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- labour market growth and commuting patterns

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Abstract

This study investigates how urban structures (as defined by compactness, concentration, and functional diversity) and labour market growth affect CO_2 emissions in Sweden's 39 largest labour markets. This study asks which urban structures are associated with fewer CO_2 emissions due to commuting. In addition, the study adjusts for sociodemographic characteristics and accessibility variables. Urban enlargement along with labour market growth affects commuting patterns and per capita CO_2 emissions from commuting. A more compact and smaller urban structure with an efficient employment distribution is associated with fewer CO_2 emissions from commuting, an effect which could be enhanced by increasing accessibility.

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1. Introduction

“Time is money”: this expression is more significant in developed countries because of the high opportunity costs of time, which lead to lives that are more dependent on faster transportation. Many environmental externalities, generated through economic and social processes, are relevant to a transport-dependent life. Carbon dioxide (CO_2) in the air, which causes climate change, is one of these external environmental costs. Many researchers and policymakers are focusing on finding the most effective ways to reduce these external environmental costs. The different features of different urban spatial structures, along with labour market growth, can play an important role in shaping patterns of mobility. This fact is argued for by some scholars and new urbanists in their attempts to find better solutions while acknowledging the limitations of those solutions (Maat, K., van Wee, B., & Stead, D. 2005).

The need to commute arises from individual connections within urban areas, and individual connections are enhanced by the dispersion of residential areas and socio-economic activities throughout the labour market (Benoit, L., 2010). The idea behind studying labour market areas is to focus on clusters of integrated municipalities and on the efficiency of the employment distribution in cases where the distribution of employment could result in structural changes in an urban area through enlargement (namely, monocentric or polycentric urban structures). These structural changes, associated with low density, dispersion, and neighbourhood sprawl, can lead to increased CO_2 emissions due to increases in car dependency among commuters (Eriksson, I.-M., 2015; Eliasson, K., Lindgren, U., & Westerlund, O., 2003; Alidadi, M., & Dadashpoor, H., 2018; Lee, S., & Lee, B., 2014; Cirilli, A., & Veneri, P., 2014).

European policymakers have begun to address the costs associated with urban enlargement and to debate whether monocentric or polycentric urban structures perform better in terms of CO_2 and other environmental emissions (Cirilli, A., & Veneri, P., 2014). Although there have been several arguments about urban structures in Sweden, the evidence shows that several labour markets, including Stockholm, Gothenburg, and Malmö, have enlarged into polycentric structures along with a sprawling labour distribution (Emtairah, T., McCormick, K., Leire, C., Palm, A., & Dehod, N. 2017; Benoit, L., 2010; Stojanovski, T., 2019). The main intention of this study is to address how enlarged urban structures influence CO_2 emissions in Sweden and to identify the most environmentally friendly urban structure in Sweden, as defined by reductions in CO_2 emissions generated by commuting.

So, K. S., Orazem, P. F., & Otto, D. M. (2001) show that households prefer to work in cities with higher wages and to live in nonurban residential locations with low housing prices and greener surroundings. The built-up areas in most enlarged regions in Europe were designed assuming dependence on private automobiles. These enlarged regions with scattered suburbs create demand for external shopping malls, along with infrastructure development that links the suburbs to historic downtowns. This encourages more automobile commuting (Stojanovski, T., 2019). Every suburban centre needs to facilitate travel each day within almost the whole urban area of a polycentric structure, suggesting that these trips are highly scattered (Benoit, L., 2010).

During the past decade, Swedish municipalities have focused on environmental policies such as, control of unsustainable transportation, control of increased energy consumption, and redesign of the built environment to shift towards more walking, cycling, and public transportation (Kramers, A., Wangel, J., Johansson, S., Höjer, M., Finnveden, G., & Brandt, N., 2013). Moreover, in these policies, the use of more green energy within the next 20 years has been promoted under the vision of developing a fossil fuel-free city (Stojanovski, T., 2019).

However, whether the Swedish urban form is an obstacle to achieving sustainable mobility is still an open question. It has been argued, based on statistical and empirical evidence, that urban transportation creates approximately one-third of all CO_2 emissions in the world (Urry, J., 2004).

The main source of CO_2 emissions in Sweden is the combustion of fossil fuels, which are mainly used in the energy, industry, and transport sectors. Statistics have shown that the total amount of CO_2 emissions in Sweden has decreased by 27% compared to that in 1990 as a result of various environmental policies. However, CO_2 emissions continue to be significant in the road transport sector, as the consumption of diesel by passenger cars has been increasing annually since 1995 (Swedish Environmental Protection agency [Naturvårdsverket], 2019). Regional enlargement means that the local labour market has also enlarged, which includes increased housing services and more work opportunities than before. The necessity of commuting goes hand-to-hand with work opportunities, which is the cause of variation in commuting patterns, including commuting time, distance, and transport mode (National Board of Housing, Building and Planning [Boverket], 2005).

Many studies have been carried out on the indicators of commuting modifications and their effects on the economy, society, the environment, and ecological sustainability. The findings indicate that an increase in spatial distances leads to more commuting, higher CO_2 emissions from road traffic, and a loss of open spaces. At the same time, it increases the cost of providing public services and reduces housing affordability through the limitation of the housing supply and higher prices in key areas (Bertaud, A., 2015). These studies have not specifically focused on urban enlargement along with labour market growth as a determinant of CO_2 emissions due to commuting in Sweden. This study works mainly on this gap and empirically explores this concept in the Swedish context.

Do the different features of urban enlargement, along with labour market growth affect CO_2 emissions due to commuting patterns in Sweden? Using appropriate indicators to differentiate the roles of different spatial structure characteristics is the key focus of this empirical study, in addition to linking these features to the level of CO_2 emissions from commuting. Some intermediate factors including commuting patterns, commuter sociodemographic characteristics, and accessibility endowments are also considered. The variables of interest in this study are the indicators for per commuter CO_2 emissions in the labour market area (including transport mode, travel time, and travel distance) and for the different spatial dimensions of the labour market area (including the degrees of compactness, of centrality, of concentration, and of activity clustering with mixed land use).

The estimation was carried out on the basis of the 39 largest Swedish labour market areas as reported by the Swedish National Institute of Statistics (SCB, 2010). The labour market area is used as the unit of analysis, as this choice makes it possible to focus on comprehensive urban agglomerations instead of just focusing on individual municipalities. The objective is to frame an empirical evaluation of the importance of regulating the built environment, taking into consideration labour market growth and the efficient employment distribution in the Swedish labour market.

The structure of the study is follows: The second chapter discusses the spatial enlargement of Swedish urban areas (within labour markets) over the past several years and discusses the relationship between the urban spatial structure and internal commuting patterns, all against an appropriate theoretical background and a relational conceptual framework. The third chapter describes the research method, wherein the data and variables and their calculation process are explained, as are the model specification, and are the supportive arguments of model extensions.

The fourth chapter presents the empirical results and a discussion with policy support arguments. Moreover, the robustness of the empirical results is examined in this chapter. Finally, the fifth chapter concludes the study by addressing its limitations, which leaves open possibilities for future research.

2. Theoretical Framework and Background

This chapter describes the concepts and theories that have been used to critically examine urban forms and the conceptual framework behind the underlying model applied in this study. In detail, the first subchapter addresses urban structure and the determinants of dispersion. The second subchapter links labour market distributions to commuting. The third subchapter links household characteristics to commuting. The fourth subchapter describes the environmental perspectives on urban form and commuting patterns. The fifth subchapter presents a conceptual framework for CO_2 emissions due to commuting.

2.1 Urban Structure and the Determinants of Dispersion

Even if the density of Swedish urban areas is higher than the OECD average, urban fragmentation increased by 12% between 1990 and 2014 (OECD, 2018), and commuting has increased both in terms of the number of commuters and of travel distance. The average commuting distance has increased over 50% relative to the beginning of 1970. More specifically, the average commuting distance has increased from 10 km per day to approximately 15.6 km per day for the entire country, and these differences are even greater in the largest commuting regions, including Stockholm, Gothenburg, and Malmö (Boverket, 2005). The determinants of dispersion can be defined as a set of municipal characteristics, such as spatial municipal developments with low residential density, physical discontinuities in newly built settlements, and an unbalanced employment distribution in the labour market, along with a low degree of employment concentration in the central municipality (Cirilli, A., & Veneri, P., 2014).

