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Sensitivity analysis of traffic congestion costs in a network under a charging policy

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ABSTRACT

The costs of congestion can be measured using three approaches: the total costs, the marginal costs and the 'excess burden'. Understanding variation in these measures with particular policies is important for planning and resource management. Assessing the cost distribution (e.g. according to priority routes or urban segments) is key to assessing the delivery of both transport objectives and wider social objectives. The aim of this research is to illustrate how the costs of congestion vary with policy-related demand changes around the city of Milan.

The case study used is the "Cerchia dei Bastioni" (called for administrative purposes Area C). This is an old urban area within the inner centre of City of Milan network, with a 'real life' charging policy that is applied to private vehicles. A large number of scenarios with differing demand levels and elasticities by vehicle classes were explored and equilibrium assignment used to assign demand to the network. Alternative measures for congestion costs were calculated along with other link parameters. Further data collection, including a parallel field survey of changes in PT speed, was also undertaken.

The results indicate a high degree of correlation between changes in the different measures of congestion and changes in vehicle speed (at different levels of demand). Changes in the total cost of congestion are, however, more marked than changes in the excess burden of congestion. Sub-optimal conditions appear to exist in certain parts of the network which (it is conjectured) arise as a consequence of the configuration of the network i.e. the presence of one way streets and vehicle restrictions. Identifying a more optimal network is left for further research, as is identifying the precise conditions for which vehicle speeds can be used as a proxy for changes in congestion.

1. Introduction

Congestion is seen as an issue in urban networks as well as inter-urban environments and as such it features heavily in regional, national and supra-national transport policies. The European Commission white paper (2011) proposed that congestion in the European Union (EU) is often located in and around urban areas and costs nearly 100 billion Euro (or 1% of the EU's GDP) annually. Congestion is invariably regarded negatively and it is seen as a limiting factor on economic efficiency as well as a source of pollution. One common policy approach associated with the costs of congestion is that of road charging schemes (for example in Stockholm (City of Stockholm, 2005)), where an understanding of the costs of congestion may create a more conducive public-acceptance of the scheme and also set an economic framework within which charges may be set.

This research is concerned with an investigation around the sensitivity of traffic congestion costs in Milan. In particular, how these costs vary with a charging policy specifically introduced to reduce congestion but with a secondary goal to achieve environmental improvements. The starting point is to consider the definition of congestion and how the costs of congestion may be measured. The calculation of congestion costs requires the use of a transport model and as such it is resource intensive for city authorities to monitor. The paper then continues to consider whether vehicle speeds can act as a proxy for congestion costs for the purposes of monitoring. A specific evaluation concerning speed changes for public transport after the charge is presented.

The principal contribution of this paper therefore is to illustrate how the different costs of congestion vary with policy-related demand changes around the city of Milan and how they also relate

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to vehicle speeds. The findings have particular relevance and implications for city policy makers by illustrating the methodology used to measure the different congestion costs in a practical and real environment, given what tools may be readily available to them. Due to the complexities of measuring the costs of congestion, the examination of the changes in vehicle speeds as a proxy for congestion costs has a strong policy interest – particularly where congestion reduction targets have been set. The analysis presented here has also highlighted specific outcomes that would be of interest to policy makers wishing to build a case for charging schemes in particular contexts, for example, changes in bus speeds following the introduction of charges. Whilst based on a firm existing theoretical foundation, the essence of the paper is as a case study rather than a theoretical exposition. The aggregate picture is made up of a number of disaggregate calculations, a sample of which are presented here. Our goal in the paper is to present information at a level that might be of interested to policy makers and as such is likely to be of interest to a broad range of transport sector stakeholders.

This paper has the following structure. Following this introductory section, the second section describes the underlying causes to congestion, what congestion is, its relevance to policy and the different methods used to measure it, as well as providing empirical estimates of the costs of congestion found in the literature. Section three sets out the modelling methods used in this paper to calculate the costs of congestion, whilst the fourth section introduces the City of Milan and the demand management schemes being analyzed. Results are presented and discussed in the fifth section and conclusions are set out in the final, sixth, section.

