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How fuel prices determine public transport infrastructure, modal shares and urban form

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ABSTRACT

Urban form and transportation infrastructure mutually influence each other. For example, dense Hong Kong is served by a viable and efficient public transit network, whereas many sprawled US cities are best served with automobiles. Here we present a simple model of a mono-centric city with two modes, public transit and automobiles, and transport infrastructure investments. The contribution to the literature is two-fold. First, adding to urban economic theory, we analyze how public transport costs are endogenously determined by fuel price and urban form if an urban planner provides the infrastructure. But a private mass transport provider would underinvest into public transport infrastructure. Second, adding to the ongoing discussion on urban transport and energy use, this two-modal model can help to explain empirical observations on urban form, transport CO_2 emissions and modal share, emphasizing the causal role of transport costs for urban form. The results encourage further research in the economics of sustainable and energy-efficient cities.

1. Introduction

Urban form has been identified as a crucial dimension of sustainable cities (Glaeser and Kahn, 2010; Weisz and Steinberger, 2010). Population density is a simple metric of urban form. While population density itself remains insufficient to explain a plethora of interactions between inhabitants

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and the built environment, it nonetheless relates to two crucial dimensions of urban transport and energy conversation. First, higher population density tends to be associated with shorter distances to travel, reducing energy demand. In a global comparison of cities, urban population density is inversely correlated with urban transport energy use (Newman and Kenworthy, 1989). This correlation is weaker in US cities once controlled for accessibility of destinations and street network design (Ewing and Cervero, 2010), and is subject to more specific metrics of urban form (Mindali et al., 2004). Second, higher density enables financially viable public transit, which usually is more energy efficient than individual motorized transport (Bongardt et al., 2013). Public transit activity is negatively correlated with private transport activity (Newman and Kenworthy, 1996). A minimum density is seen as a prerequisite for financially viable and environmentally effective public transport (Frank and Pivo, 1994; Cervero, 1998; Bongardt et al., 2010).

While causalities remain somewhat unclear in this literature, there is a disparate discipline - urban economics - which has mostly developed around models explaining the interaction between transport and urban form. The model framework dates back to von Thünen in the early 19th century, who explored the relationship between agricultural product choice, land rent, and transport distance to the central market place (von Thünen, 1826). It was Alonso, and later Muth and Mills, who transferred this framework to residential location choice, and commuting costs to the central business district (CBD) (Alonso, 1964; Fujita, 1989). In their model, increasing commuting costs are compensated by decreased land rent, resulting in decreasing population density towards the urban fringe. In turn, lower marginal transport costs imply more urban sprawl.

This world of models from urban economics remains surprisingly unconnected to the empirical data and correlation studies initiated by Newman and Kenworthy (1989). This paper connects an urban economic framework to questions of population density, mode choice, relying both on analytical and numerical observations. The focus of this paper is on the optimal municipal investment decision, which optimizes total utility when public transit and population density influence each other. We use this model to shed light on possible causal relationships between population density, modal share and energy consumption, reengaging with the empirical database of Newman and Kenworthy (1989), Newman and Kenworthy (1996). We believe that an engaged discussion between urban economists and urban transport planers is fruitful for both communities.

In Section 2, we introduce the model, in which public transit is fully endogenous to urban form and generalized costs of private transport. In this model, generalized transport costs, urban form and mode choice are nonlinearly related to each other. In Section 3, we present numerical results demonstrating the interrelationship between transport costs, population density and modal share. We also demonstrate that free-market provision of public transit is socially inefficient. Finally, in Section 4 we show that this model can reproduce some relevant results from Newman and Kenworthy (1989), Newman and Kenworthy, 1996, in particular the relationships between population density and transport energy use, and between transport distance of different modes.

2. A bi-modal city

This section introduces a density and modal share modeling framework – based on the Alonso–Mills–Muth model of a monocentric city with transport costs and housing market. The model builds on a substantial literature base from urban economics.

Mills suggested to expand the AMM model to additional transport modes, a recommendation taken up by some of his peers. Capozza (1973) emphasized the tradeoff between capital and land as scarce input factors for subway versus road infrastructure: in the inner city, land becomes so scarce and valuable that land-intensive road infrastructure is substituted by capital-intensive subway lines (Capozza, 1973). Haring et al. (1976) demonstrate that an additional transport mode reduces the land rent differential between CBD and urban fringe (Haring et al., 1976). Anas and Moses (1979) not only specify two modes but also explore the role of discrete transport corridors, producing a number of varying urban forms as a function of generalized costs in dense and sparse radial transport networks (Anas and Moses, 1979). Also in 1979, Kim, a PhD student of Mills, published a two-mode model in which a city with two million inhabitants has sufficient population density to support a subway system,