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Analysis

The drawbacks and opportunities of carbon charges in metropolitan areas — A spatial general equilibrium approach

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ABSTRACT

In cities there is a variety of economic and spatial forces that may influence to what extent a travel-related CO_2 emission pricing can be an effective instrument to contribute to the achievement of CO_2 reduction goals. Therefore, we examine the effectiveness and impact of CO_2 emission charges using a spatial general equilibrium model of an urban economy, calibrated according to an average German city. Our analyses suggest that the imposition of a Pigouvian type CO_2 emission charge on urban passenger travel may be able to reduce emissions by about 1%–11%, depending on the estimated social damage cost of carbon dioxide. Such a policy increases urban welfare mainly on account of a reduction of congestion costs. However, pricing congestion directly not only provides higher urban welfare but also higher emission reductions. Pricing congestion and CO_2 emissions simultaneously allows to achieve a wide range of emission reduction goals. If, however, the reduction goal is very ambitious the emission charge must be raised to higher levels. Then, distortions in the urban markets and in spatial travel decisions lower labor supply and thus urban production, income of city residents, federal tax revenue, income of landowners outside the city, all together implying losses in welfare.

1. Introduction

A CO_2 emission tax is a market based economic instrument to internalize climate change effects induced by greenhouse gas (GHG) emissions (see e.g. Poterba, 1993; Baranzini et al., 2000). Levying such a tax on travel-related CO_2 emissions induces effects similar to those imposed by a gasoline tax which is extensively examined in a second-best setting (see e.g. Parry and Small, 2005). Within an urban economy further effects usually not considered accrue on account of spatial location decisions. The increase in the cost of travel implies relocations such that the length of travel trips declines. This might also affect congestion. Moreover, the availability of alternative transport modes may result in a choice of less GHG intensive modes implying less automobile trips and so a potential to curb congestion. However, the benefits from the accessibility of centrally located land areas and the scarcity of land in those areas restrict the power of such an instrument. Therefore, residential, employment as well as shopping locations are spread across the urban area making travel activities essential. As a consequence, there is a variety of forces that may influence whether travel-related emission pricing can actually be both an effective instrument to contribute to the achievement of CO_2 emission reduction goals within a metropolitan area and an instrument to improve welfare in this area.

This is our point of departure. We examine the power of CO_2 emission charges for achieving different CO_2 emission reduction levels[2] in urban passenger transport and explore the impact of these charges on the city and its residents. The automobile emission charge we derive consists of two components: a tax which is proportional to individual CO_2 emissions (and thus gasoline consumption) and a route dependent toll component

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[2] CO_2 emission reduction goals can be, e.g., derived from current EU policy. The EU aims at limiting the global temperature rise to 2 °C compared with pre-industrial levels (European Commission, 2008). Among others the EU regulates that new car fleet sales should on average not exceed 95 g of CO_2 emission per km in 2020. Taking 2007 as reference year, fleet-average CO_2 emissions of automobile manufacturers in the EU amounted to about 160 gCO_2/km (European Federation for Transport and Environment, 2009). This implies a passenger car specific CO_2 reduction goal of about 40% (Tol, 2007 provides a discussion of different goals and their weak link to scientific results).

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which explicitly takes into account the interaction between congestion, gasoline consumption and emissions. This second component constitutes a price on the emission externality, i.e. on marginal external CO_2 emissions of others caused by one's decision to travel by automobile.[3] However, on account of the similarity of this externality to a congestion externality we also consider the interplay between a congestion toll and the emission charge.

Examining this issue is significant because more than 73% of the population of OECD countries lives in urban areas (World Bank, 2008) which are, thus, the center of private activities of the majority of people. This includes the emission of GHG by transport, production and housing. Although GHG emissions decline with urban density (see e.g. Newman, 2006; Brownstone and Golob, 2009; Glaeser and Kahn, 2010), traffic related activities in agglomerations are a major source of such emissions. For example, in London transportation activities cause 22% and in Barcelona 35% of all CO_2 emissions of the respective city (Dodman, 2009; Satterthwaite, 2008). In the European Union (EU) CO_2 emissions from the road sector were by about 30% higher than in 1990 and accounted for 71% of total emissions from transport (besides railway and civil aviation) in 2006. Moreover, transport as a whole is the only sector of the European economy where emissions are predicted to increase in the future (European Commission, 2008).

