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Article

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Suitability of the Monocentric City Model for Analysing Suburbanization Processes in the Czech Republic

Martin KREJČÍ – Jiří BALCAR***

Abstract

In previous decades, we could see significant growth of population in suburban areas in the Czech Republic, which was connected with significant environmental, social, and economic costs. As the rapid suburbanisation continues, the better understanding of its determinants and estimation of their effects become necessary. In this article, we test the suitability of popular monocentric city model for analysing suburbanization processes in polycentric areas in the Czech Republic, which led to employing data for Czech districts (NUTS 4) in the period 2010 – 2019. The results show that the monocentric city model is suitable for analysing suburbanization in the Czech districts (represented by suburban land growth), as all its determinants (population size, unemployment, and commute costs) with the exception of price of building plots were found to be statistically significant and with expected signs. Moreover, the alternative operationalization of the model provided evidence on the robustness of the results and heterogeneity analysis revealed interesting differences between districts different in urbanisation level and other characteristics. The application of spatial regression revealed a statistically significant spatial spillover effect of the unemployment.

Keywords: *suburbanization, urban sprawl, monocentric city model, spillover effect, spatial regression*

JEL Classification: R12, O18, C33

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Introduction

The phenomenon of suburbanization has been extensively studied in the fields of geography and urban economics over the past decades. It is defined '*as the process of deconcentration of the population and its activities from the cores of metropolitan regions to their hinterland*' (Ouředníček et al., 2019, p. 299) and it is often also called 'urban sprawl' or 'suburban sprawl' when the suburbanization is considered to be rapid and characterised by low-density housing and monofunctional use of land with a strong dependency on car usage (Rafferty, 2021). The suburbanisation causes a violation of the principle of a compact city (Couch et al., 2007), i.e., the ideal city with high density, centralized development and a spatial mixture of functions (Chin, 2002), causing negative environmental, economic, and social effects that endanger community life (Rafferty, 2021). Chin (2002) also notes the expenses associated with suburbanization and urban sprawl, including unappealing development, extended commuting distances and expenses, escalated costs of local infrastructure, and the forfeiture of arable land and green space.

The majority of literature pertaining to suburbanization concentrates on the United States. This phenomenon experienced a substantial surge after World War II due to the widespread construction of homes in suburban areas and the increased accessibility of mass-produced personal vehicles. Subsequently, suburbanization began to be explored in Western Europe and other capitalist nations. However, the situation in socialist states was notably different. Evidence from Central and Eastern Europe (CEE countries) suggests that socialist ideologies and central planning significantly influenced the formation of urban areas (Couch et al., 2007). During the socialist era, cities remained relatively compact, owing to the prevalence of intensive housing structures (particularly unified prefab panel houses), central planning, and the lack of private ownership guaranteeing control over urban development (Slaev and Nikiforov, 2013). Privatization, deregulation of economic activities, and decentralization of political power were among the primary reasons for the emergence of suburbanization in the CEE. Post-socialist planners placed their focus mainly on developing urban fringes, whereas maintenance and development of inner cities were relegated to secondary priorities. The inflow of citizens to the suburbs, coupled with an increase in purchasing power, led to greater demand for higher quality and quantity of infrastructure and services, which subsequently led to urban fragmentation. Simultaneously, industrial restructuring caused the emergence of brownfields. Furthermore, the subsequent shift to a market economy directly influenced the shape and direction of city development (Stanilov and Sýkora, 2014). On the other hand, currently, more than two decades after the fall of socialist regimes in CEE countries and the ensuing economic changes, the patterns and determinants of suburbanization appear to be identical or highly similar to those of their Western counterparts (Bertraud, 2006; Slaev and Nikiforov, 2013).

Despite the growing empirical body on suburban processes, there is still a lack of evidence on this topic for Central and Eastern Europe, as previously pointed out by scholars such as Queslati et al. (2015) and Couch et al. (2007). The majority of these studies are qualitative in nature, such as case studies of various cities and metropolitan areas (Ouředníček et al., 2019). Selecting a particular approach for quantifying and measuring suburbanization is challenging. While some authors have developed their own methodology (e.g., Burchfield et al., 2006), one of the most commonly employed models for identifying the determinants of suburban growth is the monocentric city model (see DeSalvo and Su, 2018 for a discussion on its robustness). Additionally, Schmidt et al. (2020) demonstrated that the monocentric city model is also suitable for European urban areas with a polycentric structure.

In this article, we bring evidence on suitability of monocentric city model for analysing suburbanization processes in polycentric areas in the Czech Republic. To achieve this goal, we will estimate the monocentric city model using panel data for 77 Czech districts (NUTS 4) from 2010 to 2019. The use of district-level data is primarily driven by two factors: the polycentric nature of the districts and the lack of necessary data at the municipal level. According to Belotti et al. (2017), spatial processes do not occur in isolation but are spatially correlated. This implies that developments in a district are influenced not only by changes within the district but also by changes in neighbouring districts. Therefore, spatial econometrics will be utilized in conjunction with panel data analysis to establish the presence of spatial effects.