The housing market is positively related to the labour market. It grows when the labour market grows, the inverse of which is also true. Meanwhile, accommodation affordability problems most frequently appear in the centre (Öhman, M., & Lingren, U., 2003). Therefore, it is sometimes cheaper to build new settlements in suburban areas than it is to renovate existing accommodations in historic city centres (Trilla, C., as cited in Cirilli, A., & Veneri, P., 2014). The EU housing burden rate (defined as, the net housing expenditures are 40% of a household`s total disposable income) exceeded 7.6% in Sweden in 2007 (Holmqvist, E., & Turner, L. M., 2014).

Historic changes to the Swedish housing sector occurred with the promotion of homeownership and the conversion of public housing sectors to condominiums, which occurred under conversion policies such as offering below-market prices and attractive locations to Swedish households. Moreover, real estate taxes were abolished and replaced by a lower municipal fee in 2008. These modifications make it less costly to own a home, which makes people more attracted to homeownership (Holmqvist, E., & Turner, L. M., 2014). Likewise, the insufficient and inactive decisions of the relevant authorities at the peripheral level resulted in large areas of land being used unevenly, resulting in urban spatial enlargement.

It is argued that many houses have ″excellent” European Commission Energy Performance Certificates (EPCs) even if they are positioned in isolated areas that are not in line with developed public transit nor are suitable for walking or cycling (Stojanovski , T., 2019; Eriksson, I.-M., 2015). In addition, technological developments in the road traffic sector, along with infrastructure improvements, have decreased the economic costs of commuting, which has influenced the dispersion of settlements without increasing travel durations or costs (Cirilli, A.,

& Veneri, P., 2014). Several studies have shown that variables such as job accessibility, distance to downtown, location, and the distribution of developments within a metropolitan region are important determinants of urban dispersion (Lee, S., & Lee, B., 2014).

A study by the municipality of Uppsala on the characteristics of those moving to the municipality's rural areas showed that approximately 70% are families with children. A household's characteristics, such as household size, income, age, education, and preferences, influence that household's consumption decisions and, thus, its commuting behaviour (Bin, S., & Howlatabadi, H., 2005). In addition, mobility resources, such as car ownership, the availability of time, and the economic budget for commuting, also influence the choice of commuting mode (Paleti, R., Bhat, C. R., & Pendyala, R. M., 2013). Eventually, energy use and related environmental changes, result from consumer behaviour (Feng, Z.-H., Zou, L.-L., & Wei, Y.-M., 2011). After all, more explanations for the Swedish urban structure and a proper identification of its determents are still needed since the sustainability level of recently developed Swedish urban areas is rather different from an overall consideration, according to Eriksson, I.-M. (2015).

2.2 Labour Market Distribution and Commuting

Municipalities vary depending on their characteristics such as size, demographics, urban form, and socio-economic activities (Emtairah, T., et al., 2017). Urban spatiality has been estimated according to the density of population activities in addition to population density. Those are employment distribution indicators of labour market including size, centrality or monocentricity, concentration or polycentricity, and the diversity of activities (Cirilli, A., & Veneri, P., 2014; Lee, S., & Lee, B., 2014; Lee, B., 2007; Alidadi, M., & Dadashpoor, H., 2017). These are of particular consideration when the study goal is to link urban spatiality with environmental emissions due to commuting.

In general, a central workplace tends to encourage people to choose a central residential location and to use energy-efficient public transport or bicycles (Zhao, J., Bentlage, M., & Thierstein, A., 2017). It is argued that if the distance from the centre increases, then the average density of activities and of the population will decline. Therefore, the share of employment in the central municipality of a labour market (monocentricity) has been used as an important measure of dispersion and commuting behaviour in metropolitan regions (Li, J., Zhang, W., Chen, H., & Yu, J., 2015). The concept of the concentration of the labour market (polycentricity) was also developed to clarify the employment distribution, the diversification of product functions, land use efficiency, and the connectivity scale among different sectors (Alidadi, M., & Dadashpoor, H., 2018). Because of the rapid urban and labour market transformations of the last few decades, it has been argued that polycentric determinants are more appropriate for describing the spatial structure of metropolitan regions and the largest labour markets (Sorensen, A., 2001; Alidadi, M., & Dadasshpoor, H., 2018). This study follows the same technique to estimate urban spatiality in the largest labour markets in Sweden.

The distribution of total car journeys in Sweden as follows: approximately 25% are related to leisure activities, approximately 50% are related to commuting for work, and approximately 25% are related to commuting for shopping (Swedish Institute for Transport and Communications Analysis [SIKA], 2007; Naturvårdsverket, 2010). According to Swedish National Institute of Statistics (SCB), if a person lives in one municipality and works in another municipality then he or she will be counted as a commuter, and commuting takes place across the municipal boundary. Inter-municipality work commuters (workers commuting to one municipality from another municipality) in Sweden made up on average 26% of total workers in 1990, 32% of total workers in 2000, and 38% of total workers in 2017. These percentages are remarkably higher in some municipalities with larger labour markers. Specifically, the total number of gainfully employed, 16-year-old-plus commuters in Stockholm, Goteborg, Malmö, and Uppsala increased by approximately 200%, 600%, 300%, and 500%, respectively, between 1993 and 2018. In some cases, the total number of gainfully employed 16-year-old-plus commuters leaving from a municipality is almost equal on average to the total number of gainfully employed 16-year-old-plus commuters coming into a municipality, according to the data reports of SCB. Here, a question arises about the efficiency of employment distribution within the labour market, which requires an empirical explanation.

It is argued that inter-municipality work commuters use transport modes that are more energy efficient or green than cars if those municipalities are highly compact in terms of employment (Groot, S. P.T., de Groot, H. L. F., & Veneri, P., 2012). Groot, S. P. T. et al. (2012) found that most types of workers prefer to live in the areas of municipalities where housing costs are lower, which generally leads to a trade-off between commuting time and residential location choice. This study focuses on these determinants, which are related to the spatial distribution of employment within the labour market, to examine their effect on commuting.

2.3 Household Characteristics and Commuting

Commuting behaviour could be different under similar circumstances depending on household characteristics, including household size, income, age, sex, education, car ownership, and the personality traits or psychological characteristics of its members (ego, habits, preferences, attitudes, commitments, etc.) (Metcalfe, R., & Dolan, P., 2012; Ding, C., Lin, C., Lin, Y., & Wang, Y. 2014; Stead, D., 2001). Younger individuals prefer to take on new challenges and to gain experience with new cultures and places; therefore, they are generally migratory, which leads to increased commuting (Öhman, M., & Lindgren, U., 2003). Moreover, scholars have argued that younger households prefer to work in urban locations with higher wages and to live in suburban residential locations with low housing prices. On the other hand, preferences for staying at home or working near home seem to increase with age (Vovsha, P., Guota, S., Freedman, J., Sun, W., & Livshits, V., 2012; Öhman, M., & Lindgren, U., 2003).

A balanced distribution of highly educated employees is an important component of the discussion of commuting. The length of a commute is found to increase with the educational level of workers (Groot, S. P. T., et al., 2012). Specifically, highly educated employees commute long distances to work, which was once counted as an opportunity cost because of their higher wages (Öhman, M., & Lindgren, U., 2003; van Ham, M., Mulder, C. H., & Hooimeijer, P., 2001). Moreover, young, highly educated workers prefer to live in the city centre, while older educated workers prefer to live in the quiet neighbourhoods of suburban areas (Beckers, P., & Boschman, S., 2013; Lawton, P., Murphy, E., & Redmond, D., 2013).

Car ownership is considered a conditional indicator of long-term decisions such as residential location and workplace location as well as of medium-term decisions such as transport mode choice for work trips. Moreover, car ownership, in turn, influences short-term decisions such as non-work travel destinations and the use of daily transport modes (Ding, C., et al., 2014), while commuting time is most likely a trade-off between spending more time with family and an increased salary or career progress (Öhman, M., & Lindgren, U., 2003). According to the Swedish Institute (SI, 2015), a long-run environmental goal of Sweden is to reduce greenhouse gases by approximately 40% of 1990 levels by 2020; in the process, to achieve a fossil fuel-free vehicle fleet by 2030; and to eventually, step by step reach the final goal of a green society with no net greenhouse gas emissions by 2050.

Based on national regulations, Swedish municipalities have the responsibility and the means to shape their own transportation and energy systems (Olofsson, Z., Hiselius, L., & Varhelyi, A., 2016) and to lead the transformation towards becoming fossil fuel-free cities. Swedish municipalities have made changes in favour of cleaner transport modes and alternative transport fuels (Emtairah, T., et al., 2017). Household ownership of green passenger cars is the result of these promotions. It is claimed that a green passenger car produces fewer CO_2 emissions than a conventional passenger car over the same commuting distances. According to the Naturvårdsverket (2010) ethanol (E85) cars produce 53% fewer emissions than a car powered by fossil fuels. Changes in final energy use in the Swedish transport sector since 1990 are illustrated in Figure 1, which shows green energy use going up in the transport sector. It is necessary to consider these sociodemographic characteristics, especially in the highlighted study area, to obtain reliable information about the environmental externalities due to commuting.

