs associated with serious injury and death were acquired from the CDC's Web-based Injury Statistics Query and Reporting System (Centers for Disease Control and Prevention, 2017).

As previously noted, a congestion pricing program may increase traffic speeds which would, in turn, increase business productivity and also result in quicker goods delivery, but might also increase injury severity for motor vehicle collisions. The range of business benefits was obtained from congestion pricing plans in Stockholm, Singapore, and London (Anas and Lindsey, 2011). The value of travel time was obtained from data compiled by the Texas A&M Transportation Institute (Texas A&M Transportation Institution, 2014), and the time saved as a result of the congestion pricing plan was derived from an analysis performed by Siemens (2014). All monetary costs were adjusted to 2017 U.S. dollars using the Consumer Price Index of U.S. and New York (Table 1). The dynamic interplay between speed and health system costs was obtained from the literature (Mohit et al., 2018).

2.3.4. Relative risk

Use of active transport is associated with a lower risk of mortality. The relative risk (RR) of mortality for active transport was calculated on the basis of a study by Celis-Morales et al. (2017) and the simulated transport mode shift after congestion pricing implementation. The relative risks associated with changes in exposure to air pollution and traffic noise were also obtained from the literature (Halonen et al., 2015; Rojas-Rueda et al., 2011).

2.4. Key model assumptions

(1) Only individuals in the healthy state will commute to work.
(2) Those with minor injury can recover to perfect heath, will not suffer from any changes in QALYs, and will return to multi-modal commuting.
(3) As data was lacking on the relative risks of subway and ferry use, the RR of walking was assumed to be generalizable to subway and ferry users because people will presumably walk to stations for both of the two modes of transport.
(4) For air pollution, only diseases related to PM of 2.5 μm or less were considered in this study because exposure to PM 2.5 μm has clearer associations with all-cause mortality.

3. Results

The incremental cost-effectiveness analyses are shown in Table 2. Both Fix NYC and Move NY plans are cost-saving proposals. Fix NYC's plan was associated with $24,805 in savings, and Move NYC's plan was associated with $24,777 in savings. The major differences in the plans arise from expenses associated with maintaining more equipment in Fix NYC and lower revenue from outer borough tolls in the Move NY plan. Both plans result in roughly 0.1 QALYs gained per NYC commuter relative to the status quo, with differences only observed at 4 decimal places.

As an illustrative example, a 46-year-old commuter could live to be 89.47 years old if $121,975 were spent at the status quo. In Fix NYC's higher-range plan, this 46-year-old participant would live to 89.57 years and incur health and transportation-associated costs of $107,765, resulting in 0.102 more years of life and $24,805 in monetary savings relative to the current status quo. Under Move NY, the person's life expectancy was predicted to differ only by a few hours and the costs by roughly $100 dollars. These differences are well within the range of error in the model, and can be considered equivalent.

To quantify the influence of any one variable in the model, one-way sensitivity analyses were performed across a variety of input parameters (Table 3). In both Fix NYC's and Move NY's plans, the most sensitive parameter was the rate of active transport commuting under status quo. If the rate of active transport commuting is maximally increased after implementing congestion pricing, 0.063 additional QALYs would be gained. Among costs parameters, the most sensitive input was the productivity loss due to fatal injury in both the Fix NYC and Move NY proposals. A maximum of about 0.141 QALYs could be gained after implementing either congestion pricing program. The complete results of one-way sensitivity analyses are shown in Table S1 and Table S2.

The incremental cost-effectiveness ratio (ICER) scatter-plots are shown in Fig. 2. In the Fix NYC plan, implementing congestion pricing would be cost-effective in 99.94% of simulations at a WTP threshold of $50,000/QALY gained. In other words, 99.94% of the simulations had an ICER of less than $50,000 per QALY gained. In the Move NY plan, implementing congestion pricing would be cost-effective in 99.96% of simulations at a WTP value of $50,000/QALY gained. The difference in simulation results between the two plans is not considered to be statistically significant.

Table 2
Costs (in 2017 USD), quality-adjusted life years (QALYs), and incremental cost-effectiveness ratio (ICER) data of the Fix NYC and Move NY congestion pricing programs relative to the status quo (no program).

Strategy	Cost	Incremental Cost	QALY	Incremental QALYs	Incremental Cost-Effectiveness
Status quo	$107,765		8.27		
Fix NYC higher-range plan	$82,960	-$24,805	8.37[a]	0.10[a]	Cost-saving
Move NY flat toll plan	$82,989	-$24,777	8.37[a]	0.10[a]	Cost-saving

[a] These numbers appear similar because the differences are only notable at 4 decimal places. Because the differences between the models fall well within the range of model error, the plans can be considered equally cost-effective relative to the status quo.