It is possible to identify three important contributions of this article: Firstly, it presents new evidence on suburban processes in the Czech Republic. To the best of the authors' knowledge, this study is the first to utilize the monocentric city model to investigate the determinants of suburbanization in the Czech Republic. Secondly, it compares the determinants of suburbanization across districts of varying sizes, wage levels, and spatial distribution. Finally, the article analyses the spatial spillover effects to shed light on the influence of neighbouring districts on suburbanization processes.

The findings of this study demonstrate the applicability of the monocentric city model for examining suburbanization in Czech districts. All determinants derived from the model, with the exception of the price of building plots, were found to be statistically significant. In addition, the analysis revealed that the significance of particular determinants in suburbanization varies across districts with varying levels of urbanization. Furthermore, the spatial dimension was identified as a crucial factor in suburbanization, as it was observed that suburban development is not only influenced by changes within the focal district but also by spillover effects from adjacent ones.

1. Literature Review

1.1. Models of Suburban Growth

There are several theoretical frameworks that have been developed to explain the causes of suburbanization and urban sprawl. The Accessibility Model was among the first models to explain suburbanization as a byproduct of economic growth, whereby the rise in income of the population leads to an increased demand for better housing, which is met by the construction of new houses in the suburbs (Follain and Malpezzi, 1981). In contrast, the Edge City Model, introduced by Garreau (1991) and further developed by Henderson and Mitra (1996), provides a distinct perspective on suburbanization. This model proposes that new urban areas built on the outskirts of major American cities, which are characterized by a high degree of strategic development, compete with central districts of cities, and thus present an alternative spatial organization of production in metropolitan regions. The Monocentric City Model, originally developed by Burgess (1925) as the Model of Concentric Zones and later modified to the Alonso-Muth-Mill model (Wheaton, 1974), is one of the most commonly used models to understand the spatial organization of cities and urban areas. The term 'monocentric' refers to the spatial concentration of urban development around a city core, or the central business district (CBD). This model assumes that residents of a given area live around the CBD and commute to work there. The CBD is considered a non-residential area located in the central, high-density area of the city/metropolitan area. Furthermore, it assumes that all individuals in the area are identical, have the same needs, and that the money they earn is spent on housing costs, amenities, and commute to work. As commuting is costly and increases with distance from the CBD, households must decide whether to live closer to the CBD and incur lower commuting costs but higher housing costs, or vice versa. This, in turn, forces housing builders to rationalize land use near the CBD and try to produce more housing per unit of land. In other words, they seek to minimize costs by building multi-storey buildings and smaller flats, since the rent from the land per square metre grows with the height of the building. Households then need to choose whether to live in well-located but smaller and more expensive apartments, or in more distant but larger and relatively cheaper dwellings toward the outskirts of the city, at the cost of higher commuting costs (Kulish et al., 2011; Brueckner and Fansler, 1983).

Brueckner and Fansler (1983) are among the first researchers to apply the monocentric city model to real-world data. Their study used data from the 1970 US Census to estimate cross-sectional ordinary least squares (OLS) regression. They empirically validated the model using base variables, and found that only one variable, which was a proxy for commuting costs, was statistically insignificant. According to Brueckner and Fansler (1983), this was caused by the wrong assumption that the variables they have chosen are a good proxy for the cost of commuting. The popularity of the monocentric city model surged in the first decade of the new millennium. For instance, Song and Zenou (2006) focused on the impact of property tax on suburban growth using the model and a variable representing the current level of tax within urbanized areas in the USA. They concluded that property tax is negatively related to suburbanization. Su and De Salvo (2008) developed a more comprehensive model by including a wide range of variables that could potentially affect suburbanization. Their primary objective was to determine whether subsidies for transport services (infrastructure and bus services) affect suburbanization in US metropolitan areas based on 2000 US Census data. Their comparative analysis revealed that an increase in subsidies for public transport has a negative effect on suburban growth, while an increase in government subsidies for car transportation leads to an increase in suburbanization in city areas. They also confirmed the findings of Song and Zenou (2006) that property tax negatively influences suburbanization processes. Paulsen (2012) took a different approach to applying the monocentric city model. He used data from the U.S. Census for the years 1980, 1990, and 2000 and discussed the suitability of commonly used proxy variables in the monocentric city model. Paulsen (2012) decided not to incorporate the variable approximating commuting costs given previous difficulties in specifying it. Despite this, he achieved the expected results and concluded that the monocentric city model provides robust evidence on suburbanization.

As suburbanization (and urban sprawl) is a global phenomenon, the monocentric city model has been applied beyond the United States, in places such as China, Europe, and other urban areas with both monocentric and polycentric structures. Deng et al. (2008) employed the monocentric city model to study the expansion of Chinese cities, while Queslati et al. (2015) examined suburbanization in European metropolitan areas using a panel of 282 European cities from 1990, 2000, and 2006. Both studies found that the monocentric city model is appropriate for predicting suburbanization processes, not only in the United States but also in other countries. Despite employing different methods and approximations of the model variables, it can be concluded that the monocentric city model is a robust estimator of urban development determinants. Nonetheless, we will focus on suburbanization in Central and Eastern European countries in the subsequent sections.

