

# **An Empirical Analysis of Urban Form, Transport, and Global Warming**

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## **Abstract**

Does urban form affect travel choices and thus CO<sub>2</sub> emissions by individuals? If this is the case, then urban form and policies that influence it deserve serious attention in the context of long-term climate policy. To address this issue, we examine the impact of urban density on commuting behavior, and the consequences for CO<sub>2</sub> emissions. The empirical investigation is based on an instrumental variable approach (IV), so as to take account of endogeneity of residence location. We decompose travel demand into components related to modal split and commuting distance by each mode.

## **1. Introduction**

Despite its short history, research on climate policy has generated an immense literature. This paper addresses a theme that has received little attention so far, namely the effect of urban form on greenhouse gas (GHG) emissions through transport. Urban form covers such aspects as density, geometric shape, use of land (residential, industrial), and infrastructure (road, rail, waterway), with implications for indicators such as density, fragmentation and accessibility.<sup>1</sup> Urban form may be affected by policies in a number of ways. In Europe, spatial (or physical) planning is the most common approach, which covers the set of policy instruments available to regulate and manage land use in the broadest sense of the word, including infrastructure, settlements, parking spaces, etc (Grazi and van den Bergh, 2008). Spatial planning can take the form of zoning of business areas, regulating density (and thus height) of buildings, and investment in infrastructure. Studying the role of urban form in global warming is relevant for two reasons. First, there is likely a close relationship between urban structure and global warming through GHG emissions and energy consumption from economic activities located in cities. Second, urban form affects transport activity, which in turn contributes to global warming (Greene and Schafer, 2003). The latter relationship is the focal point of this article.

Worldwide CO<sub>2</sub> emissions from transport have been increasing rapidly over the last two decades. According to last available data, in 2004 the transport sector accounted for one-fifth of the world energy-related CO<sub>2</sub> emissions (IEA, 2006). This illustrates the relevance of analyzing transport in the context of global warming. What is more, this share is expected to grow at a rate of 1.7% per year up to 2030 (IEA, 2006). The annual growth rates of CO<sub>2</sub> emissions by the transport sector in the developing world and in economies in transition are projected to be even higher, namely 3.4% and 2.2%, respectively (IEA, 2006). These increases are mainly due to increases in the volume of road transport, with passenger movements accounting for 60–70% of increases in total emissions (IEA, 2004). Reducing GHG emissions by transport leads to considerable ancillary benefits, as other environmentally harmful gases (notably NO<sub>x</sub> and SO<sub>2</sub> and particulate matter) resulting from fossil fuel

combustion will be reduced as well (e.g., Elkins, 1996). This in turn improves local health and well-being. In addition, spatial planning aimed at mitigating GHG emissions might reduce traffic congestion. All in all, this suggests that direct local and global benefits of climate policy through spatial and transport planning go well together. Recognizing this potential, leading international institutions (OECD, 2007) and national governmental agencies (EPA, 2001) consider land-use policies — especially in urban areas — as an effective instrument to combat the contribution of transport to global warming.

The impact of urban form on urban transport and associated GHG emissions follows a number of routes. Urban form affects transport distances and the number of trips made — between home, work and service areas like city centers and shopping areas.<sup>2</sup> In particular, residential density affects travel behavior by getting people in close proximity to destinations and consequently increasing the number of possible destinations that can be reached within the same range of distance. Here we focus on the impact of residential density on commuting behavior, but our findings seem to be extendable to other travel choices.<sup>3</sup>

A number of theoretical studies suggest a negative relationship between commuting distance and residential density (e.g., Fujita, 1989). The main reason is that workers choose a residential location (conditional on workplace location) by making a trade-off between generalized commuting cost (or distance or duration) and housing prices. In high density areas, workers benefit from a shorter commuting distance but face higher housing prices, whereas in low density areas they enjoy lower prices but travel longer distances. In addition, changes in modal split, notably a shift from car to more energy-efficient transport modes like walking, biking and public transport will contribute to a reduction in transport-related GHG emissions.