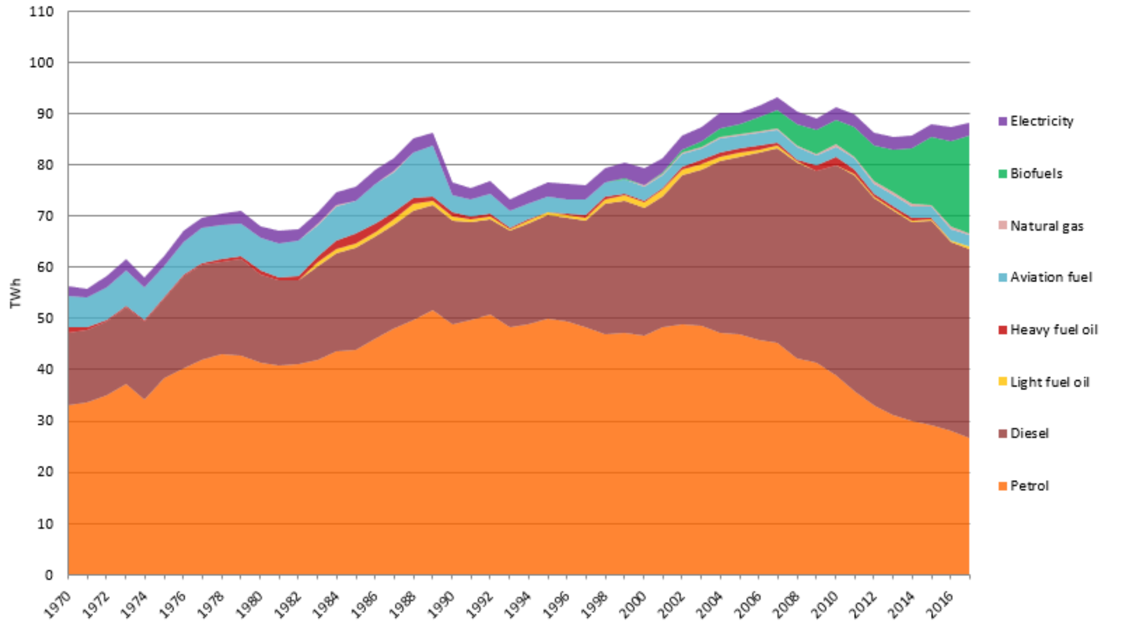
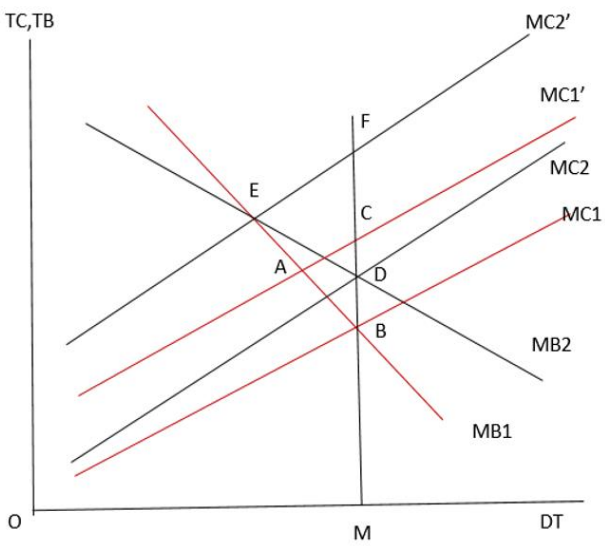


Figure 1: Final energy use in the Swedish transport sector (domestic), from 1970-2017.
Source: "Energy in Sweden 2019, an overview" by, Swedish Energy Agency, 2019. P. 10.

2.4 Environmental Perspective on Urban Form and Commuting Patterns

Economic scholars agree that each urban form (compact or scattered) and its commuting patterns impose both economic and noneconomic costs on the relevant society and environment (Cirilli, A., & Veneri, P., 2014; Lee, S. & Lee, B. 2014; Stojanovski, T., 2019). A dispersed urban form can influence travel costs, for example, increasing the distance from a destination, which increases travel time, thus increasing the cost of commuting directly through economic losses and indirectly through external social costs (welfare loss). The volume of these external costs could vary depending on the mode of transport and the type of energy used (Crane, R., 1996; Stojanovski, T., 2019). The external environmental costs are a part of these external social costs. Likewise, the CO_2 emissions are a large part of these environmental external costs. The difference in the volume of social external costs across different transport modes or energy choices can be explained by "Authors modification of Figure 5-2" (Saez & Berkeley, 2007), which is presented in Figure 2.



In this figure, TC = travel costs, TB= travel benefits, DT = distance travelled, MC1= private marginal cost of travelling by energy-efficient transport (public transport for instance), MC1'= social marginal cost of travelling by energy-efficient transport, MC2= private marginal cost of travelling by energy-inefficient transport (passenger car for instance), MC2'= social marginal cost of travelling by energy-inefficient transport, MB1= private benefit of commuting by public transport, MB2 = private benefit of commuting by passenger car. Under consideration of the economic mechanism this figure clearly shows that expected fact.

Figure 2: External social cost due to commuting.
Reprinted from "Problems and solution. 131 undergraduate public economics." by Saez & Berkeley, 2007.P. 6.

The triangle ABC is the external social cost of commuting distance M by energy-efficient public transport. On the other hand, triangle DEF is the external social cost for commuting distance M by energy-inefficient passenger cars. The triangle DEF is clearly greater than triangle ABC for the same commuting distance M when the use of transport mode is different. This situation appears when the social marginal cost is greater than the private marginal cost of a specific economic action. ″Market failure" is a relevant term for these situation (Neves, V., 2012), which could arise from the failure to enact proper regulation by the relevant authority. Sweden is enacting various environmental policies to handle situations in transport commuting such as the development of public transit infrastructure, controlled car parking, the adjustment of road prising strategies for fair mobility, carbon taxes, and green car tax relief (Lindfors, A., & Roxland, M., 2009).

There are several private and public economic costs related to an isolated built environment that ought to be considered (Henry, G., as cited in Cirilli, A., & Veneri, P., 2014). Moreover, reduced accessibility for dependent household members, the separation of social groups based on income levels, safety problems, and other factors could be identified as noneconomic costs of dispersed urbanisation. Eventually, unplanned regional enlargement means that passenger cars are used for more trips overall. According to Swedish municipalities and county councils (SKL, 2008), on average, out of all the all-day trips in Sweden, only 10% are by public transport, half of them are by passenger cars and one-third are on foot or by bicycle. Moreover, SKL (2008) has also shown that commuting among low-income groups has increased in some sparsely populated municipalities. In addition, the benefit to those commuters is approximately zero if commuting increases for economic reasons such as higher housing prices in the centre. However, commuting is detrimental from an environmental perspective if it is done by fossil-fuel-powered passenger cars (SKL, 2008). Furthermore, using up more open space interferes excessively with nature, as it destroys biodiversity and interrupts the life of wild animals. These are the direct environmental costs of isolated built environments. Hedblom, M., & Söderström, B. (2008) showed Swedish suburban sprawl is responsible, to an extent, for the decrease in peri-urban woodlands.

For every commute, a rational commuter always makes trade-offs among economic costs, time, distance, security, comfort, etc. (Stojanovski, T., 2019). Therefore, a rational commuter will consider a higher time cost, for example, to be the effect of congestion due to commuting in a higher density urban area. However, it is necessary to examine the impact of the other determinants of spatial structure beyond simple density, such as the distribution of employment in the labour market, household characteristics (socio-economic and demographic variables), and existing accessibility endowments. To what extent does labour market growth, along with features of the urban structure, affect commuting? To some extent, it depends on the influence of household socio-demographic characteristics. Likewise, to what extent does commuting affect the environment? It depends somewhat on the patterns of commuting and where the commuting takes place. However, some argue that despite regional enlargement, the environment will not be affected that much by commuting if it takes place via green transport modes (Boverket, 2005).