1.2. Development of Suburbanization in the Central and Eastern European Countries

During the 1950s in the 20th century, the establishment of socialist regimes strongly influenced urban development in the Central and Eastern European (CEE) countries. The central planning system implemented five-year plans that were directed from the top tiers of government to the lower levels and were subject to state secrecy. As noted by Borén and Gentile (2007), the priorities for spatial suburban development were focused on heavy industry and military-industrial complexes, while agriculture, light industry, and services were given lower priority. Moreover, land did not have market value, and its use was determined by administrative decisions rather than market competition, leading to projects mainly being carried out in greenfield areas of cities.

According to Kovács et al. (2019), housing demand was met through the mass construction of high-density standardized prefabricated panel houses on the outskirts of cities. These facts led to differences in spatial organization between western and socialist towns, with the population density of the socialist city outskirts growing at a faster rate than the city centres. However, the city centres often remained densely populated and cities themselves compact (Borén and Gentile, 2007). It can be concluded that extensive suburban growth and urban sprawl were '*halted during communist times by the state's central planning urbanisation policies*' (Sýkora and Mulíček, 2014, p. 133).

With the transition from centrally planned to market economies in Central and Eastern European (CEE) countries, the formation of urban regions underwent significant changes due to processes such as democratisation, globalisation, economic restructuring, social differentiation, and the adoption of market economy and neoliberal policies, as observed by various scholars (Sýkora and Mulíček, 2014; Tsenkova and Nedović-Budić, 2006; Stanilov and Sýkora, 2014). According to Stanilov and Sýkora (2014), the privatisation and restitution of state assets, deregulation of economic activities, and decentralisation of political power were crucial in furthering suburbanisation. The trading of land became possible, leading to spatial fragmentation of both rural and urban areas. Kovács et al. (2019) noted that people who gained agricultural land in restitutions in Hungary were not interested in working on it and sold the land to developers, resulting in the mass conversion of vast areas of agricultural land to residential and business uses. The economic boom, higher wages, and the emergence of an affordable low-interest mortgage market created opportunities for suburbanisation in urban fringes, which were suppressed during the socialistic regime (Borén and Gentile, 2007). Slaev and Nikiforov (2013) also agree that the transition to the market economy supported suburbanisation in CEE countries during the 1990s.

According to Stanilov and Sýkora (2014), the decentralisation of political power granted local municipalities in stronger position in decisions about their land use and local urban planning. This autonomy led to the loosening of the rules of urban development, facilitating suburbanisation as a revenue-generating strategy for municipalities in the Czech Republic through tax allocation mechanisms. Stanilov and Sýkora (2014, p. 299) further point out that '*another notable component of the post-socialist decentralisation policy has been the breakup of large administrative territories into smaller independent units, which has created further fragmentation of the CEE metropolitan landscapes.'* Large landowners often hold seats in the local council and have a direct influence on land conversion processes in Hungary and other CEE states, as observed by Kovács et al. (2019). This could potentially create a conflict of interest and accelerate the process of suburbanisation.

During the past few decades, the pattern of suburbanization in Central and Eastern European (CEE) countries has undergone significant changes, which has contributed to the reconciliation of CEE and other European countries. Although suburbia represented by new low-density housing areas, new commercial zones and amenities grew, the core city centres were shrinking (Sýkora, 1999). The reason was deindustrialization of the areas of the core industry of the city, and the effort of local municipalities near the cities to attract new investors and inhabitants. However, this trend has posed a problem for the future development of wider metropolitan areas of cities as the spatial planning of cities has been limited by their administrative boundaries (Stanilov and Sýkora, 2014). Additionally, insufficient coordination among municipalities has been identified as one of the biggest negatives and reasons for extensive suburban growth, as pointed out by Sýkora and Mulíček (2014) and Mulíček and Toušek (2004). Although some legislation has been adopted, such as The National Spatial Development Policy of the Czech Republic in 2009, the issue of coordination among municipalities still remains.

Despite the wide empirical body on suburbanisation processes in the Czech Republic, most studies have used the case study methodological approach. Additionally, there is a lack of a common methodological framework for exploring suburbanisation at the national level, as highlighted by Ouředníček et al. (2019) and Kovács et al. (2019). This article aims to test the applicability of the widely used monocentric city model for analysing suburbanisation processes in polycentric areas (districts) in the Czech Republic. The significance of this article is heightened by the examination of the use of the monocentric city model for Central and Eastern European (CEE) countries. For instance, Wiest (2012) criticised the application of this model to post-socialistic urban development. The assumptions of the model are often criticised, such as the assumption that present cities are monocentric, although they are often polycentric, or the assumption of commuting of all workers to the central business district (CBD). However, Borén and Gentile (2007) argue that CEE countries have made significant progress in overcoming their vices, and the patterns of urbanisation should correspond to those in Western countries. Although city centres have lost their functions as commercial and office centres, during recent years the "CBD-ization" process occurred, which means the renewal of their previous functions and the return to commercial and office function. Furthermore, according to Bertraud (2006), CEE cities have maintained their monocentric structure, and the development of cities has only diverged, although the patterns brought by the socialist regime have to be gradually revised and corrected. Additionally, Schmidt et al. (2020) tested the monocentric city model on German cities that are considered rather polycentric, and their robust results prove that the monocentric city model is still consistent. Their findings are even more relevant because the eastern part of Germany developed under socialist conditions, indicating that the model is also applicable to CEE countries. In the following section, the relevance of the monocentric city model for the Czech Republic will be investigated.