Here we intend to study to what extent urban form affects individual travel behavior and consequently the transport-induced level of CO<sub>2</sub> emissions. In line with other studies, urban form is measured through density (Pushkarev and Zupan, 1977; Niemeier and Rutherford, 1994; Schimek, 1996; Kenworthy and Laube, 1999; Schafer and Victor, 2000). Although this does not capture all aspects of spatial organization, residential density can in fact serve as a reliable proxy for urban form when measured at a sufficiently disaggregated level (see for example, Pushkarev and Zupan, 1977; Niemeier and Rutherford, 1994; Schimek, 1996; Giuliano and Narayan, 2003). Higher density generally goes along with more efficient public transport services, better spatial coordination between services, activities and individuals, and better accessibility to infrastructure. Our method of analysis consists of three steps. First, we undertake an econometric analysis of the impact of density on commuting distance using OLS and instrumental variable (IV) approaches. Second, we decompose the specific effects into the contribution of choice of transport mode and travel distance. Third, we assess the impact of urban density on CO<sub>2</sub> emissions.

The relevance of devoting policy attention to urban density so as to gear processes of urban re-organization towards more efficient energy use (from building and transport) is underlined by an increasing number of ongoing national projects on this issue (in France, The Netherlands, Germany, etc.). In many countries in Europe and in particular in The Netherlands, urban density is strongly determined by national governmental policy, through spatial planning. As an extreme case, consider Almere, one of the youngest cities in The Netherlands, which was built on land gained from the sea about 50 years ago. It was almost entirely planned by the national government so that the location, size, type of residences, and therefore urban density are more the result of planning than of autonomous development.

Obtained insights from the present empirical analysis can support policies affecting urban form such as spatial planning aimed at reducing energy consumption or CO<sub>2</sub> emissions. On the other hand, if the results suggest that in making travel decisions individuals are hardly affected by urban structure, then these policies cannot be expected to play an important role in combating GHG emissions. Note finally that our approach does not address the impact of urban form on social welfare or individual happiness. This is no shortcoming, as we focus on

carbon dioxide emissions that create external costs which in turn harm social welfare. Evidently, such external costs are by definition undesirable for a society and must be taken care of regardless of other effects of urban form.

The remainder of this paper is structured as follows. Section 2 outlines the theoretical background of the relationship between urban density and travel behavior. Section 3 presents the results of the econometric analysis and performs a decomposition analysis. Section 4 calculates the impact of differences in urban density on CO<sub>2</sub> emissions. Section 5 concludes.

## **2. Urban Density and Travel Behavior**

The study of the relationship between urban form and transportation demand has a long history, starting with the study of Pushcarev and Zupan (1977), and it covers both aggregate and disaggregate studies of individual travel behavior. In disaggregate studies (e.g., Boarnet and Sarmiento, 1998, Crane and Crepeau, 1998, Giuliano and Narayan, 2003; Handy et al., 2005; Bento et al. 2005) the dependent variable (e.g., commuting) is measured at the individual level, whereas in aggregate studies (e.g., Newman and Kenworthy, 1989a and 1989b; Cervero and Gorham, 1995; Kenworthy and Laube, 1999; Newman and Kenworthy, 1999) the dependent variable is measured at the level of the city or region (e.g., the average commuting distance within a city). This literature covers at least 70 studies, which deliver mixed results (see Ewing and Cervero, 2001). The majority of studies find a statistically significant but usually small effect of density on transport (e.g., Handy, 1996; Levinson and Kumar, 1997; Boarnet and Sarmiento, 1998; Ewing and Cervero, 2001). Other studies find a negative correlation. For example,

Newman and Kenworthy (1999) used a sample of 32 cities in four continents and found a negative statistical correlation between residential density and transport demand. Gordon et al. (1989) find that there is a positive relation between metropolitan residential densities and commuting times. The variety of findings may be due to data limitations, the use of different density measures, and differences in statistical methods. For example, some studies do not account for socio-demographic variables, whereas others only include attitudes and preferences of respondents.

Few studies distinguish clearly between statistical correlation and causality in terms of the effect of urban form on travel (see Handy et al., 2005).<sup>4</sup> We then intend to verify that the relationship between the two variables considered is such that individual travel choices are the result of urban form rather than the other way around. It is important to note that urban form only gradually changes over time, whereas simultaneously many other changes occur in the economy at large. As a result, in terms of a particular time order, the effect of urban form on transport is difficult to identify. Hence, we rely on cross-section data, which is common in the literature (see, e.g., Handy and Clifton, 2001; and Bagley and Mokhtarian, 2002).<sup>5</sup> In the case of cross-section data, a number of criteria have to be met then, in order to show causality between an independent variable (the cause) and a dependent one (the effect): (1) association: a statistical association between the cause and effect is found; (2) a causal mechanism: the mechanism by which the cause influences the effect is known; and (3) non-spuriousness: no third factor contributes to an accidental relationship between the variables (Singleton and Straits, 1999; Wooldridge, 2002). Correlation is a minimum condition and satisfies only the first criterion. That the second criterion is satisfied is clear from the discussion in Section 1 in which the various routes were outlined through which urban form affects urban transport and associated GHG emissions. Both the first and the second criteria have often been addressed in the literature on urban form, while the third one has received less attention. It is tested for in the current study, so that in effect we address all three criteria and therefore be able to assess whether the impact of urban form on GHG emissions is of a causal nature.