2.5 Conceptual Framework for CO_2 Emissions due to Commuting

Recent empirical studies have shown that the urban form and socio-demographic characteristics of households significantly influence household commuting behaviour, including travel mode, trip frequency, and trip distance (Lee, S., & Lee, B., 2014). The framework for this study is used to explain the key relationships among the relevant variables. This explanation is based on the 39 largest labour market areas in Sweden. Figure 3 illustrates the expected causality links between average per capita CO_2 emissions due to commuters in labour market areas and urban spatial structure indicators, including population density or compactness, the degree of employment concentration (a component of polycentricity), the degree of functional diversity of land use, and socio-demographic variables such as age and education. Moreover, two other controls are included, one of which is green passenger car ownership as a highlighted issue in Swedish context, and the other is the infrastructural endowments within the labour market. These indirect links are assumed to be influenced by commuting patterns (time, distance, the amount of fossil fuel-powered transport, and the amount of green energy-powered transport). The spatial structure of a municipality influences individual commuting behaviour in several ways, including costly public transport services in low-density areas, low demand for public transport because of time costs in dispersed areas, and other relevant opportunity costs (Cirilli, A., & Veneri, P., 2014).

The efficiency of the distribution employment within the labour market plays a very important role in these conceptual links. The determinants of the polycentric urban structure depend on these distributions. A balanced spatial distribution of employment means that employment is equally dispersed over the whole labour market area, which leads to efficient work commuting under a well-managed transportation system. Stojanovski, T. (2019), The Organisation for Economic and Co-operation and Development (OECD, 2018), and Swedish National Institute of Statistics (SCB, 2019) argued in data reports (about commuting in and commuting out within Swedish municipalities) that Sweden has sprawling labour and population distributions, which cause inefficient urban commuting. In consideration of these consequences, the conceptual framework requires assumptions of complex relations among the underlying variables. In addition, it indicates the necessity of empirical judgement for a better explanation of the answers to the research questions.

Compactness has been measured by the residential density of the labour market. Compactness is assumed to reduce the distance between residential areas and workplaces within a higher-density urban area and to support green commuting modes, including walking, cycling, and energy-efficient public transport (Gaigné, C., Riou, S., & Thisse, J.-F., 2012; Newman, P. W. G., & Kenworthy, J. R., 1989). However, congestion tends to be more severe in densely inhabited areas (Camagni, R., Gibelli, M. C., & Rigamonti, P., 2002), which makes trips over a given distance longer and which has an inverse relationship with CO_2 emissions from commuting. Since different arguments about compactness have been made by scholars, an empirical explanation is needed to clarify the net effect of compactness on CO_2 emissions.

Conceptual framework of factors influencing the average per capita CO_2 emissions of commuters

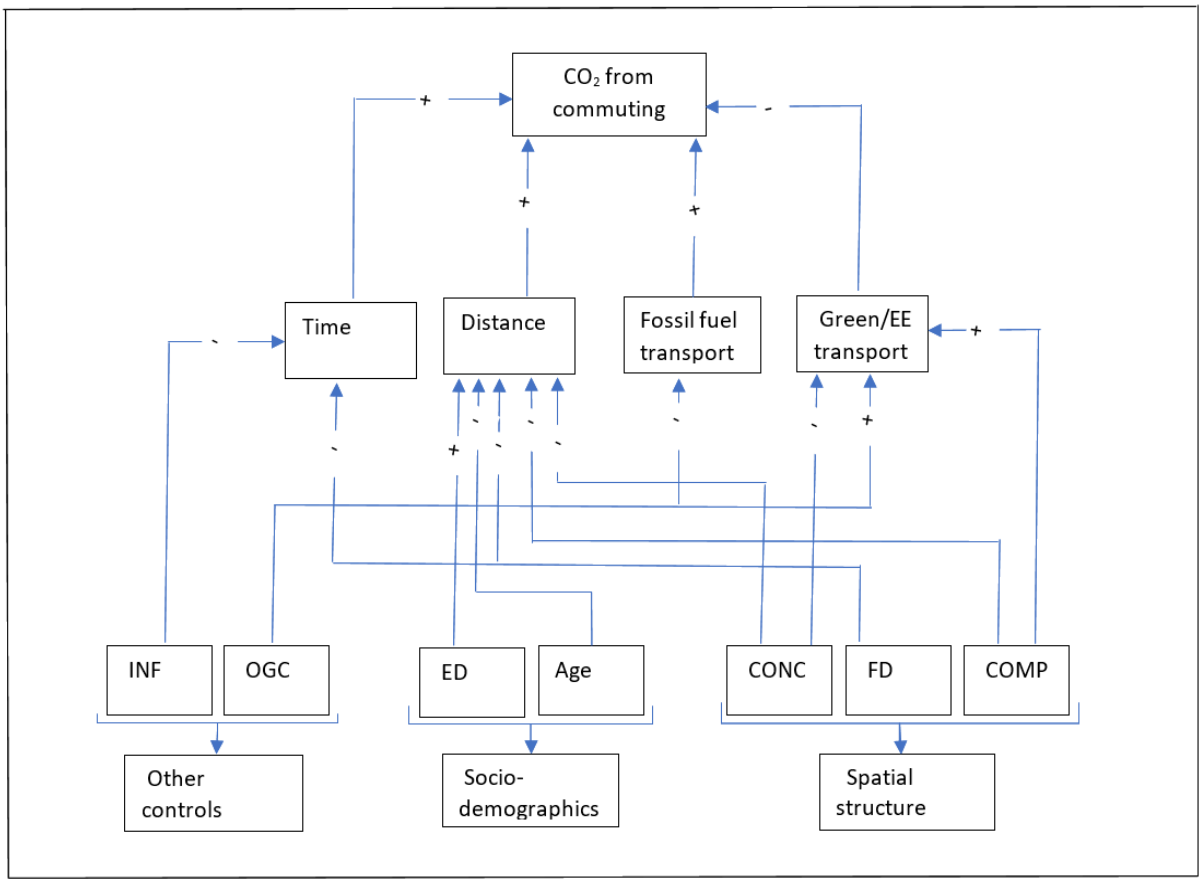


Figure 3: Commuting indicators and CO_2 emission due to commuting patterns in Swedish municipalities.
In this figure: functional diversity (FD), compactness (COMP), concentration (CONC), age (Age), education (ED), ownership of green passenger cars (OGC), and infrastructure endowment (INF).

Centrality (monocentricity) is assumed to increase commuting distances and CO_2 emissions. It often has similar consequences to those of compactness, especially in smaller urban areas. The study also assumes that a polycentricity indicator, namely, employment concentration, has mixed effects on commuting modes: it reduces commuting distances, given a balanced decentralized population in urbanised areas. It could also discourage public transit use if these decentralized urban areas were not developed in line with the existing public transit infrastructure. However, it is generally assumed that a concentrated urban structure with a higher population density is associated with efficient commuting in the largest labour market area (Haines, V. A., 1986). Ultimately, the direction of the net effect of concentration on commuting is an empirical question.

This study also considers another important driver of polycentric indicators, namely, functional diversity in urban land use. Increases in functional diversity are expected to be associated with reduction in CO_2 emissions, because such increases have a negative relationship with commuting time and distance (Cervero, R., 1996). Efficient functional diversity means mixed land use with a balanced spatial distribution between residential areas and workplaces. This leads to shorter travel distances and encourages of non-car commuting for work and other purposes because of the increased variety of commuting options (Cirilli, A., & Veneri, P., 2014).

Commuting behaviours also depend on household socio-economic characteristics, including age, income, education, and car ownership (Stead, D., 2001) and household preference characteristics, such as for job type, transport mode, living area, house price or rent, and having a partner or not. Moreover, household preferences are also one of the determinants of mixed land use's effect on individual commuting behaviours (Cirilli, A., & Veneri, P., 2014), but this effect sometimes differs among high-income workers if they prefer to reside near their workplaces.

Younger workers are expected to live in suburban areas because of a lack of housing availability, a lack of housing affordability, and their job requirements. Therefore, they make longer and less environmentally sustainable trips, for instance, by making greater use of passenger cars. The opportunity cost of time influences them to use such kind of transport mode. On the other hand, older workers on average may enjoy more work flexibility so that they can work from home or close to home with less commuting, which is environmentally sustainable (Vovsha, P., et al., 2012). The opposite effect has also been explained by the fact that older people often live in area with plenty of space and greener surroundings, which sometimes leads to long-distance commutes (Lujanen, M., 1993). Ultimately, the direction of the net effect of age on commuting is also an empirical question. The spatial distribution of highly educated householders plays an important role in determining CO_2 emissions, as scholars argue that there is a positive relationship between long-distance commutes and highly educated householders (Groot, S. P. T., et al., 2012). At the same time, highly educated workers are found to be more concentrated in the central municipality. Because they prefer to enjoy city life amenities, therefor, they are uncompromising in accepting a higher co-location share in their commuting (Nässén, J., 2014).