Table 3
One-way sensitivity analyses of congestion pricing programs.

Variable	Incremental Cost (in 2017 USD)	Incremental Effectiveness	Incremental Cost-Effectiveness
Fix NYC higher-range plan			
Rate of active transport commuting-status quo (Low: 0.62; High: 1.00)	$-19,916	0.063	Cost-saving
Productivity loss of fatal injury (Low: 1,011,909; High: 1,686,515)	$-39,790	0.141	Cost-saving
Move NY flat toll plan			
Rate of active transport commuting-status quo (Low: 0.62; High: 1.00)	$-19,887	0.063	Cost-saving
Productivity loss of fatal injury (Low: 1,011,909; High: 1,686,515)	$-39,761	0.141	Cost-saving

4. Discussion

We find that implementing congestion pricing in New York City would result in life expectancy gains, health benefits, and cost savings relative to the status quo. Despite the fact that Fix NYC's plan is more complex and expensive to implement than Move NY's flat toll plan, both have essentially the same long-term costs and health benefits. While the average value of Fix NYC's plan suggests that it is slightly more cost-saving, the range of error in the cost estimate is over $10,000 (Fig. 2). Likewise, the range of error in effectiveness values is nearly a fourth of a year of healthy life (0.25 QALYs, Fig. 2). Therefore, the two plans should be considered equivalent.

As such, decisions about which plan to implement should be made purely based on local urban planning and political needs rather than economic grounds.

Congestion pricing is a somewhat crude tool for shifting the demand of vehicle use, but it is an important one. As taller and more buildings are being constructed, the density and population of cities are increasing along with vehicular traffic. Single-occupancy vehicles are becoming an increasingly impractical means of transport.

Public transportation has become a major consideration of quality of life (and thus attractiveness) of a city. New York City has successfully created demand for alternative forms of transportation, including walking, cycling, and public transportation. As demand for alternative forms of transportation increases, there will be a need to issue bonds to pay for the infrastructure required to implement them (e.g., more bike lanes and wider sidewalks). In addition, the Regional Plan Association has proposed a plan to use the revenues from congestion pricing implementation to improve the service and capacity of the subway and public transportation systems under the MTA (Barone, 2018). This would accelerate the transformation of these modes of transportation in NYC, but the plan requires funding. Congestion pricing serves as an important stream of revenue for a system that some have describes as a crisis, and one that threatens the sustainability and desirability of New York City.

There are a number of limitations in this study. First, the model only evaluates the effects of a congestion pricing program on average. Although children and the elderly do not need to commute to work, they are affected by transit delays, traffic noise, and air pollution in ways that the average commuter is not (Halonen et al., 2015).

Second, people using other forms of transportation could switch to subway use under congestion pricing implementation. This paper did not consider whether the current subway system can cover the subsequent increased demand or the possible resulting delays from inability to accommodate higher capacity. There is a “catch 22” situation in which public transportation systems are required to support congestion pricing, but funding from congestion pricing is needed to expand and improve public transportation networks. Substantial investments in public transit may be needed prior to the implementation of congestion pricing (as considered in the Fix NYC proposal), but it is not clear that these improvements will be made prior to the rollout of congestion pricing in 2021.

In addition, the Transport for London annual impact reports concluded roads around the congestion zone faced slightly more delays, and reallocating road space mainly to accommodate additional buses and pedestrian spaces further exacerbated the congestion issue. Our model did not include the potential productivity loss associated with such delays. On the other hand, New York City is unusual in that the border of the proposed congestion pricing zones (Fig. 1) are neighborhoods with few privately-owned vehicles.

Third, we could not account for the fact that Fix NYC allows for experimental changes in the design of congestion pricing that Move NY does not. This ability to produce subtle changes in factors such as charges for trips made by downtown residents or changes in pricing in some areas but not others may give Fix NYC an advantage that we did not account for. On the other hand, Move NY carries the advantage of addressing regressive fees associated with driving in areas with little by way of public transit and much lower incomes. Income re-distribution can also produce positive health effects that we did not account for (Muennig et al., 2005).

Finally, since this study was conducted within the context of a major city, people have the option to choose among driving, public transportation, walking, or other similar modes of transport. Previous studies have mainly examined how one changed impact (in isolation) will affect others, but there is a dearth of literature of examining several different factors in an interrelated manner (Basso and Jara-Diaz, 2012). Our model only partially accounts for the possibility that transportation modalities are based upon external factors such as weather, time of day, and the availability of nearby bike docks or taxis.