The problem associated with the third criterion requires special attention and can be illustrated as follows. Individuals who do not mind or even enjoy traveling driving long distances are more likely to live relatively far from job centers. Therefore, such individuals

would sort themselves into residential areas where housing prices are relatively low. This phenomenon is known in the literature as ‘self-selection’, and it is influenced by such factors as preferred lifestyle, accessibility to educational and recreational facilities and security concerns. Whether, and the extent to which, this process occurs is an issue that has been long debated in transport economics, urban economics and regional science (Cao et al. 2006). The literature that considers residential self-selection is rather small, and the results are somehow mixed. For example, Boarnet and Sarmiento (1998) and Greenwald and Boarnet (2001) both use an instrumental variable technique to test the impact of the urban structure at the neighborhood scale on travel decisions regarding non-working purposes. But while the former study considers automobile trips and shows that urban structure has little impact, the latter study focuses only on walking as a travel mode and finds that urban structure affects travel choices considerably. Krizek (2003) applies linear regression to a longitudinal design to show that modifications in neighborhood and regional residential structure are responsible for most changes in travel behavior. Yet, the study does not account for individual characteristics, which may lead to biased interpretation of the findings. Finally, Schwanen and Mokhtarian (2005) show that the influence of urban structure is stronger for suburban residents than for urban residents, once self-selection of residence location is controlled for.

Not accounting for the effect of this residence location selection mechanism may lead to spurious interpretations of the effect of urban form on individual travel behavior. Self-selection is ultimately concerned with the issue of causality or, in a model-technical sense, endogeneity. To be able to exclude endogeneity, and as a result a spurious relationship between variables related to urban form and travel preferences of individuals, we employ standard instrumental variable (IV) techniques (e.g., Angrist and Evans, 1998; Angrist and Krueger, 2001; Wooldridge, 2002). In this way we can address ‘causality criterion’ 3 (cf. Frankel and Rose, 2005). Standard regression techniques would in case of endogeneity most likely overestimate the effect of urban form on distance. An instrumental variable approach addresses the causal nature of the relationship between residential density and travel by taking into account that the urban density is self-selected (and therefore potentially endogenous with respect to individuals’ commuting behavior). In addition, our study assesses the underlying mechanism by which the impact of urban density on commuting distance occurs, by decomposing the effect on travel demand into effects on modal split and travel distance per transport mode. This further supports criterion 2. In effect, we address all three criteria and therefore are able to establish the causal direction of the effect of urban form on GHG emissions.

### 3. Econometric Analysis

#### 3.1 Data and variables

The data used for this study are on individual workers and come from the Dutch housing survey 1998. They cover housing characteristics, individual job characteristics, and individual commuting behavior. The dataset contains 25,991 valid observations.

*Urban density* is used as the main independent variable of interest. It is measured at the municipality level as the percentage of the population living in an area with a specific local density. For this purpose, the number of addresses per km<sup>2</sup> is categorized into five discrete classes at the municipality level. The data covers 458 municipalities. A municipality in the Netherlands contains on average about 12,000 residences.<sup>6</sup>

Three dependent variables of interest are *use of travel mode*, (the logarithm of) *commuting distance*, and *commuting distance by travel mode*. As a result, three separate models are estimated, i.e. one for each of these variables.

is the most important travel mode from the perspective of CO<sub>2</sub> emissions.<sup>7</sup> Table 1 shows that the probability of using a car to commute rapidly decreases with an increase of urban density.

