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News and Views

Ought a green citizen to bicycle or take public transport to work?[☆]

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ABSTRACT

We theoretically study whether an environmentally conscious or "green" citizen ought to bicycle or take public transport to work. Focusing on the criterion of travel time minimization, we construct and analyze a simple stochastic model that sheds light on the above question. Our investigation leads to three findings. First, we compute the expected amount of time it takes to commute to work. Second, we derive a key inequality condition and show that only two cases need to be considered to determine whether a green citizen ought to bicycle or take public transport to work. Finally, we provide an intuitive explanation of why it suffices to consider only two cases to answer the question in the title of this note.

1. Introduction

It has now been twenty-five years since the publication of the so called Brundtland Report (1987). This Report heralded the beginning of a new era in which the notion of sustainable development would be a cornerstone of societal and technological progress. This awareness has now prompted interest in a number of sustainability strategies such as the focus on "green industries," "smart cities," "ecological agriculture," and "sustainable transportation." Specifically, the concept of sustainable mobility has now become a popular and multi-faceted notion that encompasses freight transport, logistics and distribution, private transport, mass transit, and individual modes of mobility including bicycling and walking. Both institutional and technological incentives have been provided to alter the spatial and behavioral patterns of the modern "homo mobilis." In a densely populated nation like the Netherlands, this has led to a large number of policy initiatives including the upgrading of public transport quality, the institution of dedicated bicycle lanes, and the implementation of priority rules for cyclists.

In addition to the Netherlands, in contemporary times, regulatory authorities in many other nations of the world have also begun to focus on the ways in which they might encourage the use of sustainable modes of transportation. As noted by Pucher and Buehler (2009) and Buehler (2010), this focus has typically led these authorities to discourage the use of private automobiles and encourage the use of public transport and other forms of transport such as bicycling.

Given this very practical focus on "green" or environmentally friendly modes of transport, it is not surprising to see that researchers have studied the pros and cons of green transport from a variety of perspectives. In an early paper, Rietveld et al. (2001, p. 539) contend that the unreliability of public transport chains in the Netherlands means that the best way to improve the overall quality of these chains is to encourage travelers to use the bicycle "as an entrance or exit mode." Martens (2004) focuses on Germany, the Netherlands, and the United Kingdom and studies the combined use of the bicycle and public transport for a single trip as a multimodal alternative to the private automobile. Taniguchi and Fujii (2007) point out that effective marketing of what they call mobility management can increase the use of sustainable transportation modes such as bicycling, public transport, and walking.

Martens (2007) studies the extent to which "bike-and-ride" schemes that are popular in the Netherlands might be implemented in other cities and nations that do not have a developed bicycle infrastructure. Debrezion et al. (2009) show that the availability of parking spots and bicycle standing areas has a significant and positive effect on the choice of railway stations as a departure point for travelers.

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Focusing on small cities in the United States, Xing et al. (2010) point out that the key factors affecting the extent to which the bicycle is used for transport are an aversion to driving and what they call "bicycling comfort." Finally, Buehler and Pucher (2012) focus on ninety cities in the United States and note that bicycle commute rates depend significantly on the supply of bike lanes and paths.

The studies discussed in the preceding two paragraphs have certainly advanced our understanding of the many and varied factors that influence the decision to adopt more environmentally friendly modes of transport by green citizens. This notwithstanding, it is worth emphasizing two points. The more general point is that the majority of extant studies about environmentally friendly modes of transportation are empirical in nature. The more specific point is that we are unaware of any theoretical studies that have directly compared the usefulness of the bicycle with public transport from the standpoint of a citizen who is concerned about the environment and is time conscious.

Given this lacuna in the literature, the central objective of this note is to address the following question: Ought a green citizen to bicycle or take public transport to work? To answer this question, Section 2.1 below focuses on the yardstick of travel time and then analyzes a simple probabilistic model. Section 2.2 computes the expected or mean time it takes our green citizen to commute to work. Section 2.3 derives a key inequality condition and points out that only two cases need to be considered to ascertain whether a green citizen ought to bicycle or take public transport to work. Section 2.4 intuitively explains why it suffices to consider only two cases to answer the question posed in the beginning of this paragraph. Finally, Section 3 concludes and then discusses three extensions of the research delineated in this note.

2. The Theoretical Framework

2.1. Preliminaries

Consider a citizen in a geographic region who in principle can commute to work using any one of three possible alternatives. First, she can drive to work in her car. Second, she can take public transport to work. In the remainder of this note, we shall think of this public transport alternative concretely as a bus. Finally, she can also bicycle to work. However, since our objective in this note is to study the commuting behavior of an environmentally conscious or green citizen, in what follows, we remove the first of these three alternatives from any further consideration. Therefore, for all practical purposes, the relevant question for this citizen concerns whether she should bicycle or take the bus to work.