It is necessary to take into account different levels of transportation supply among the labour market areas to obtain a precise estimation of the effects of an enlarged labour market on commuting and CO_2 emissions (Lee, S., & Lee, B., 2014). Sweden is one of the leading countries in enacting effective environmental policies, and therefore, energy efficient green passenger car ownership is increasing in most municipalities (Swedish National Institute of

Statistics [SCB], 2019). This has led to fewer CO_2 emissions over a given commuting distance and thus reduces the effects of urban dispersion on the environment. Therefore, this study includes this variable to examine the real relationship between urban enlargement and CO_2 emissions from commuting. Finally, infrastructure development is an indicator of accessibility, which is assumed to have a negative relation with travel time and a positive relation with the use of energy-efficient transport, namely, competitive public transportation, which leads to fewer CO_2 emissions from commuting (Stojanovski, T., 2019).

3. Research Method

This chapter discusses in detail the data, variables, and model specifications. The data sources and variable measurement techniques for the analysis of the study are explained here. Moreover, the descriptive statistics of all variables and their pairwise correlations are also presented to provide a preliminary explanation and understanding. The fitted models used in this study and the arguments for their use in the context of the study area and with the variables are described in the model specification subchapter.

3.1 Data and Variables

The analysis sample in this study is the largest 39 labour market areas in Sweden, which are assumed to cover most of the Swedish urban areas. This sample was specified according to a Swedish National Institute of Statistics (SCB) report 2010, and the study only considered those largest labour market areas that have at least two municipalities within the labour market, where one of them is a central municipality with at least 20,000 people. Therefore, the sample areas are groups of connected municipalities. The labour market areas are illustrated in Figure 4, where the different colours indicate different types of municipalities according to commuting patterns and the blue parts indicate the central municipalities in the Swedish labour markets.

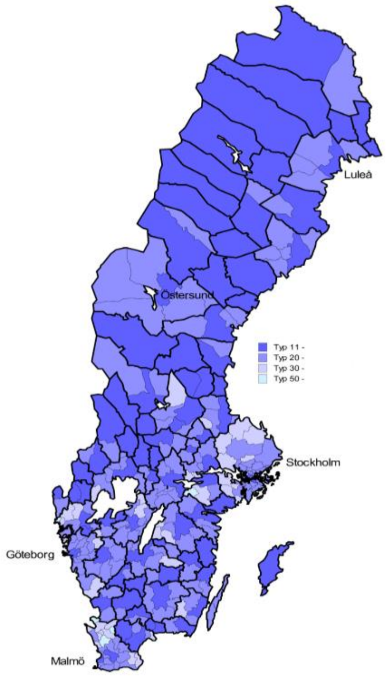


Figure 4: Swedish local labour markets (LA).
Source: Sweden national institute of statistics (SCB).

Each variable is calculated at the labour market level in this study. Since the study used a total of eight years data (2010 to 2017), a panel data set is considered to be the best fit for the empirical analysis. All the variables were calculated with the help of the Swedish National Institute of Statistics (SCB), Swedish Meteorological and Hydrological Institute (SMHI), and Bil Sweden (BS). This fact indicates that all the data that have been used in this empirical analysis are secondary. The dependent variable was calculated using the latest available data on CO_2 emissions (tons/year) from specified transport modes provided by SMHI, which estimates the external environmental costs of commuting in Swedish labour markets in terms of CO_2 emissions. Household commuting-related CO_2 emissions have been considered a part of total road transport CO_2 emissions due to fuel consumption.

Fuel consumption and CO_2 emissions are allocated to five types of vehicles, namely, passenger cars, light commercial vehicles, heavy goods vehicles, buses, and mopeds and motorcycles (Naturvårdsverket, 2019). Irrespective light commercial vehicles and heavy goods vehicles, per capita commuter CO_2 emissions (tons/year) in the labour market areas (La_CO2) are calculated as:

$$La\_CO2_{it} = PC\_CO2_{it} + BU\_CO2_{it} + MM\_CO2_{it}$$

where, PC_CO2 represents per capita CO_2 emissions in the labour market from passenger car, BU_CO2 represents per capita CO_2 emissions in the labour market from buses, MM_CO2 represents per capita CO_2 emissions in the labour market from mopeds and motorcycles, and the subscript, i indexes entities (labour markets) and t indexes time (2010-2017) because of panel nature of the data set.

As far as environmental externalities for commuting emissions are concerned, different aspects of commuting within a labour market may have different degrees of environmental impact. These aspects have different identifiers, one of which could be considered the gross population density, which approximates the labour market´s degree of compactness (*COMP*). Here, the degree of compactness assumed to vary with density. Two variables are also presented to estimate the deviation of the employment distribution within the labour market from uniform dispersion (Gordon, P., Richardson, H. W., & Wong, H. L., 1986); in other words, these variables estimate the polycentricity of the labour market. These two variables are measured as two Gini-type concentration indexes: one of them is concentration *(CONC*), which assesses whether labour market employment is concentrated in some municipalities or it is equally distributed across municipalities within the labour market (Tsai, Y.-H., 2005). Another index is diversity (*DVS*), which is calculated as a proxy for functional diversity at the labour market level. This proxy indicates a balanced distribution between residential and productive functions when it takes on the value zero, meaning the population and employment distributions are equally dispersed (Lee, B. 2007; Lee, S., & Lee, B., 2014).

The degree of urban diversity (*DVS*) is measured using the technique described in Cirilli, A., & Veneri, P. (2010), which adds together the absolute values of the difference between the population share and the employment share of all municipalities within a labour market. The degree of urban concentration (*CONC*) is also measured using the technique described in Cirilli, A., & Veneri, P. (2010), which adds together the absolute values of the difference between the area share and employment share of all municipalities within a labour market. These variables can also be obtained by using the Delta index (DELTA) in line with Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J., (2001). The following municipality characteristics variables or urban spatial structure indicators from the labour market perspective are also considered in this study:

$COMP_{it}$ Compactness in the labour market area based on population density for 2010 to 2017.

DVS_{it} Degree of functional diversity in the labour market area for 2010 to 2017 (Cirilli, A., & Veneri, P. (2010) define this as the "*sum, for each municipality within an urban area, of the differences in absolute value between the population and the employment shares of that municipality over the whole urban area*").

$CONC_{it}$ Degree of concentration in the labour market area for 2010 to 2017 (Cirilli, A., & Veneri, P. (2010) define this as the "*sum, for each municipality within an urban area, of the differences in absolute value between the area and the employment shares of that municipality over the whole urban area*").

Moreover, the different socio-demographic characteristics of householders may influence the external environment in different ways in terms of CO_2 emissions. The socio-demographic variables considered in this empirical analysis are as follows: average age of the population (*AGE*), which is measured by taking the arithmetic average of the population age in a municipality, and the share of high-skilled householders in the central municipality (*ED*), which is measured as municipality householders with a post-secondary education of 3 years or more. This measure can be used as a proxy for centrality (monocentricity) while in Sweden, most highly educated householders are assumed to be employed. All household characteristics variables (socio demographic) controlled for in this study are as follows:

AGE_{it} Average population age in the labour market area for 2010 to 2017.

ED_{it} Share of education (post-secondary education of 3 years or more) in the central municipality within the labour market area for 2010 to 2017.

Finally, this empirical study includes two additional control variables: one of them is the ownership of green passenger cars (*OGC*), which is measured as the per capita (registered) ownership of green passenger cars among householders within the labour market area. The other control variable is the infrastructure endowment of the labour market area (*INF*), which is measured as the per capita net cost of street and road development in municipalities within the labour market area. All accessibility variables controlled for in this study are as follows:

OGC_{it} Per capita ownership of green passenger cars in the labour market area for 2010 to 2017.

INF_{it} Per capita infrastructure endowment in the labour market area for 2010 to 2017.