In conclusion, we find that implementing a congestion pricing program can save both money and lives. However, deciding which

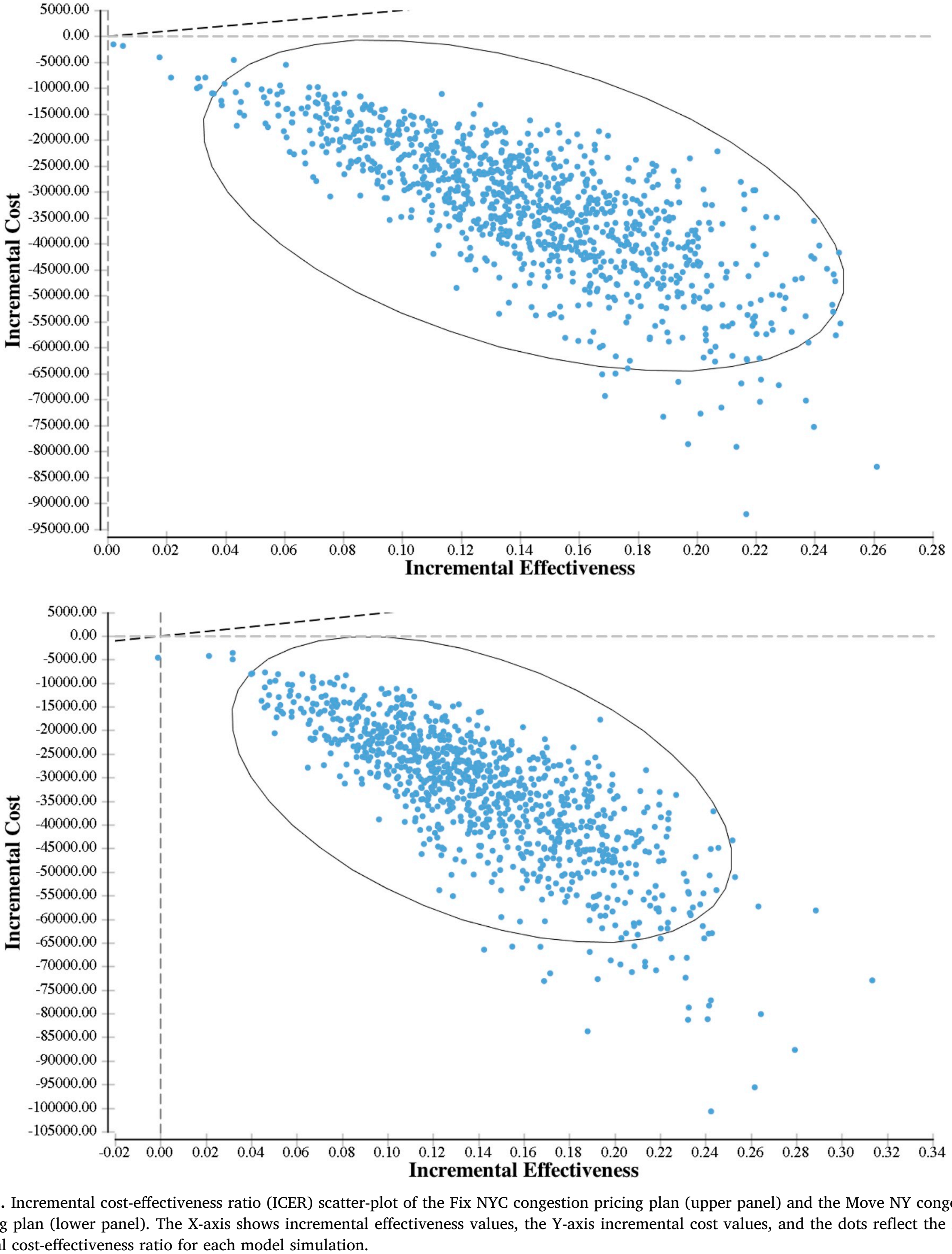

Fig. 2. Incremental cost-effectiveness ratio (ICER) scatter-plot of the Fix NYC congestion pricing plan (upper panel) and the Move NY congestion pricing plan (lower panel). The X-axis shows incremental effectiveness values, the Y-axis incremental cost values, and the dots reflect the incremental cost-effectiveness ratio for each model simulation.

plan to employ should consider additional influencing factors because there were no significant obvious differences between the plans we included in the study. These two plans represented the extremes of all of the proposals that were under consideration. Given how similar our results were despite the range of variable inputs and assumptions inherent to each model, it is likely that different plans would also produce essentially equivalent results in other cities. We would conjecture, then, that political science, rather than economics or public health, should drive decision-making.

Disclosure statement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2019.100586.

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