2. Empirical Strategy

The monocentric city model (see previous section for details) represents the theoretical basis for our analysis. In the model, the suburban growth (as a dependent variable) is explained by four independent variables, i.e., current population size, their income, transport costs, and the value of land. Brueckner and Fansler (1983) assume the following relationships:

- The growth of the urban population leads to the expansion of the city boundary to provide housing to more people in the area.
- The increase in the level of income will increase the demand for better housing, especially in the proximity of the CBD, due to the increase in purchasing power of the population and thus increased suburban growth.
- Increasing costs of commuting reduces disposable income in the whole area, meaning reducing housing demand further from the CBD, which leads to a smaller city.
- Growing price of land increases the alternative costs of urban land, leading to a smaller and more compact city.

Studies investigating suburbanization have mainly focused on metropolitan areas in the United States (e.g., Brueckner and Fansler, 1983, or Su and De Salvo, 2008) or large urban zones (LUZ) in European countries. However, Eurostat's published LUZ data is incomplete or entirely missing (noted also by Queslati et al., 2015), making it inadequate for panel data regression. To address this issue, the Czech districts (NUTS 4 level) are used as a rough approximation of metropolitan area, where the district capital serves as the territorial centre, and the ‘suburbanization’ occurs in the surrounding zones. Given the assumption of the monocentric city model that citizens commute to the CBD, we presume that individuals commute to the district capital. As Körner et al. (2017) noted, the district capital is usually the most important and populated city among others and provides jobs to its catchment areas. The unavailability of data prevents us from using territorial units at the municipal level. On the other hand, more aggregated NUTS 3 and NUTS 2 territorial units are too large (especially due to limited commuting distance in the Czech Republic; see Vontroba et al., 2020) to be used as a reasonable approximation of metropolitan areas.

The present study employs the total built-up area of land within a given district and time as the dependent variable to measure suburban growth, which is consistent with most studies on suburbanization (i.e., Su and DeSalvo, 2018; Song and Zenou, 2006; Queslati et al., 2015; Schmidt, 2020). The data for suburban growth were obtained from the summary overview of the land fund provided by the Czech Office for Surveying, Mapping and Cadastre (2021) database for each year of the period 2010 – 2019 and all districts. The variable used to approximate suburban growth includes built-up area, other surfaces, and gardens. It is worth noting that although gardens are not typically regarded as built-up areas in the context of suburbanization, they constitute a significant part of family houses to which they clearly belong. The suburban growth is explained, according to the monocentric city model, by four independent variables: First, population is measured as the number of inhabitants with permanent or long-term residence at the end of a given year in each district, irrespective of their citizenship. Data for population were obtained from the Public Database of the Czech Statistical Office (CZSO, 2021). Second, the income variable is primarily operationalized by the share of unemployed persons, as employment status is strong determinant of individual income. We employed data provided by Czech Statistical Office (CZSO, 2021), i.e., the share of registered unemployed persons in the total population aged 15 – 64 years. It is noteworthy that the average gross wage was used as an alternative operationalization for income level, approximated by wage level in NUTS 3 region to which the district (NUTS 4) belongs. Data on wage level for NUTS 3 regions were obtained as well from CZSO (2021). Third, the costs of commuting were approximated by the total density of motorways and roads, which is calculated as the total length of motorways and roads divided by the area of a district. This approach is similar to that used by Queslati et al. (2015) and Deng et al.

(2008). Data for this variable were obtained from the CZSO (2021). Fourth, the average value of agricultural land is approximated by the proxy variable of the price of building plots (in CZK/m^2), as agricultural land is not available for building and development purposes according to Czech law. Data for this variable were obtained from the CZSO (2021) database. It is noteworthy that the robustness of this variable was tested by using its alternative operationalization as the house share, i.e., the number of completed flats in houses related to the total number of completed flats. This share is a measure of demand for land, since low land prices lead to an increased demand for housing in family houses compared to apartments. Therefore, a positive correlation between the house share and suburbanization can be expected.

These data were used to estimate the empirical model explaining logarithm of artificial land area in km^2 by unemployment rate and logarithms of population size, road density and price of building plots in district i (i = 1 to 77) and year t (t = 2010 to 2019), where βs represents regression coefficients and ε error terms.

$$\begin{aligned} \ln\_artificial\_land_{it} = \beta_0 + \beta_1 \cdot \ln\_population_{it} + \beta_2 \cdot unemployment\_rate_{it} + \\ + \beta_3 \cdot \ln\_road\_density_{it} + \beta_4 \cdot \ln\_price\_of\_building\_plots_{it} + \varepsilon_{it} \end{aligned} \quad (1)$$

The 10-year period was chosen with regard to data availability, since most of the data has been published since 2010. Moreover, a period of 10 years can be considered a sufficiently long period for capturing major changes in the territory and its development, while longer time period is also helpful to smooth annual variation in the case of less populous districts. It is worth noting that all variables, except for the share of unemployed individuals, were transformed by natural logarithm. As a result, the focus of the analysis will be on their elasticity, rather than absolute change. Specifically, a 1% growth in the variable will correspond to the given percentage change in the artificial built-up area.