Table 1: Descriptive statistics

Variables	Description	Data source	Minimum	Maximum	Mean	Std. deviation
La_CO2	Per capita commuter CO_2 emissions (tons/year) in the labour market.	SMHI	1.085811	3.229745	1.72373	.355709
COMP	Compactness of population in the labour market.	SCB	4	766.2306	60.5890	117.712
DVS	Diversity in the labour market.	SCB	.0005286	1.200393	.090178	.201523
CONC	Employment Concentration in the labour market.	SCB	.0026849	1.216125	.495761	.326917
ED	Share of education in central municipality.	SCB	.2944126	.9698356	.679761	.155569
AGE	Average population age in the labour market.	SCB	39.55278	45.66667	43.6027	1.13905
OGC	Per capita ownership of green passenger cars in the labour market.	BS	.0005556	.0391341	.010124	.007149
INF	Per capita infrastructure endowment in the labour market.	SCB	2.109669	9.191208	3.73722	1.09003

Note: according to the SCB classifications, people who work in a municipality do not necessarily reside in it.

Before the empirically evaluating the relationships between the features of the labour market and per-commuter CO_2 emissions, some descriptive statistics for all variables are presented in Table 1. In addition, the correlation coefficient among all the relevant variables are also presented in Table 2. Table 2 suggests that more compact labour market areas are associated with lower levels of CO_2 emissions generated by commuting. The correlation between CO_2 emissions and the concentration index indicates that a balanced distribution of employment relative to municipality population shares is associated with fewer external environmental costs.

Table 2: Bivariate correlation among the variables

Variables	La_CO2	COMP	DVS	CONC	ED	AGE	OGC	INF
La_CO2	1.0000							
COMP	-0.2603	1.0000						
DVS	0.1902	0.0787	1.0000					
CONC	-0.0756	0.3373	-0.4513	1.0000				
ED	0.2256	-0.3297	-0.0552	-0.1718	1.0000			
AGE	0.2232	-0.6363	-0.1364	-0.2039	0.1884	1.0000		
OGC	-0.0718	0.1524	0.2711	-0.2393	-0.0801	-0.2084	1.0000	
INF	-0.1563	-0.1546	-0.0718	-0.2447	0.0479	0.0657	-0.1222	1.0000

The share of energy-efficient transport users and green car users appears to be higher within high-density labour market areas, where employment is highly concentrated. Interestingly, the development of infrastructure goes hand-in-hand with the labour market enlargement process. Remarkably, the lower correlation between these variables may be due to newly developed urban built environments, which are fragmented, isolated, and not linked with the developed infrastructure or pre-existing public transit. These cases have already been highlighted by Stojanovski, T. (2019) and Eriksson, I.-M. (2015), such a situation forces commuter to use motorized means of transport. Ultimately, the external environmental costs generated by commuting depend on commuting patterns, including transport mode, travel time, and distance.

3.2 Model Specification

A panel data set is used in order to control for the most common threats to internal validity in econometric models, such as omitted variable bias or unobserved heterogeneity issues. The basic approach of this study is the use of a fixed-effects model since it analyses the impact of variables that vary over time. Moreover, such a model helps here to control for specific endogeneity issues, namely, time-invariant omitted variable bias. The fixed-effects model used in this study can be written as:

$$La\_CO2_{it} = \beta_0 + \beta_1 COMP_{it} + \beta_2 DVS_{it} + \beta_3 CONC_{it} + f(CON_{it}) + \alpha_i + \vartheta_{it} \quad \ldots\ldots\ldots(1)$$

where La_CO2_{it} is per-commuter CO_2 emissions (tons/year), $COMP_{it}$ is compactness, DVS_{it} is diversity, $CONC_{it}$ is concentration, CON_{it} represents the control variables used in the study, α_i control for unobserved heterogeneity labour market fixed effects, and ϑ_{it} is the error term. For each variable, i indexes the 39 labour markets and t indexes the years in the 2010-2017 time period.

The concern about internal validity issues leads to an extension of the model specification. Household decisions about residence and job locations are influenced by commuting patterns such as transport mode (public or private), time, and distance. In light of all these facts, two endogeneity issues, namely, simultaneous causality and self-selection bias, have been controlled for in most of the studies that have worked to investigate the effects of urban dispersion on commuting and with the associated environmental emissions (Brownstone, D., & Golob, T. F., 2009; Cirilli, A., & Veneri, P., 2014; Lee, S., & Lee, B., 2014).

In this study, all the determinants of the dispersion of the labour market area were treated as potential sources of these endogeneity issues. The arguments for the feasibility of simultaneous causality as follows. There is a positive correlation between population density and CO_2 emissions in Table 2, which means that if the density increases, then pollution also increases. The opposite relationship is true to an extent in Nordic counties. According to Fransson, U., Rosenqvist, G., & Turner, B. (2001), people in the largest cities prefer to reside near recreational sites more than do those in smaller cities. The Swedish tradition regarding what is considered a recreational site is less polluted forested areas (Hörnsten, L., & Fredman, P., 2000). Hasanzadeh, K., Kyttä, M., & Brown G. (2019) argue that residential location choices are negatively influenced by negative environmental issues such as noise and pollution. Eventually, the level of CO_2 emissions (pollution) might influence the population density in the largest urban areas in Sweden.

In addition to negative environmental issues, there might be some other unobservable characteristics related to the demographic, socio-economic, and geographical determinants. These unobservable characteristics create self-selection bias in the data. This problem occurs when those determinants account for difference among residents in the largest urban areas and thus biases the error term. Therefore, the population density variable and other related regressors in the model could be potential sources of endogeneity bias. This problem could still exist even after including all possible controls in the model (Brownstone, D., & Golob, T. F., 2009). In consideration of all these endogeneity issues, an instrumental variable (IV) model is estimated in addition to the fixed-effects model. Then, to conduct the estimation, one of the main variables related to labour market growth (namely, compactness) is instrumented by the corresponding variable as measured in the data prior to 2010 (1993-2000), which fulfils the conditions for a valid instrumental. Therefore, the first-stage of the IV model can be written as:

$$COMP_{it} = \delta_0 + \delta_1 P\_COMP_{it} + f(CON_{it}) + \alpha_i + \varepsilon_{it} \text{ ....(2)}$$

where each variable is the same as in equation (1), P_COMP_{it} represents compactness in each labour market area i and each year t in the 1993-2000 time period, and ε_{it} is the error term.

The instrument in this study is chosen because the variable compactness (*COMP*) is fairly correlated with itself over time, and the "*relevance*" condition for a valid instrumental is fulfilled, since the F-statistic is greater than 10. The "*exogeneity*" condition cannot be statistically verified, since only one instrument is used (H. Stock, J., & W. Watson, M., 2011). The arguments for the validity of this instrument are as follows. The CO_2 emissions from commuting during the 2010-2017 period should not be affected by the population density in 1993-2000; in other words, the instrument is exogenous: corr(P_COMP_{it}, ϑ_{it}) = 0. However, the population density in 2010-2017 could have been influenced by the population density in 1993-2000; in other words, the instrument is relevant: corr($P\_COMP_{it}, COMP_{it}$) $\neq$ 0. Borgegård, L.-E., Håkansoon, J., & Malmberg, G. (1995) showed that the population distribution is influenced by demographic components, economic conditions, and geographic conditions. These determinants have strong effects in large urban areas, and large urban areas are complementary with compactness.

4. Results and Discussion

4.1 Empirical Results

First, a standard analysis is conducted to determine if the basic classical assumptions of the fixed-effects (FE) model is satisfied. According to the mean variance inflation factor (VIF) listed in Table 3 and the pairwise correlations in Table 2, there are no multicollinearity problems in the data set. The Breusch-Pagan test tells us that a pooled ordinary least square (OLS) regression would not be appropriate, while the fixed-effects model fits the data well according to the Hausman test. There is some heteroscedasticity in the data set, which was addressed by the modified Wald test. This issue is taken care by calculating robust standard errors, and found a result very similar to that obtained without robust standard error. Since our panel data set has a short time series (less than 20 years), it is not necessary to be concerned with serial correlation and cross-sectional dependence or contemporaneous correlations (Baltagi, B. H., 2008).

In the empirical investigation, the environmental impact variable, as calculated above, is regressed on the main variables defining the spatiality of the labour market area, including compactness, concentration, and diversity. In addition, it is regressed on some controls indicating the study concern of omitted variable bias. Therefore, it is regressed on two important householder socio-demographic variables contribute to the structure of labour market area enlargement, including average age of householder and householder education. Moreover, the dependent variable is also regressed on two other controls related to underlying issues: infrastructure endowment and ownership of green passenger cars. The estimated results in Table 3 were found using the FE model and the IV model. There are significant differences between FE and IV estimates, especially for the polycentricity indexes. However, the results for most of the main regressors those indicate the labour market spatial structure are statistically significant.