This suggests a strong impact of urban density on the use of car, but — as emphasized above — it is an insufficient basis to infer the presence of a causal effect. Table 1 further shows that urban density is negatively related to *commuting distance*, *distance traveled by car*, and *use of car*. Finally, note that given the choice of the car, density is negatively related to distance, but that given the choice of other modes, a reverse relation is found. The average value of the commuting distance in our sample is in line with what is generally found in the literature, which is about 21 kilometers (CBS, 2004; van Ommeren and Dargay, 2006).<sup>8</sup>

### 3.2 The estimation procedure

In previous studies, it was assumed that unobserved variables that affect both density and travel are absent. This assumption is unlikely to hold as has been emphasized in the introduction. It is difficult in the empirical analysis to fully control for the variation in the spatial environment (e.g., supply of public transport, congestion, motorway accessibility, etc.), which may cause urban environment to become endogenous. In particular, it is extremely plausible that the individuals selection of a certain residence location depends on the individuals' travel behavior. Consequently, households sort themselves in neighborhoods based on travel preferences that are reflected by the urban form variables (self-selection). This would imply that the estimated coefficients on these variables are inconsistent due to their correlation with the error term. In other words, the relationship between the urban form variables and individual travel preferences might be spurious. Hence, in case of endogeneity, criterion (3) is not met and the causal nature of the relationship cannot be assessed. To avoid such endogeneity, we estimate a series of models using an instrumental variable approach (IV) (Boarnet and Sarmiento, 1998; Boarnet and Greenwald, 2000; Angrist and Krueger, 2001; Frankel and Rose, 2005). The accuracy of IV analysis depends on the validity of instruments that are employed. As instruments for density, we employ the following variables: *same gender of children*; *number of children in the household*; *number of adults in the household*; *partner's type of job*; *partner's sector of employment*; *partner's specialization level of employment*.

From a theoretical perspective, these variables *should not* directly influence the commuting behavior of workers (*commuting distance, use of the car*) but only indirectly via the choice of residential density. The choice of these specific instruments can be motivated as follows:

*Same gender of children* — The same gender of children reduces the need for rooms, because bedrooms can be more easily shared among children of the same sex. This in turn allows households to search for a residence in urban centers, where houses are generally smaller and with fewer rooms (Angrist and Evans, 1998). Consequently, household with children of the same gender are more likely to live in higher density neighborhoods.

*Number of children in the household and number of adults in the household* — The number of people in a household generally implies more need for space. This translates in such households being more likely to be found in residences in areas with a low price per square meter of housing, i.e. in suburbs.

*Characteristics of the partner's employment* — It is supposed that the qualification level and sector of employment of the *partner* do *not* directly influence individual travel behavior but do affect the geography of labor opportunities of the partner and therefore are likely to influence the choice of residence location.

In order to test the strength of the instrumental variables, we regress *urban density* on these three types of instruments and exogenous regressors. Results are reported in Table A1 in the Appendix. The instruments show a statistically significant effect. This implies that the first condition for validity of the instruments (instrument relevance) is satisfied. Moreover, to check whether our instruments satisfy the second condition for validity (instrument exogeneity), we perform a standard Hausman test for over-identifying restrictions (Wooldridge, 2002, pp 118–122). The *chi-square* is less than  $X_{247}$ , ensuring this condition to be satisfied.

### 3.3 Regression analysis of distance

Both OLS and IV estimates of the effect on (the logarithm of) *commuting distance* are presented in Table 2, along with goodness-of-fit and test statistics.<sup>9</sup> The estimated parameters are generally close to each other for the two approaches, the main exception being *urban density*.<sup>10</sup> The effect of density on commuting distance is estimated to be  $-0.063$  employing OLS, and  $-0.139$  employing IV. A test based on the Hausman *t* statistic (Wooldridge, 2002, pp 122–124)<sup>11</sup> indicates that the difference between the OLS and IV estimates is *just* not statistically significant at the 5% confidence level but significant at the 10% level, suggesting that the bias in the OLS estimate cannot be ignored.



Recall that *commuting distance* is expressed in logarithmic terms and that the commuting distance is on average 21.6 kilometers. The marginal effects of the explanatory variables on commuting distance can then be easily calculated and are presented in Table 2. These marginal effects are  $-1.355$  and  $-2.989$ , respectively. These estimates imply that workers living in the most dense locations tend to travel about 5.3 km and 11.9 km less, respectively, than workers in the least dense location.

### 3.4 Estimates of use of travel modes

Next, we consider the four main categories of commuting travel mode in more detail. The relevant dependent variables here are *car*, *public transport* (except *train*), *train*, and *slow modes* (*bike and foot*).<sup>12</sup> Table A3 in the Appendix reports the descriptive statistics of the travel modes in terms of frequency. We perform a multinomial Probit analysis employing a standard and IV approach. Given the small number of alternative categories, this allows for assessing the ‘across effect’ between alternatives. As a result, we can examine substitution between modes, i.e. modal split (Winston, 1985). Also here we compare standard OLS and IV approaches.