In this study, we employed panel regression analysis using the ordinary least squares (OLS) method. As Wooldridge (2012) notes, panel analysis combines elements of both time and cross-sectional analysis. Panel data, also known as longitudinal data, are collected over two or more time periods (years 2010 – 2019) and two or more units (districts in our case), providing distinct advantages over time series or cross-sectional data. With more observations and lower aggregation, more complex hypotheses of dynamics and interactions can be tested. Furthermore, panel data analysis allows for more effective analysis of hidden, unobserved, and random relationships in the econometric structure of the relationship between units. In panel regression analysis, various methodological approaches can be employed, including models with fixed, random, and between effects. Fixed effects models are used when it is necessary to control for entity-specific characteristics, assuming that such features are time-invariant. In contrast, random effects models assume that the variation between entities is random and uncorrelated with any of the explanatory variables. The selection of random effects models is based on the belief that differences between units have some impact on the dependent variable (more in Wooldridge, 2012). The third approach, between effects estimation, is less common as it disregards time variability, thus resulting in information loss. However, the between-effects estimator is useful in identifying variables that do not have a significant time effect (Wooldridge, 2012). To account for potential heteroskedasticity and autocorrelation, all models are estimated using clustered robust standard errors.

In the section '*Spatial spillover effects between districts'* the advanced models of the spatial panel data analysis are used. In standard panel regression, the entities are considered to be independent of each other, and thus we need to use spatial econometric models to consider the spatial spillover effects. First, it is necessary to define the spatial neighbourhood of units. This was done by ($n \times n$) matrix, where n is the number of districts, containing value 0 when there is no neighbourhood and value 1 when districts have a common border. Subsequently, we applied three different types of estimators, i.e., Spatial Durbin Model (SDM), Spatial-Autoregressive Model (SAR), and Spatial Error Model (SEM), to capture the spatial spillover effects. All models are estimated with the quasi-maximum likelihood estimator (Belotti, Hughes and Piano Mortari, 2017). The SAR model is a basic spatial model applicable for panel and cross-sectional data. This model does not account for exogenous interaction effects. However, the value of the dependent variable for a spatial unit might be affected by some independent explanatory variable of other spatial units as well. In that case, it is appropriate to use the SDM model instead. The SDM model can be described as a generalisation of the SAR model and also includes spatially weighted independent variables as explanatory variables (with prefix W in our data). Both the SAR model and the SDM model account for endogenous interaction effects. However, in some cases, there might be an interaction among error terms. In such cases, you might consider a spatial error model (SEM), which addresses spatial interaction among error terms (LeSage and Pace, 2009).

3. Results

Results in Table 1 support expectations that stem from the monocentric city model, since an increase in population and road density, i.e., decrease in commuting costs, leads to an increase in the built-up area. Additionally, an increase in the share of unemployed persons, serving as a proxy for lower income, is linked to a decrease in suburbanization (see Models 1 and 2). Notably, the price of building plots has no significant effect on suburbanization, which corresponds to results provided by Paulsen (2012), Su and De Salvo (2008) or Song and Zenou (2006). Moreover, the differences in magnitude and significance of the regression coefficients observed in Models 2 and 3 imply that the impact of specific determinants of suburbanization may vary between districts, which will be investigated later.

Given our interest in controlling for the specific characteristics of each district and not in differences between time-invariant characteristics, we will focus our further analysis on models estimated with fixed effects. Nonetheless, the results presented in Table 1 indicate that the findings are consistent across model specifications. In particular, Model 2 demonstrates that a 1% increase in district population and road density leads to a 0.27% and 0.85% growth in the urban area, respectively. Meanwhile, a 1 percentage point increase in the unemployment rate results in a 0.2% decrease in artificial urban land. Notably, the price of building plots does not exert a significant influence on the artificial urban area. Furthermore, we re-estimated Model 2 with the dependent variable advanced by one year (see Model 4) to establish evidence on the causality between suburbanization and explanatory variables. The results of Model 4 are consistent with those of Models 1 – 3, as neither the magnitude nor the statistical significance of the explanatory variables changed significantly. These results support the expected causality described by the monocentric city model.

T a b l e 1

Determinants of Urban Growth According to the Original Monocentric City Model

	(1)	**(2)**	**(3)**	**(4)**
Variables	**Random effects**	**Fixed effects**	**Between effects**	**Fixed effects**
				(dependent var. t+1)
Ln population	0.256*** (0.041)	0.267*** (0.056)	0.306*** (0.084)	0.280*** (0.062)
Unemployment	–0.002*** (0.001)	–0.002*** (0.001)	0.005 (0.017)	–0.002*** (0.001)
Ln Road density	0.800*** (0.124)	0.854*** (0.131)	0.393*** (0.101)	0.719*** (0.118)
Ln price of building plots	–0.001 (0.005)	–0.001 (0.004)	–0.094 (0.261)	–0.002 (0.003)
Constant	1.586*** (0.484)	1.442** (0.653)	1.751** (0.711)	1.342* (0.740)
Observations	770	770	770	693
R-squared	0.3358	0.3343	0.3635	0.3452
Number of districts	77	77	77	77

Note 1: Clustered robust standard errors in parentheses.