There is only one variable in the FE model, namely, per capita average age (*AGE*), which is not statistically significant. Additionally, only two variables in the IV model, namely, concentration (*CONC*) & per capita ownership of green passenger cars (*OGC*) are not statistically significant. The goodness of fit of the FE model indicates that the model explains approximately 60% of the total variance in the dependent variable, which is a satisfactory result. On the other hand, the IV model explains approximately 20%, which is also a satisfactory result considering that this is a social sciences study.

The significant coefficient on compactness (*COMP*) suggests that in terms of per capita CO_2 emissions, densely populated labour market areas are more sustainable. In particular, this coefficient shows that the average CO_2 emissions from commuting will be fewer (by 0.1 tons/year) if the gross population density increases (by 50 people/sq. km). Commuting distance could be reduced because of closer destinations, even after controlling for accessibility endowments and socio-demographic characters. This finding is consistent with previous studies such as Cirilli, A., & Veneri, P. (2014) and Lee, S., & Lee, B. (2014), which considered the effect of density on commuting mode. Theoretically, commuters might be influenced by the opportunity costs of traffic congestion and of using a private car in a more compact area (Jayasooriya, S. A. C. S., & Bandara, Y. M. M. S., 2017). Therefore, such commuters prefer to use more cost-effective transport modes, such as public transport, which is more carbon-efficient in terms of per passenger-mile. In addition, commuters tend to own more green vehicles in compact areas.

T*able 3: Estimation results of specified models.*

Models	Fixed effect (FE) (robust)		Instrumental variable (IV) (robust)	
Variables	Coefficient	Standard errors	Coefficient	Standard errors
(intercenpt)	.9710093 (0.746)	2.973272	.0882612 (0.904)	.7313006
COMP	-.0019931* (0.079)	.0011038	-.0006766*** (0.000)	.0001442
DVS	-2.174552*** (0.006)	.7549174	.5279893*** (0.000)	.1069486
CONC	-2.353946*** (0.003)	.7343044	.1425375 (0.131)	.0940767
ED	5.18872* (0.087)	1.242091	.3936671*** (0.000)	.0884795
AGE	-.0279969 (0.626)	.0570602	.034927** (0.029)	.0159647
OGC	5.236813*** (0.000)	.9819908	-3.487771 (0.222)	2.816469
INF	-.0328575* (0.055)	.0122599	-.0527169*** (0.000)	.0119106
Number of observations	312		312	
Number of groups	LA 39		--	
R^2	within = 0.5625		0.1973	
Adjusted R^2	0.5524		0.1788	
F-statistic	F(7,38) = 53.46		F(7, 304) = 22.32	
Mean variance inflation factor (VIF)	1.50 (from OLS)		--	
Breusch-Pagan test	837.05 (0.0000)		--	
Hausman test	75.98 (0.0000)		--	
Modified wald test	5200.86 (0.000)		--	

In this table: compactness (COMP), diversity (DVS), concentration (CONC), average age (AGE), share of education in central municipality (ED), ownership of green passenger cars (OGC) infrastructure endowment (INF).

The coefficient of concentration (*CONC*) is statistically significant in the FE model and suggests that a polycentric employment distribution is associated with higher CO_2 emissions from commuting. This may indicate that decentralized urbans are not all developed in line with the public transit infrastructure. Moreover, this could also explain the sprawling neighbourhoods with detached accommodation systems in Sweden, which is consistent with the argument of Stojanovski, T. (2019). The significant coefficient on diversity (*DVS*) in the IV estimation suggests that labour market areas with unequal employment distributions are associated with higher levels of external environmental costs in terms of CO_2 emissions. In other words, if the distribution of residential areas and workplaces in a labour market are 100% matches, then the CO_2 emission due to commuting for the work will decrease by approximately 50% of the existing amount. This finding also indicates that there are dispersed or isolated residences along with poor distributions of residential areas and employment. Considering the opportunity cost of time, people have prioritized private cars as the best alternative transport mode for long distance commutes between home and workplace. However, a certain flexibility generated by polycentric spatial labour market enlargement may be suggested by the study findings.

The accessibility variables for the labour market areas are related to a lower level of CO_2 emissions according to the empirical estimates. The coefficient suggests that perfect infrastructure development reduces the travel time of more competitive transport endowments, a fact which is highlighted in Große, J., Fertner, C., & Groth, N. B. (2016). Moreover, this coefficient may also explain why commuters are inspired to use more green vehicles by proper infrastructure development, such as energy-efficient public transport and bicycles. Interestingly, the coefficient on ownership of green passenger cars is not significant. Decentralization with insufficient infrastructure development, neighbourhood sprawl, and increased dependency on commuting via energy-inefficient passenger cars could offset the beneficial effect of green passenger car ownership. This finding is also consistent with the recent argument of Stojanovski, T. (2019).

The findings for the socio-demographic characteristics of commuters significantly explain their effects on commuting. The coefficient on the share of education in the central municipality (ED) is highly significant with a large value. This suggests that a lower concentration of highly educated commuters in the central municipality associated with lower external environmental costs in terms of CO_2 emissions. This finding may indicate that highly educated householders commute longer distances on average, which leads them to use a faster mode of transport. Therefore, they prefer commuting by car due to their higher opportunity cost of time. This finding supports the claim that young highly educated householders prefer to live in the city centre to enjoy the city-life amenities (Beckers, P., & Boschman, S., 2013; Pateli, R., Bhat, C. R., & Pendyala, R., M., 2013), while they work in high-tech industries on the periphery. On the other hand, if this variable is considered as a proxy for centrality, then a positive relationship could be interpreted as the effect of congestion in a highly concentrated large-scale urban area and as longer distance commuting between home and workplace.

The per capita average age (AGE) is also significant in IV analysis and is associated with higher CO_2 emissions from commuting. The coefficient suggests that older householders in Sweden prefer to live with more space in isolated areas and with greener surroundings. Their residence choice makes their commute longer and generates additional external environmental costs in terms of CO_2 emissions because they have prioritized private cars as the best alternative for commuting, considering the opportunity cost of time and their comfort level.

4.2 Robustness Checks

For robustness, the effect of an alternative measure of spatial labour market enlargement on the study analysis is examined. Therefore, a new control, namely, housing supply (HS), is considered. This is an indicator of availability and of the concentration of housing in a municipality (Stojanovski, T., 2019), which is assumed to increase the use of energy efficient transport modes, especially public transport, thus leading to fewer CO_2 emissions. On the other hand, the scattered development of new settlements could result in increased CO_2 emissions by increasing commutes for longer trips (Cirilli, A., & Veneri, P., 2014). The variable is measured as the per capita housing supply in the labour market area for 2010 to 2017 (HS_{it}), which includes the total stock of projected one or two-dwelling buildings in each municipality.

The estimated results of the fixed effects (FE) model with the new variable is presented in Table 4 in Appendix 1. Interestingly, the output of the newly specified model is almost the same as before, and shows that the coefficient on housing supply has an insignificant adverse effect on CO_2 emissions. Otherwise, the spatial labour market variables and the other controls have exactly the same effects and have significant coefficients. The age variable is still insignificant, as in the previous FE model. Ultimately, the interpretation of the newly specified model's estimation remains exactly the same as described before with the same goodness of fit. Robustness is also checked by excluding of a variable from the original model; and the estimated results of the FE and IV models are presented in Table 4 in Appendix 1.

All the variables related to urban spatiality are still statistically significant after excluding the infrastructure endowment (*INF*) of the labour market area. The coefficient on concentration (*CONC*) is now statistically significant in the instrumental variable (IV) analysis. Without controlling for the accessibility variables, the effect of urban structure dispersion on the environment is more severe with higher external costs in terms of CO_2 emissions from commuting. This is also explaining the impact of accessibility development. All socio-demographic controls played the same significant role as in the originally specified model. Ownership of green passenger cars (*OGC*) is still insignificant with a negative coefficient.

4.3 General Discussion

A combined discussion is worthwhile for a better understanding of the implication of the study findings and the specification of an argument for cost-effective policies. A very small value for the coefficient of compactness could explain the lower effectiveness of city compactness in the Swedish context. This might be the reason for neighbourhood sprawl and unbalanced employment distributions in locations where car commuting is assumed be prioritized due to the opportunity cost of travel time. Therefore, a balanced distribution between residential areas and employment might enhance the benefit of a compact labour market area. This balanced distribution should reduce the distance between residential areas and workplaces. The opportunity cost of traffic congestion and other relevant factors could influence commuters to avoid car commutes for shorter distances in a compact area. Likewise, this opportunity cost could influence highly educated householders to reduce their car commutes. Hence, they would mitigate the external environmental costs of their commutes. Moreover, a well-managed transportation system with a developed infrastructure could increase the benefit to the environment of a balanced employment distribution in compact areas. This development could even help to reduce commuting emissions in less compact areas and thus in communities with a higher average age. Eventually, the benefits of green passenger cars ownership would be highlighted positively.