Tables 3 and 4 show the results. The reference category is *slow mode*. Marginal effects are also presented. The standard estimates suggest that a marginal increase (i.e. changing one class up out of five) in density corresponds with a decrease of 5.7 % in the use of car, whereas for public transport and train a response of 1.6 % and 1.1 % are found, respectively. The IV estimates have the same sign but a different magnitude: the marginal effect on car use is 9.3%, whereas the marginal effect on the use of public transport and train is equal to 3.4%. Hausman tests indicate that the standard estimate of car is not biased, but the marginal effects of density on train and other public transport modes are substantially higher.

These results make sense and are in line with a utility maximizing framework where commuters choose between different modes (e.g., Jara-Diaz, 2007). In high-density areas, the utility of driving versus cycling or the use of public transport is substantially reduced because of higher congestion costs and costs related to parking. This is likely reinforced because with higher urban density, the time-cost of public transport is substantially reduced due to a more detailed public transport network and more frequent services. The predicted modal choice outcomes are shown in Figure 1. As a result, in more densely populated areas workers tend to shift from car to other travel modes, notably public transport (metro and tram).

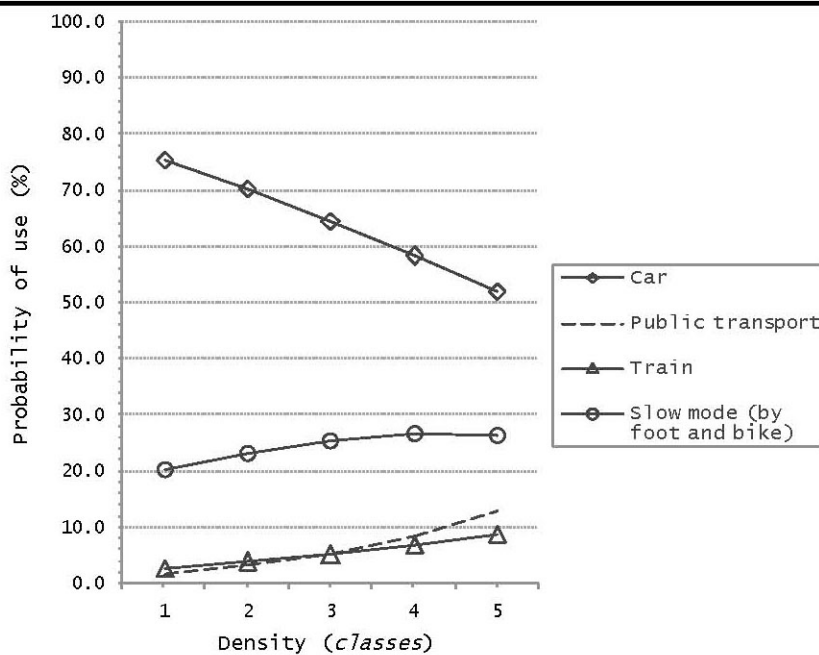
### 3.5 Estimates of commuting distance by travel mode

Previous subsections have analyzed the impact of *urban density* on *commuting distance* and *use of travel mode*. In order to complete the picture, we analyze the effect of density on a third variable, namely *commuting distance by ‘specific mode’* (*car*, *public transport*, *train*, and *slow mode*). For example, the commuting distance by car is zero when another mode is used. The same holds for commuting distance by other modes. We therefore use a range of Tobit models.





**Figure 1. The impact of urban density on modal shift**



Note: Class 1 denotes lowest degree of density, 5 denotes highest.

The full set of results for the Tobit analysis of *commuting distance by car* is reported in Table 5. The marginal effect on *commuting distance by car* is equal to  $-3.374$  using the IV approach, and  $-2.706$  ignoring endogeneity.<sup>13</sup> Therefore, by ignoring endogeneity the effect is slightly underestimated. When comparing the most dense location to the least dense one, OLS and IV estimates indicate that workers tend to travel about 10.8 km and 13.5 km more by car, respectively, which is substantial.