2. Congestion and its costs

Despite frequent use of the term, the concept of congestion is often understood but less frequently defined. Congestion can be present as a physically measurable phenomena but perceived congestion (by users of the road network, residents and others) may be as important as the more objective evidence in driving the need for policy measures. The definition given by the Highways Agency (1997) captures the wide understanding of congestion as: '*the situation when the hourly traffic demand exceeds the maximum sustainable hourly throughput of the link.*' Alternatively, Goodwin (2004) defines congestion as '*the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches its capacity*'. In addition, the evidence to date is that congestion, however defined, is closely linked to externalities that include environmental impacts (Barth and Boriboonsomsin, 2008) and safety (Brownfield et al., 2003). In the case of the first, the presence of congestion leads to a driving behaviour that includes frequent 'stop-start' and periods where the engine is near stationary with the engine idling, leading to increases in emissions of local pollutants. In the case of safety, congestion can lead driving behaviour whereby vehicles have reduced headways, drivers may lose attention to the driving task or (due to frustration) take risks in the task, increasing the accident rate. It is clear on an intuitive basis that congestion results in a set of costs – to the driver, other traffic network users, residents and the environment. On a more rigorous basis, it is possible to not only define congestion but to calculate the costs of congestion and link these calculations to future policy priorities and instruments. Grant-Muller and Laird (2007) give an elaboration of two fundamental approaches to interpreting congestion: firstly a 'traffic engineering' perspective (which underlies many measures of congestion) and secondly an economic view (related to principles behind marginal costs of congestion). At the practical level of measuring congestion, approaches fall into four approximate classes comprising travel time (or speed) based measures, volume based measures, area based measures and summary indices (or more complex model outputs). This also opens other questions about reliability and the costs of traffic estimation (Waadt et al., 2009). More recent definitions have taken a three-dimensional concept of congestion, for example Marfia and Roccetti (2011) who define a road to be 'in a congested state (be it high or low) when the likelihood of finding it in the same congested state is high in the near future'. Moran and Koutsopoulos (2010) frame a definition of congestion from the users' perspective and as a stochastic process. In practice, the simpler measures are more commonly applied than relatively complex measures. Bilbao-Ubillos (2008) identifies eight main costs (most of them financial and environmental), to measure the total cost of congestion in comparison to smooth traffic flows.

All networks, whether they are telecommunication networks, energy networks, transport, etc. are subject to congestion (Shy, 2001; Mayer and Sinai, 2003). Congestion arises in networks due to a mixture of network properties including the sunk costs of construction, invariant capacity and the fact that networks invariably operate under conditions of economies of scale, scope or density. From a policy perspective it is therefore essential that any network, including a transport network, is managed properly. The size (scope and capacity) of the network needs to be sufficient for the needs of its users specifically and society in general. Typically there therefore exists a tension between the wishes of the users of the network and the ability of the owners/managers to expand that network. The price to access and use the network needs to be efficiently managed so as to ensure excessive prices are not charged, and that operating, renewal/investment costs are recovered to an appropriate degree. In a transport context, policy commentators often estimate the costs of congestion as part of this debate – particularly the aspect of the debate related to the provision of additional capacity. This has led to a wide range in the estimates. For the UK, for example, the range extends from £2 billion per year (Dodgson et al., 2002) to the often quoted Confederation of British Industry (CBI) estimate of £20 billion per year (CBI, not dated, cited in Grant-Muller and Laird, 2007). In this case there exists a factor of almost 10 between the estimates.

This large range stems from the fact that there are two principal definitions for the cost of congestion: the total cost of congestion (TTC) and the excess burden of congestion (EBC) (Grant-Muller and Laird, 2007). The *total cost of congestion* effectively compares the current or predicted situation against a reference state of zero congestion. The concept is illustrated in Fig. 1 where the total cost of congestion is given by area A. In this figure V_0 trips experience a

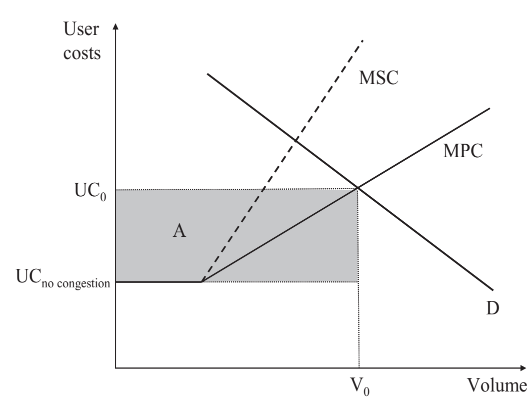

Fig. 1. Total cost of congestion.

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