The discussion of the study findings indicates that a balanced distribution between residential areas and employment could be an argument for enacting policy. This would improve the connectivity between employers and employees. Considering the constant effect of all other characteristics, a balanced employment distribution should cost-effectively reduce the external environmental costs of urban enlargement. Such a distribution enhances the positive impact of population compactness and Infrastructure developments on the environment. On the other hand, a more balanced distribution is associated with reduction in the negative impact of commuting by highly educated householders and higher-aged groups of people on the environment.

To clarify the cost-effectiveness of this policy argument, we need to recall the direct and indirect costs of urban structure due to inefficient commuting. Specifically, the cost of CO_2 emissions can be considered as due to its role as a GHG. This GHG causes climate change and produces other relevant external environmental costs, such as sea level rise, increased evaporation, and changing conditions for plants and animals. The cost of redistribution to balance residences and employment locations could be defined as follows: the loss of revenue to specific local governments from investment crowding out and the costs of incentivize and motivate the resolution of area and situation-based problems. Therefore, a significant level of redistribution could be suggested considering the income level of residents and the size of investment.

Implementing a balanced employment strategy is often less costly than mitigating congestion in highly compact areas in the USA (Giuliano, G., 1991). Likewise, a balanced distribution between residential areas and employment locations could be an even more cost-effective policy argument in Sweden, as such a policy would reduce a significant amount of per commuter CO_2 emissions by reducing the distance between homes to workplaces. At the same time, a more balanced distribution is expected to enhance connectivity between employers and workers and thus enhance productivity (Xesha, D., Iwu, C. G., Slabbert, A., & Nduna, J., 2017). This is consistent with the arguments of Anderstig, C., & Mattsson, L.-G. (1991) that a balanced residence and employment distribution could contribute to the national economy in the long run. As such a balanced distribution helps employers to save their time by reducing commuting distances and leads to better health by reducing car commuting. Less car commuting means less fuel consumption and hence less CO_2 and other emissions, namely, nitrogen oxide (NOx) which is harmful to human health (Östblom, G., & Samakovlis, E., 2004).

Many arguments in favour of policy supports have been suggested by scholars to control external environmental costs of commuting. Lee, S., & lee, B. (2014) emphasised a "*smart growth policy*" for a better urban structure in the USA to reduce greenhouse gas emissions. An unbalanced employment distribution might be the cause of environmentally inefficient commuting even in a modernized urban area. Since commuting distances will not be effectively reduced in this situation, the opportunity cost of time will influence car commuting. When considering congestion issues in highly compact cities, Yang, J., Liu, A. A., Qin, P., & Linn, J. (2019) showed a better result for the "*private vehicle licence plate lottery system*" in Beijing, China. This is likely impossible in the Swedish context. However, carbon taxes, green car tax relief, and well-controlled car parking have already been applied in Sweden (Lindfors, A., & Roxland, M., 2009; Creutzig, F., Javaid, A., Koch, N., Knopf, B., Mattioli, G., & Edenhofer, O., 2020). A proper redistribution of revenues from the transport and energy sectors to fair mobility could be an effective policy for mitigating external environmental costs in Sweden, according to Creutzig, F., et al. (2020). Even this policy could be less effective under an unbalanced employment distribution, especially among highly educated employees who have a higher opportunity cost of time.

5. Conclusion and Limitations

A panel data analysis with fixed effects (FE) and an IV approach using data on the 39 largest Swedish labour market areas were used to empirically evaluate a conceptual framework. This evaluation interconnected knowledge about the complex links among urban forms (along with labour market enlargement) and the transport mode choices of commuters. Eventually, this evaluation explains external environmental costs in terms of CO_2 emissions from commuting. The findings have supported the hypothesis stated in this study that smaller and more compact urban areas are associated with a lower level of per commuter CO_2 emissions. The coefficients on the key indicators (concentration, functional diversity, and population density) were statistically significant. These results all explain why per commuter CO_2 emissions are influenced by urban enlargement, which supports the study hypothesis. These supportive results were obtained even after controlling for household socio-demographic characteristics and the accessibility of the labour market.

In addition to population density, the labour market polycentricity indicators provide better answers to the research questions. Labour market enlargements that occur without a balanced employment distribution are associated with increased external environmental coats in terms of CO_2 emissions. This effect could be even worse if the extended urban area is not developed in line with the existing public transit infrastructure. The socio-demographic characteristics of households, especially the level of education, play an important role. The travel behaviour of highly educated householders seems to support the assumption that a higher degree of monocentricity in urban structures is associated with a higher level of per commuter CO_2 emissions. The accessibility control variables indicate that the negative externalities generated by commuting can be reduced through infrastructure development. The influence of the high opportunity cost of highly educated householders' time could also be reduced by an efficient employment distribution along with accessibility development. The estimated empirical results are strongly robust, as indicated by the results of the new model specification.

The results of this study suggest a more compact and smaller urban structure with an efficient employment distribution is associated with fewer CO_2 emissions from commuting. On the other hand, sprawling neighbourhoods and decentralized urban development without in line of existing public transit infrastructure are associated with higher CO_2 emissions from commuting. Infrastructure development plays a significant role in enhancing competitive transportation. This competitive transport influences commuter choices of transport mode and is thus associated with reducing external environmental costs. It is not easy to quickly redesign existing sprawling and dispersed urban areas (Eriksson, I.-M., 2015; Stojanovski, T., 2019). Therefore, infrastructure development along with effective transport management could be associated with the achievement of the Swedish sustainable development goals for 2030 and beyond. After focusing on Swedish labour markets, the study findings suggest that an efficient employment distribution with equal dispersion could reduce existing inefficiencies in commuting. Likewise, it could reduce the effects of labour market enlargement on the environment and could lead to a better urban structure that produce fewer CO_2 emissions.

There are some limitations to this empirical work: only labour market specification reported by the Swedish National Institute of Statistics (SCB) in 2010 is considered in this study. According to the SCB the Swedish labour market area specification changes over time. This study used only a specific labour market definition to avoid many calculation difficulties. Moreover, the study included only those labour markets that encompassed at least two municipalities and that had a central municipality with at least 20,000 inhabitants in 2010. Study-relevant determinants such as the monocentricity index and other relevant controls were not included in the study to simplify the analysis. These limitations leave open possibilities for future research. Ultimately, this study is an effort to provide an empirical explanation of the role of the labour market employment distribution in urban structure formation.

Appendix 1

Table 4: Estimation results of specified extended models.

Fixed effect (FE) model with robust (with, HS)									
variables	intercept	COMP	DVS	CONC	ED	AGE	GCO	INF	HS
Coefficient	1.13448	-.0024*	-2.14**	-2.3***	5.393*	-.0181	5.23***	-.0304*	-1.087
Probability	0.694	0.067	0.006	0.002	0.067	0.762	0.000	0.067	0.464
S. errors	2.863373	.00126	.7308	.7095	2.858	.0594	.97047	.0161	1.470

Number of observation	Number of group	R^2	Adjusted R^2	F-statistic
312	39	within = 0.5659	0.55441	F(8,38) = 44.91

Note: ***= p<0.01, **= p<0.05, *= p<0.1

Fixed effect (FE) model with robust (without, INF)							
variables	intercept	COMP	DVS	CONC	ED	AGE	GCO
Coefficient	.7689	-.00217*	-2.1693**	-2.352***	5.159*	-.0256	5.36***
Probability	0.803	0.062	0.007	0.003	0.098	0.675	0.000
S. errors	3.0614	.00113	.7678	.7457	3.044	.0603	.9618

Number of observation	Number of group	R^2	Adjusted R^2	F-statistic
312	39	within = 0.5507	0 .5418	F(6,38) = 64.07

Note: ***= p<0.01, **= p<0.05, *= p<0.1

Instrumental variable (IV) with robust (without, INF)							
variables	intercept	COMP	DVS	CONC	ED	AGE	GCO
Coefficient	-.4576	-.00063**	.5882***	.2102***	.4123***	.0414*	-2.094
Probability	0.635	0.005	0.000	0.004	0.001	0.055	0.457
S. errors	.9616	.00022	.1088	.0722	.1269	.0215	2.809

Number of observation	Number of group	R^2	Adjusted R^2	F-statistic
312	39	0.1749	0 .1587	F(6,305) = 10.95

Note: ***= p<0.01, **= p<0.05, *= p<0.1

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