Results for the impact of urban density on traveled distance by the other modes are derived similarly and presented in Table 6. To avoid repetition, we only report findings for the main independent variable *urban density* on (a) *commuting distance by public transport*, (b) *commuting distance by train*, and (c) *commuting distance by slow mode*. Hausman tests indicate that the difference between the standard and IV estimates is not statistically significant, except for *slow mode*, where according to IV estimates changes in density have hardly an impact on commuting distance by bike or foot. The marginal effects of urban density on the three dependent variables for standard Tobit are 0.28 km, 0.34 km and 0.23 km, respectively. This implies increases in *commuting distance by public transport means*, *commuting distance by train* and *commuting distance by slow mode* of 1.1 km, 1.4 km, and 0.9 km, respectively, when passing from least dense to most dense locations. According to the IV approach, the increased commuting distance associated with one unit increase in urban density (out of five classes) are 0.37 km, 0.9 km, and 0.06 km for public transport, train, and slow mode, respectively. The overall marginal effects increase up to 1.6 km, 3.6 km, and 0.24 km, respectively, for a change in density from the lowest to the highest density level.



### 3.6 Decomposition of travel demand

In order to investigate some of the underlying mechanisms by which the impact of urban density on average commuting distance occurs, we provide a decomposition of the effect of density on travel demand. In doing so, we capture the effect of urban density on commuting distance via mode choice.

$$E(y) = E(y|m=1)p(m=1) + E(y|m=0)p(m=0) . \quad (1)$$

Here  $E(y)$  is the expected value of commuting distance and  $p$  indicates the probability of using a certain mode ( $m$ ) to commute. The marginal effect of density on commuting distance can then be decomposed as follows:

$$\begin{aligned} \frac{\partial E(y)}{\partial \alpha} = & \frac{\partial E(y|m=1)}{\partial \alpha} p(m=1) + \frac{\partial E(y|m=0)}{\partial \alpha} p(m=0) + \\ & + E(y|m=1) \frac{\partial p(m=1)}{\partial \alpha} + E(y|m=0) \frac{\partial p(m=0)}{\partial \alpha} . \end{aligned} \quad (2)$$

The term on the left-hand side of equation (2) is the marginal effect of density on distance. The first two components on the right-hand side indicate the marginal effect on distance per mode keeping mode choice constant, whereas the last two terms capture the marginal effect on modal choice while keeping the distance per mode constant. Equation (2) can be easily generalized to more than two modes. We use the four modes described above.

The decomposition reflects some of the complex mechanisms by which urban density acts on commuting distance. Using the estimates presented above, the decomposition indicates that the effect of urban density on commuting distance occurs by approximately equal magnitude through a change in commuting distance given the mode and a change in the probability of using a certain mode.<sup>14</sup>

### 4. Calculating CO<sub>2</sub> Emissions For Different Urban Forms

To analyze the potential effect of spatial organization on carbon dioxide emission abatement we employ conversion factors. We adopt these from TREMOVE baseline version 2.4, a policy evaluation model of the effects of spatial, transport and environmental measures on the emissions of the transport sector (EC, 2006).<sup>15</sup>

We use data on CO<sub>2</sub> emissions by transport activity for the Netherlands, for the year 2005, which include both exhaust (or tailpipe) and lifecycle emissions. The latter represents emissions that occur during the production of fuels and electricity. Since the operational emissions tend to decrease in the future, the relative share of lifecycle emissions will increase and may become substantial.

Table 7 reports indicative values for total (exhaust and lifecycle) CO<sub>2</sub> emissions (in *tons of CO<sub>2</sub>*) and transport activity (in *passenger kilometers*), for all four categories of travel modes under consideration. Transport volume is measured in *passenger kilometers* instead of *vehicle kilometers* to incorporate the contribution of occupancy rate. To show the magnitude of the impact of a specific travel mode on CO<sub>2</sub> emissions, all the variables related to CO<sub>2</sub> emissions, namely *transport activity*, *(exhaust and lifecycle) emissions* and *CO<sub>2</sub> emission factors*, are reported at the subcategory level (see Table A3 in the Appendix). Exhaust CO<sub>2</sub> emissions of slow transport and of electric public transport means (metro and tram) are zero, whereas train has positive values for exhaust CO<sub>2</sub> emissions. The last column of the table shows the CO<sub>2</sub> emission conversion factors. Their values are derived for each transport mode by dividing total CO<sub>2</sub> emissions by the total travel by that mode (in *passenger kilometers*). The factors are expressed in grams of CO<sub>2</sub> per traveled km (*g of CO<sub>2</sub>/passenger-km*). The subdivision of the travel demand by travel modes is derived from the descriptive statistics in Table A3 in the Appendix.<sup>16</sup>

