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A 'sustainability window' of urban form

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ABSTRACT

With global environmental change and the rise of global megacities, environmental and social externalities of urban systems, and especially of urban form, become increasingly prevalent. The question of optimal urban form has been debated and investigated by different disciplines in numerous contexts, including those of transport costs, land consumption and congestion. Here we elucidate theoretically how urban form and the urban transport system systematically modifies sustainability concerns, such as greenhouse gas emissions, local air pollution and congestion. We illustrate our analytical considerations with empirical analysis. Denser urban form would almost unambiguously mitigate climate change, but it would also lead to undesired effects, such as a higher proportion of urban dwellers affected by air pollution. Our study presents a 'sustainability window' by highlighting trade-offs between these sustainability concerns as a function of urban form. Only a combination of transportation policies, infrastructure investments and progressive public finance enables the development of cities that perform well in several sustainability dimensions. We estimate that a residential population density between 50 and 150 persons/ha and a modal share of environmental modes above at least 50% corresponds to the sustainability window of urban form. The parameters of the sustainability window of urban form is subject to policy changes and technological progress.

1. Introduction

The sustainability of cities challenges scientific constituencies that emphasise issues of participation (Portney and Berry, 2010), or global environmental governance (Bulkeley and Betsill, 2005), or the transportation system (Newman and Kenworthy, 1999). By 2050, about 67% of the world's population is expected to live in cities – a total of 6.3 billion urban dwellers in a world population of 9.3 billion people (UN DESA, 2012). Issues of urbanisation and global environmental change, local environmental challenges along with equity concerns become increasingly prevalent. Catching perhaps the highest attention, cities also enter the spotlight as places combatting climate change. Inversely, climate change literature focuses progressively on cities, revealing a significant potential for local mitigation and adaptation in an age of rapid expansion of urban areas (Seto and Reenberg, 2014). About 40% of all transport emissions occur in urban areas (I.E. Agency, 2008), and therefore CO_2 reduction efforts increasingly focus on this mitigation potential (Kahn Ribeiro et al., 2012; Sims et al., 2014; Creutzig, 2015).

The key issue underlying the city-transport-climate nexus is, arguably, urban form. It has long been argued that higher urban density translates into lower per capita transport energy consumption (Newman and Kenworthy, 1989), a relationship

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which also emerges straight from theory, specifically from the canonical framework of urban economics (Fujita, 1989; Creutzig, 2014). Detailed analysis elucidates that this relationship can in fact be explained by more specific urban form indicators, such as 'distance to work' and 'connectivity' (Ewing and Cervero, 2010). Nonetheless, urban population density remains a reasonable proxy for energy use in transportation.

Clearly, urban modifications are subject to multiple objectives. Urban transport – especially individual motorised transport – causes manifold environmental and social externalities that go beyond the climate change externality. Air pollution from vehicle exhaust constitutes one of the most serious public health hazards in cities, and congestion is an economic externality with high costs. For example, in emerging economies like China, urban transport, air pollution and congestion are perceived as much stronger concerns than climate change Creutzig and He (2009) and in the 1980s, the European environmental debate focused on acid rain as one of the most negative consequences of transport. However, the magnitudes of all of these externalities change with urban density (Parry et al., 2007; Creutzig and He, 2009; Creutzig et al., 2011). Importantly, while energy use reduces with increasing urban density, air pollution and costs of living become increasing burdens for residents. Hence, the local and global rationales for policies influencing urban form indicate a considerable trade-off between the benefits and harms of increasing urban density. The increasing pervasiveness of the climate change mitigation challenge, along with local environmental and social urban issues calls for a fundamental overhaul of urban mobility. This debate is spanning from the climate change community to urban planners, architects and also local initiatives who think about the wider goal of 'sustainable cities' and liveable urban centres (Gehl, 2013). The debate hence needs to tackle many issues simultaneously.

Urban density alone, however, cannot explain urban transport energy use. Modal shares also influence urban energy use and emissions. Higher modal shares of public transit, cycling and walking – i.e. lower modal shares of car use – typically result in lower greenhouse gas emissions in urban transport systems (Kahn Ribeiro et al., 2012; Bongardt et al., 2013). Urban form and modal shares are co-dependent on each other. A minimum urban density is required to enable a shift towards low-carbon modes and, in fact, increases financial viability of public transport systems (Creutzig, 2014). Sprawling cities with long distances such as Los Angeles or Houston encounter tough challenges to enable bike commuting, or to get sufficient ridership numbers for public transport systems in suburban areas. Choosing the right infrastructure design plays another important role for enabling modal shift to cycling. This been demonstrated by the city of Copenhagen, which has driven a massive modal shift to cycling by providing the pertinent infrastructure for its citizens, and also improved urban quality of living (Pucher and Buehler, 2008; Gehl, 2013). Besides urban energy use, modal shares also have relevant impacts on congestion, air pollution and urban quality of life. Hence, there is a strong rationale to include modal shares as a co-factor of urban form when investigating the trade-offs of urban form and the environment.

Here we contribute to this challenge by systematically analysing how urban density and modal share modify global and local environmental and social benefits. We are basing this study on a straightforward monocentric urban economics model. This allows us to conceptualise trade-offs between the individual dimensions and to identify a 'sustainability window' of urban form where all of these concerns are adequately addressed. The choice of a monocentric city model means that the study stays conceptual, and that we do not account for polycentricity, technological change or other more complex issues that lie in the very nature of urban studies. We conclude by indicating policy options that can modify the sustainability window to further improve the benefits in at least some dimensions.

We proceed as follows. In Section 2, we explain how urban form modifies climate change, congestion, air pollution and urban land rent. We provide an analytical model that predicts how transport costs and modal shares influence these sustainability concerns, and how changes in urban form can realise concurring benefits. In Section 3, we present the results of this conceptual analytical model and the emerging 'sustainability window'. We also provide examples of policy options that improve the performance of the sustainability window. In Section 4, we statistically analyse the factors contributing to the sustainability window. Section 5 discusses policy implications and concludes the article.

2. Urban form, urban transport and its co-benefits

The quality of urban life depends on multiple dimensions and on the local context, but it seems clear that it is virtually always influenced by a few important dimensions. At the heart of our analysis lie the sustainability concerns of urban transport and urban form. A thorough and general description of urban transport externalities is given by Parry et al. (2007), for example. In the following, we first describe the classic urban economics framework upon which our study is built. It is used to compute density profiles for several types of cities, differing from each other through their modal shares and urban densities. The key control variables which influence the externalities of urban transport are the generalised transport price and a parameter modifying the share of individual motorised transport. Section 2.2 follows by describing the implementation of each sustainability concern, or in economic parlance, externality, that can be attributed to car transport: air pollution, road congestion and climate change. A social concern to represent variability of land rents with density is also described.

2.1. Modelling urban form and the dimensions of urban transport

We have chosen to use a straightforward monocentric city model (see description below) and thus build on the well-founded framework of urban economics. It is straightforward to implement the sustainability concerns and conceptually