Note 2: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Authors.

3.1. Robustness Check

As outlined in the ‘Empirical strategy’ section, various predictors were operationalized differently to test the robustness of the results, as shown in Table 2. In particular, the unemployment rate was replaced by the average gross wage rate at NUTS 3 level (Model 5), and the price of building plots was substituted with the house share, which is the number of completed flats in houses relative to the total number of completed flats (Model 6). The house share was selected as an indicator of land demand, as low land prices typically result in an increased demand for housing in family homes versus apartments. Therefore, a positive correlation between the house share and suburbanization can be anticipated.

Table 2

Determinants of Urban Growth According to the Original Monocentric City Model – Robustness Check

	(2)	(5)	(6)
Variables	**Base model (with fixed effects)**	**Model with wage level (with fixed effects)**	**Model with house share (with fixed effects)**
Ln population	0.267*** (0.056)	0.210*** (0.064)	0.266*** (0.054)
Unemployment	–0.002*** (0.001)		–0.002*** (0.001)
Ln Wage		0.044*** (0.011)	
Ln Road density	0.854*** (0.131)	0.846*** (0.132)	0.859*** (0.131)
Ln Price of building plots	–0.001 (0.004)	–0.001 (0.004)	
House share of completed house			0.015***
flats on total number of completed flats			(0.005)
Constant	1.442** (0.653)	1.647** (0.661)	1.432 (0.629)
Observations	770	770	770
R-squared	0.3343	0.3214	0.3349
Number of districts	77	77	77

Note 1: Clustered robust standard errors in parentheses.

Note 2: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Source: Authors.

The findings of Model 5 indicate that a 1% increase in average gross wage at NUTS 3 level leads to a 0.04% increase in the artificial urban area. This result aligns with the outcomes of Model 2, which employs unemployment rate as a proxy for income level and suggests a negative correlation between income and suburbanization. Moreover, the use of the house share as an indicator of demand for land in Model 6 yielded the expected outcome, where a 1 percentage point increase in the share of completed house flats to the total number of flats resulted in a 1.5% increase of the artificial urban area. Notably, the estimated effects of population and road density on suburbanization remained largely consistent across the different operationalizations of the predictors, indicating the robustness of the results.

3.2. Heterogeneity Check

In order to examine the effects of specific determinants of suburbanization under different conditions, Model 2 was re-estimated for districts with different characteristics. Table 3 presents model estimations for districts that were grouped according to the median of population density (Models 7 and 8), income level measured at NUTS 3 level (Models 9 and 10), and index of municipalities proximity (Models 11 and 12).

It is posited that districts with higher population density are more likely to exhibit suburban growth than rural ones. A closer examination of the disparities between Models 7 and 8 reveals that population growth does not have a statistically significant effect on the overall growth of built-up area in districts with lower population density.

However, in districts with high population density, population growth has a statistically significant effect on the growth of built-up area. There are several reasons for this phenomenon. Firstly, cultural ties and traditions may play a role. Individuals residing in districts with low population density may be more connected to family ties and may not typically relocate from their native village, instead opting to construct dwellings for themselves and their children there. Thus, the total population may remain constant in absolute terms while the total built-up area continues to expand. Secondly, the prevalence of tourism and recreational activities may also be a contributing factor. This rationale is particularly applicable to mountainous and Czech border districts, where the overall population does not increase, but built-up area may grow due to the expansion of recreational amenities.

Furthermore, the statistical significance of road density is greater in districts with low population density compared to those with high population density. This could be attributed to several reasons. Given that the distances between points of interest in districts with lower population density are greater, the construction of additional roads or motorways would enhance the efficiency of commuting to work or shopping more so than in densely populated districts where the traffic network is already well-established and efficient. Hence, the coefficient of road density in sparsely populated districts is 0.38 percentage points higher in comparison to densely populated districts, reflecting the lower initial state of the density of roads and highways in sparsely populated districts.

T a b l e 3

Determinants of Suburban Growth in Districts with Different Characteristics

	(2)	(7)	(8)	(9)	(10)	(11)	(12)
	All districts	High population density	Low population density	High-income	Low-income	High proximity index	Low proximity index
Variables	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects	Fixed effects
Ln population	0.267*** (0.056)	0.297*** (0.059)	0.181 (0.170)	0.321*** (0.049)	0.173 (0.112)	0.241*** (0.070)	0.306*** (0.071)
Unemployment	–0.002*** (0.001)	–0.002* (0.001)	–0.002*** (0.000)	–0.001 (0.000)	–0.003*** (0.001)	–0.002*** (0.000)	–0.002** (0.001)
Ln Road density	0.854*** (0.131)	0.576* (0.274)	0.951*** (0.120)	0.914*** (0.096)	0.148 (0.285)	0.836*** (0.067)	0.917** (0.317)
Ln price of b.p.	–0.001 (0.004)	–0.005 (0.008)	0.002 (0.004)	0.003 (0.005)	–0.001 (0.003)	–0.002 (0.004)	0.001 (0.006)
Constant	1.442** (0.653)	1.163 (0.738)	2.386 (1.904)	0.762 (0.582)	2.797* (1.315)	1.830** (0.817)	0.893 (0.832)
Observations	770	385	385	386	384	385	385
R-squared	0.3343	0.4423	0.2088	0.4677	0.1817	0.4529	0.4045
Number of districts	77	39	39	47	45	39	39

Note 1: Clustered robust standard errors in parentheses.