Table 8 presents predicted CO<sub>2</sub> emissions for each travel mode under different classes of urban density based on the IV estimates as reported in Tables 5 and 6. Figure 2 shows the trend graphically. A difference in urban density between its lowest and highest level is associated with a considerable reduction in CO<sub>2</sub> emissions by motorized (*car*) mode. Electric public transport and train show relatively small increases in CO<sub>2</sub> emissions due to the increase of both use and distance by those modes. Note that the values for *public transport* are very low. For this reason, the corresponding line in Figure 2 cannot be well observed.

net difference in total CO<sub>2</sub> emissions from lowest to highest urban density level is equal to 2087 *grams/km* (see bottom row of Table 8), which amounts to 47% reduction. The CO<sub>2</sub> reduction associated to a difference from the current situation (i.e. the sample) with *urban density* = 3 and *urban density* = 5 is equal to  $\pm 1041.6$  *grams of CO<sub>2</sub>/passenger-km* (31% reduction).

## 4 Conclusions

In order to answer the question whether urban form affects travel behavior by individuals and consequently environmental quality, this paper has performed an analysis of the influence of urban density on GHGs emissions through commuting behavior. From a policy standpoint, our study has indicated the potential contribution of policies that affect urban form (notably spatial planning) to reduce CO<sub>2</sub> emissions by the transport sector. Such policies may complement more direct regulation of CO<sub>2</sub> emissions, such as through incentives for energy efficiency.

To address this issue, we examined the impact of urban density on commuting behavior, and subsequently determined the consequences for CO<sub>2</sub> emissions. The econometric approach adopted here has involved a range of techniques, including OLS, Probit and Tobit. An instrumental variable (IV) technique served the purpose of addressing the endogeneity of urban density, which potentially invalidates previous estimates.

Our findings indicate that with respect to commuting distance, endogeneity problems with urban density are small. Based on our results for distance, we therefore believe that the OLS estimates are quite accurate. In the case of the choice of travel mode, however, OLS generates inconsistent results and IV estimation is preferred. In particular, the effect on the use of public transport and the train are far more pronounced. In addition, a decomposition of travel demand into modal split and commuting distance per transport mode has been performed so as to shed light on the underlying mechanisms by which the impact of urban density on commuting distance occurs. It has been shown that the effect of urban density on commuting distance arises by approximately equal magnitude through the effect on commuting distance, given the transport mode and the effect on the probability of using a mode.



Combining the IV results of the travel demand analysis with mode specific emissions factors, the impact of a difference in urban density on CO<sub>2</sub> emissions was calculated for different values of urban density. Our results show that in the densest urban locations CO<sub>2</sub> emissions by motorized (car) mode are considerably reduced. Electric public transport and train, as opposed, show increases in CO<sub>2</sub> emissions due to an increase in both use and distances by these modes.

In terms of policy implications, the lesson emerging from this study is that a higher urban density is likely to lead to a change in travel behavior. The magnitude and direction of this change are observed by modal shifts in individual travel choices, from motorized vehicle use to other transport modes, notably public transport, train and slow modes (bike and foot). Our estimates imply that in locations where density is 500 addresses per square meter higher, CO<sub>2</sub> emissions from transport are on average 15% lower. These results also imply that the commuting-related CO<sub>2</sub> emissions associated with a high-density city such as Amsterdam (more than 2500 addresses per square meter) are about half the emissions from low-density villages (less than 500 addresses per square meter).

The CO<sub>2</sub> reduction associated with a difference between the current average urban density situation (about 1250 addresses per square meter) and an extremely high density situation (more than 2500 addresses per square meter) is 1041.6 grams of CO<sub>2</sub> per passenger kilometer, which means a 31% reduction. The main implication of this finding is that policies that try to enforce or stimulate a higher density of activities may have a rather small but favorable effect in terms of reduction of CO<sub>2</sub> emissions. To give an example, if due to policy 10% of the workforce would live in high-density instead of low-density areas, the reduction in CO<sub>2</sub> would be about 5%. Note that if one is interested in the effect of more substantial changes in density due to purposeful policies, indirect or general equilibrium type of effects may have to be taken into consideration.