Given that our citizen is green, she could, of course, focus on several other criteria to determine which of the above two transport modes to use to get to work.[1] However, many existing studies have convincingly shown that the criterion of *travel time* is an important consideration for commuters.[2] Therefore, in this note, we focus on the criterion of travel time to determine whether our green citizen ought to bicycle or take the bus to work.[3]

Rietveld et al. (2001) and others have pointed out that public transport schedules are unreliable. Second, with regard to public transport, accidents and breakdowns occur and both these events are generally unpredictable. Third, in the case of bicycling, one typically bicycles in designated bike lanes or paths.[4] Putting these three pieces of information together, we assume that relative to the bus alternative, our green consumer has a much better idea about how long it will take her to bicycle to work from home. To model this feature concretely, we suppose that there is a *stochastic* aspect to commuting to work by bus but that there is no similar probabilistic aspect to bicycling to work from home.

Buses arrive at a bus stop in front of our green citizen's home in accordance with a stationary Poisson process[5] with time invariant rate $\zeta>0$. If our green citizen boards the bus from the stop in front of her home then, counting from the time she gets on the bus, it takes her T_{pt} time units to get to work. On the other hand, if she bicycles to work from the same bus stop in front of her house then it takes her T_b time units to commute to work.

Now, focusing on the minimization of the travel or commute time, we suppose that our green citizen utilizes the following decision rule when she gets to the bus stop in front of her home. Specifically, she waits for τ time units and if a bus arrives within τ time units then she takes the bus to work. In contrast, if no bus arrives within τ time units then she bicycles to work. Note that this decision rule makes sense because of our assumption that the bus stop is right in front of the green citizen's home. Specifically, this means that the time spent walking to the bus stop is negligible and hence can safely be ignored in the formal analysis in Sections 2.2–2.4 below. If this were not the case and the bus stop were a couple of minutes walking distance from the green citizen's home then it would be necessary to model this additional time spent walking, explicitly in the model. Alternately, one could also analyze a scenario in which the transport mode choice is made not at the bus stop but instead in the green citizen's home. With this caveat in mind and given the above description of our green citizen's commuting environment, our next task is to compute an explicit expression for the expected or mean time it takes our green citizen to commute to work.

2.2. Expected Commute Time

To compute this expectation, let $E_\tau=E$[*travel time for decision rule* τ], where $E[\cdot]$ is the expectation operator. It is clear that the travel time of interest depends on the first arrival time of the rate $\zeta>0$ Poisson process describing the arrivals of buses at our green citizen's bus stop. Now, from the properties of stationary Poisson processes, we know that the bus inter-arrival times are exponentially distributed with parameter ζ. Therefore, we deduce that

$$E_\tau=\int_0^\infty \zeta e^{-\zeta t}\left\{\left(t+T_{pt}\right)I(t\leq\tau)+(\tau+T_b)I(t>\tau)\right\}dt, \tag{1}$$

where $I(\cdot)$ is the indicator function.

Simplifying the expression on the right-hand-side (RHS) of Eq. (1), we get

$$E_\tau=\int_0^\tau \zeta t e^{-\zeta t}dt+T_{pt}\int_0^\tau \zeta e^{-\zeta t}dt+(\tau+T_b)\int_\tau^\infty \zeta e^{-\zeta t}dt. \tag{2}$$

[1] The actual motivational structure of travel decisions is rather complicated. We could decompose this structure into two parts where one part consists of objective and measurable factors and the second part consists of subjective and perception related factors. However, a detailed analysis of this sort of two-part travel motivational structure is beyond the scope of this note.

[2] See Bhat and Sardesai (2006) and Lo et al. (2006) for a more detailed corroboration of this point. Note that we have implicitly subsumed transport costs in the criterion of "travel time." Such transport costs are relevant not only for individuals but also in other contexts as well. See Larue et al. (2007) and Kamal et al. (2012) for more on this point.

[3] We have accounted for the fact that the citizen under study is green by eliminating the automobile transport option. By doing so, we are acknowledging that the environmental impact of transport decisions is salient. This notwithstanding, as noted in footnote 1, we agree that when selecting a mode of transport, a green citizen may choose to focus on a whole host of factors in addition to the travel time criterion. Although a complete analysis of these additional factors is beyond the scope of this note, in Section 3, we suggest extensions to the research described here that touch on the potential use of the above mentioned additional factors.

[4] Although this is generally true in the United States, a referee points out that this is not true in general in the countries of the European Union.

[5] See Ross (1996, pp. 59–97) or Tijms (2003, pp. 1–32) for textbook expositions of the Poisson process.