Note 2: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: Authors.

When districts are separated according to income level (Models 9 and 10), the results indicate that unemployment rate is the only significant determinant of suburban growth in low-income districts, while population growth and road density are statistically significant in high-income districts. These findings shed light on the core of the inequalities between high- and low-income districts. In low-income districts, the growth of built-up land is primarily sensitive to the availability of resources (reflected by the unemployment rate), whereas in high-income districts, which are mainly urban with a high proportion of large cities, the growth of total built-up land is typically associated with the influx of the workforce and the accessibility of services and institutions through dense infrastructure. The level of unemployment does not have as significant an impact on suburban growth, as the number of employed inhabitants provides sufficient purchasing power for construction and offsets the income loss associated with unemployment. It can be observed that the coefficients of determination are higher for districts with a higher population density and income level, indicating that the original monocentric city model is better suited and intended for urban areas.

Finally, we re-estimated Model 2, this time stratifying by districts with varying levels of proximity index, which measures the spatial distance between municipalities within a district. Results from Models 11 and 12 suggest that regression coefficients in districts with lower proximity indices tend to be higher than those in districts with higher proximity indices, with the exception of the share of unemployment persons, which exhibits no difference. This implies that suburban growth tends to be more pronounced in districts where municipalities are situated further apart, as determined by the investigated predictors. Thus, the spatial distance between municipalities, and by extension, the districts themselves, may serve as a salient determinant of suburban growth. Accordingly, we directed our focus towards exploring the spatial spillover effects in the monocentric city model.

3.3. Spatial Spillover Effects between Districts

The results discussed in the previous paragraphs stem from models that ignore the spatial relationship between districts, assuming independence among them. Nonetheless, this assumption does not reflect the reality, since each spatial unit is impacted by its nearby units. For instance, if there is an increase in unemployment in one district, it will alter the market conditions in the other districts as well. Therefore, in order to capture the spatial spillover effects in panel data, we will use the SDM, SAR, and SEM models (see 'Empirical strategy' section for details).

Table 4 demonstrates significant positive effects of the spatial dimension. The spatial parameters ρ and λ, which indicate the presence of spatial effects, are statistically significant at the 0.01 level in all spatial models (Models 13 – 15). These results suggest that changes in the independent variables in nearby districts influence suburbanization in the focal area. Based on the AIC and BIC scores, the Spatial Durbin Model (SDM) with fixed effects is discussed in the following text (we can see the spatially weighted independent variables with prefix W as explanatory variables in Model 13). The AIC and BIC scores are smaller than those of the basic fixed effects model (Model 2), which suggests that extending the base model by the spatial dimension is a reasonable choice.

As the Spatial Durbin Model appears to be the best fitting model for our data, Table 5 presents the direct, indirect, and total effects resulting from the spatial dimension. The direct effect reveals how a variable affects the growth of the built area in the focal district. The indirect effect, on the other hand, illustrates the spatial spillover effect. Our findings show that a negative spillover effect is significant only for the share of unemployed persons. This implies that a 1 percent increase in the share of unemployed persons in neighbouring districts results in a 0.4% reduction in the growth of the built area in the focal district. It is worth noting that the spillover effect has a much stronger impact than the direct effect, suggesting that the suburbanization processes in a district are more dependent on unemployment in the neighbourhood than in the focal district. For other predictors such as road density, total population, and building plot prices, no spatial spillover effects were detected. The total effect represents the combination of both direct and indirect effects. These results emphasize the importance of considering spillover effects, as many districts (i.e., including Praha-západ, Brno-venkov, Karviná, etc.) are spatially interrelated and frequently connected with neighbouring districts.

T a b l e 4

Determinants of Suburban Growth and the Spatial Spillover Effect

	(2)	(13)	(14)	(15)
Variables	**Fixed effects**	**Spatial Durbin Model**	**Spatial-Auto-regressive Model**	**Spatial Error Model**
Ln population	0.267*** (0.056)	0.222*** (0.069)	0.230*** (0.049)	0.262*** (0.059)
Unemployment	–0.002*** (0.001)	0.002* (0.001)	–0.002*** (0.001)	–0.002*** (0.001)
Ln road density	0.854*** (0.131)	0.844*** (0.121)	0.856*** (0.139)	0.868*** (0.124)
Ln price of building plots	–0.001 (0.004)	0.000 (0.005)	–0.002 (0.004)	–0.000 (0.005)
W*Ln population		–0.021 (0.086)		
W*Unemployment		–0.004*** (0.001)		
W*Ln road density		–0.292 (0.186)		
W* Ln price of building plots		0.004 (0.006)		
ρ		0.261*** (0.089)	0.185*** (0.061)	
λ				0.273*** (0.097)
sigma2_e		0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Observations	770	770	770	770
R-squared	0.3343	0.3202	0.3242	0.3326
Number of districts	77	77	77	77
AIC	–4823.7	–4875.5	–4840.3	–4849.1
BIC	–4805.1	–4829.1	–4812.4	–4821.2

Note 1: Clustered robust standard errors in parentheses.