To address these issues we employ a spatial computable general equilibrium model of an urban economy calibrated to an average German metropolitan area. As far as we know, this is the first time that such an approach is applied to CO_2 emissions. In this regard, our analysis is, to the best of our knowledge, the first modeling framework that deals systematically with the relationship between spatial structure, transport, climate change and economics in a spatial urban model.[4] This approach allows to offer more specific insights into the performance of the various instruments for the purpose of combating global warming as postulated by Grazi and van den Bergh (2008). Most computable general equilibrium (CGE) models considering transportation focus on congestion costs and tolls imposed to internalize external time delays (e.g. Anas and Xu, 1999; Anas and Rhee, 2006; Conrad and Heng, 2002), though there are papers on carbon taxes (e.g. Berg, 2007; Böhringer and Rutherford, 2002), other environmental taxes (e.g. Bovenberg and Goulder, 1996), or emission allowances (e.g. Böhringer and Rosendahl, 2009). However, a spatial equilibrium is not implemented in most CGE studies except for Anas and Xu (1999) or Anas and Rhee (2006). Moreover, as far as carbon taxes are considered these studies do usually not consider congestion-related externalities. In contrast, we derive a CO_2 emission charge by applying the marginal cost principle on an empirically derived emission function where the charge level is endogenous and may vary across urban space depending on spatially differentiated traffic which is endogenous as well.

According to our simulations levying a pure Pigouvian type CO_2 emission charge may reduce urban passenger traffic related emissions by about 1–11% depending on the assumed social damage costs of CO_2. In addition, such a policy increases urban welfare, even if emission charge revenues are not used to cut other distortionary taxes such as labor taxes. This result contrasts with the standard outcome that environmental taxes cause a welfare decline. Though there might be a double dividend (Pearce, 1991) in the labor market which implies an opposite force to the negative effects of higher transport or energy taxation it is usually too weak to offset welfare losses induced by higher transport or energy costs and the interaction with other distortionary taxes (see Jorgenson and Wilcoxen, 1993; Bovenberg and De Mooij, 1994; Goulder, 1995; Berg, 2007). The main reason for our results is that we also consider congestion externalities. In this case the emission charge causes positive side-effects on congestion (see also Parry and Bento, 2002).

However, we also find that implementing a congestion toll imposed in order to internalize costs associated with congestion-related automobile travel time delays is a more efficient instrument in various respects, even the reduction of travel-related CO_2 emissions.

Imposing both levies an emission charge and a congestion toll simultaneously at a Pigouvian level reduces CO_2 emissions by about 19–21% depending on the damage cost of carbon dioxide and raises urban welfare (but not non-urban welfare).

Increasing the emission charge level in order to realize more ambitious emission reduction goals causes stronger distortions in the urban markets and in spatial travel decisions. This lowers labor supply, urban production, income of city residents, federal tax revenue and income of landowners outside the city, all together implying welfare losses. As a consequence, a very ambitious climate-related policy based on additional CO_2 emission charges on traffic related emissions may become harmful for residents.

The paper is organized as follows: in Section 2 we present the main features of the spatial model. Section 3 describes the model calibration and some results of the initial benchmark simulation. In Section 4 we analyze the impacts of different urban travel-related pricing policies. Particularly, we discuss effects regarding changes in emissions, location decisions, the spatial distribution of economic activity and welfare. Section 5 concludes and gives some suggestions to further research.

2. The Urban Model

We use a spatial urban general equilibrium model in the tradition of the polycentric model of Anas and Xu (1999). The model explicitly takes into account the interactions between different markets (land, labor, commodities), households and firms. All location decisions of households and firms are determined endogenously in the model. Households (HH) can vary in idiosyncratic tastes for locations within the urban area such that decisions of households create mixed land use and various possible travel patterns, a result which is commonly observed in real urban areas. Novel model features comprise heterogeneous households who are subject to a progressive income taxation scheme, travel mode choice, endogenous gasoline consumption and CO_2 emissions with the corresponding marginal cost based emission charges which depend on traffic conditions. Moreover, main characteristics of the German interdependencies among fiscal authorities are explicitly taken into account. In the following we only present the main features of the model which are specific particularly to the climate policy.

The agglomeration area (see Fig. 1) encompasses $I=9$ zones (locations), where the innermost zone $i=5$ is assumed to be the city center. All zones have a length of $d_i=4.5$ kilometers (km) so that the whole urban area expands over 40.5 km. The zones 3–7 shape the city of the complete circular urban area. Furthermore, one can think of zones 2 and 8 as the surrounding inner suburbs and zones 1 and 9 as the surrounding outer suburbs.

In each zone i a given homogeneous land area, A_i, is available for residences, establishments and roads. Supply of land increases with distance from the city center. The zones are linked via a transport network with distance d_{ij} between the centers of the zones.

A sufficiently large number of firms produce in each zone i a zone-specific commodity by applying a Cobb–Douglas technology that combines land and labor supplied by low-skilled and high-skilled

[3] While we use the terms “tax” and “toll” to distinguish between both components, the term “charge” is used to denote the complete levy.

[4] There are agent based studies, e.g. Hensher (2008), which also consider spatial decisions such as working location and residential location choices as well as travel mode choice. However, those models do not consider economic features such as labor markets, good markets or production and, thus, full general equilibrium analysis (see Irwin, 2010).