All taken together, urban form, and therefore policies that affect urban form, such as spatial and transport planning, deserve more attention in climate policy debates, as they can contribute to a reduction in greenhouse gases. For example, transport planning may try to stimulate modal shift by increasing density through the development of new public transport, such as the planned additional subway line in the centre of Amsterdam, and thus allow the design of a more effective transport infrastructure network as well as the creation of fast lanes for buses and separate lanes for bicyclists. Therefore, a key challenge is to find ways to increase density in existing urban areas in the face of financial, political, historical, social and environmental constraints. Density-increasing policies are feasible in countries like The Netherlands, as spatial planning here traditionally is very effective in influencing urban density. The results presented in this study may be of particular interest when considering urban and transport planning in the context of new, emerging urban areas and rapidly growing cities, notably in developing countries. For instance, combating CO<sub>2</sub> emissions through spatial and transport planning may be a wise second-best strategy as other types of climate policies, such as externality taxes on fuels, are perceived as politically unacceptable and are severely hampered by vested interests and public good features of global warming. Nevertheless, the two types of policy are generally complementary and in the long run may need to be implemented simultaneously.

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## Notes

<sup>1</sup> Harvey and Clark (1965), Anas et al. (1989), and Burchfield et al. (2006) offer excellent syntheses and economic interpretations of the genesis and development of urban forms over the last two centuries.

<sup>2</sup> A choice between urban concentration and urban sprawl is relevant here, which involves both environmental and welfare considerations. In the US this has given rise to a debate about ‘Smart Growth’ strategies (Bertaud, 2003; Handy et al., 2005).

<sup>3</sup> Urban density has been shown to cause negative effects on other types of trips (Greenwald and Boarnet, 2001; Bagley and Mokhtarian, 2002; Cao et al., 2006; Khattak and Rodriguez, 2005; Schwanen and Mokhtarian, 2005; Cao et al., 2007). Hence, we might underestimate the effect on all trips by considering only commuting. The latter in fact accounts for a quarter of total individuals’ travel distance (Hamilton and Roell, 1982; van Dender, 2006).

<sup>4</sup> By ‘causality’, we do not mean the *behavioral process* but the *direction* of the influence (Singleton and Straits, 2005). Hence we aim to show to what extent an exogenous change in urban form affects travel.

<sup>5</sup> Changes over time in urban form and travel may also provide evidence of any causal effect, but identifying the effect of urban form on travel may even be more difficult, as urban form and travel patterns change rather slowly over time.

<sup>6</sup> For discussion of urban density in relation to patterns of residential land use and measures of urban density see McDonald (1989), Fujita (1989), Fujita et al. (1999), Schafer and Victor (2000), and Bento et al. (2005).

<sup>7</sup> The category ‘car’ includes not only travel by car but also travel by other motorized commuting modes, namely motorbike, scooter and moped. Due to the low proportion of the other motorized subcategories in our sample (less than 3%), it does not make sense to treat these subcategories separately.

<sup>8</sup> The share of the population using a car to commute in our sample is in line with other Dutch data, and may thus be considered to be representative for the Netherlands as a whole.

<sup>9</sup> We also show results of OLS because the IV approach is conceptually not more appropriate *a priori*. OLS estimates are usually preferred when they are statistically equal to the IV estimates, because the former have smaller standard errors. If the IV estimates are statistically different from the OLS estimates, the latter must be inconsistent and cannot be used.

<sup>10</sup> Note that in the results shown for the IV estimates, urban density is assumed to be a continuous variable. We have also estimated models taking into account the discrete character of all observations of urban density. It appears that the results are very similar (see Table A2 in the Appendix).

<sup>11</sup> Rather than comparing the OLS and IV estimates of a particular linear combination of parameters, as the standard Hausman test does, it makes more sense to test for the change in the estimate of the coefficient of interest, which in our case is the parameter of *urban density*. The Hausman *t*-statistic reduces then to: , which gives a value of  $-1.92$ .

<sup>12</sup> The variable *public transport means* combines tram and metro, while train is separately addressed. The reason is that tram and metro mainly relate to intra-urban transport, whereas train covers mainly inter-urban transport (longer travel distances). The distinction evidently is relevant for assessing environmental impacts.

<sup>13</sup> The marginal effect on commuting distance by car given the use of car is equal to the coefficient reported.

<sup>14</sup> The values for the predicted scenario of modal shift are calculated by multiplying the mean of all the variables in the sample (except *urban density*) by the coefficients from the Probit model and adding the results. For *urban density*, which is the scenario variable, we calculate the product of the marginal effect from Probit and each class of density.

<sup>15</sup> This model includes both passenger and freight transport in the EU 15, covering a period of 35 years, from 1995 (historical data) to 2030 (forecasted data).

<sup>16</sup> Note that the TREMOVE model computes emissions as dependent on travel speed, and thus accounts for congestion effect in denser areas.