Note 2: *** p < 0.01, ** p < 0.05, * p < 0.1

Source: Authors.

T a b l e 5

Direct, Indirect, and Total Effects for the Fixed Spatial SDM

Variables	**Direct effects**	**Indirect effects**	**Total effects**
Ln population	0.227*** (0.070)	0.051 (0.077)	0.278*** (0.073)
Unemployment	0.001* (0.001)	–0.004*** (0.001)	–0.004*** (0.001)
Ln road density	0.844*** (0.126)	–0.114 (0.217)	0.730** (0.321)
Ln price of building plots	0.000 (0.004)	–0.005 (0.007)	–0.005 (0.007)

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

Source: Authors.

Conclusions

Between 1930 and 2002, the number of inhabitants decreased by 0.4 million in the Czech Republic, while the total built-up area doubled during this period (Jackson, 2002). Ouředníček et al. (2019) confirm this trend continues, since the population living in suburbs grew from 1.24 million to 1.44 million during 2008 – 2016 and its growth accelerates. These trends, according to Sýkora (1999), are attributable to changes in Czech society's values after the velvet revolution and the subsequent economic restructuring, which have placed less emphasis on the relationship with land and nature and more on total property ownership, resulting in extensive and excessive land use. The rapid suburbanization has had far-reaching environmental, social, and economic consequences, particularly on the urban and metropolitan fringes. The deindustrialization of some cities further shaped the postsocialist development. According to Mulíček and Toušek (2004), several cities lost their previous function as industrial city and experienced an identity crisis. Large areas of abandoned industrial zones emerged and only gradually were revitalised, whereas large suburban, commercial, amenity, and warehousing plot areas were extensively built up. Municipalities must therefore focus on directing and controlling urban growth using alternative urban forms that limit economic and ecological issues by making use of their urban vacancies, brownfields, and following sustainability principles. Insufficient public policies and a lack of coordination among municipalities are the primary reasons for the continued growth of suburbs (Stanilov and Sýkora, 2014).

As suburbanization processes continue to rapidly develop in the Czech Republic, it is important to identify and examine their determinants. This task requires the selection of an appropriate theoretical framework. In light of this, this study seeks to assess the suitability of the popular monocentric city model for analysing suburbanization processes in polycentric areas of the Czech Republic, using panel data for Czech districts (NUTS 4) in the period 2010 – 2019.

The paper confirmed the assumptions of the monocentric city model for changes in the total built-up area in Czech districts. The model with fixed effects showed that 1% increase of district population and road density leads to the growth of the urban area by 0.27 and 0.85% respectively. The growth of unemployment rate by 1 percent point leads to the –0.2% decrease the urban area. The price of building plots was found to be statistically insignificant as a predictor of the artificial urban area. These findings are robust to changes in model specification and are consistent with earlier empirical studies conducted in other countries. Upon re-estimating the model for districts with varying degrees of urbanization, approximated by population density and income level, the study revealed significant disparities in the determinants of suburbanization. In districts with lower population density, the population variable was not identified as a statistically significant predictor of the total artificial area. This may be attributed to the influence of cultural and social ties in these districts, or to the presence of a recreational area, where the expansion of the built-up area is not dependent on population development. Comparing the results for districts by income level yielded interesting findings. Specifically, in high-income districts, suburban growth was found to be influenced by population and road density, while unemployment was the sole statistically significant determinant of built-up area in low-income districts. These results align with the conditions in these districts, given that low-income areas are relatively more affordable to live in, whereas high-income areas have better accessibility and more employment opportunities.

Special attention was paid to the hypothesis that suburban activities are not affected only by characteristics of explored area, but also its neighbourhood. Therefore, we explored spatial spillover effects employing Spatial Durbin Model, Spatial-Autoregressive Model, and Spatial Error Model. The spatial parameters in all these estimators found statistically significant confirming the spillover effects between districts. The results of Spatial Durbin Model confirmed results from previous panel regression, i.e., statistical significance of all variables with an exception of price of building plots, and identified spatial spillover effect of unemployment.

The present study has demonstrated the suitability of the monocentric city model for analysing suburbanization processes in polycentric areas of the Czech Republic. The findings regarding the determinants of suburbanization in the Czech districts have practical implications for local municipalities in terms of planning economic development while minimizing suburban growth, coordinating development processes with other municipalities, and contributing to the formulation of relevant policies. Moreover, the results of this study, which provide detailed information on districts with different levels of urbanization and quantify spatial spillover effects, may also be useful in designing regional policies tailored to the specific characteristics of the relevant municipality or district. Further analyses at the local level may enhance the generalizability and practical relevance of our findings.

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Appendix

Appendix 1

Descriptive Statistics

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
Artificial area (km^2)	770	130.40	43.53	55.43	320.51
Population (number of inhabitants)	770	137261.70	142482.00	37968.00	1324277.00
Unemployment share (%)	770	5.98	2.70	1.10	14.33
Price of building plots (CZK/m^2)	770	766.52	1075.91	171.36	11842.99
Road density (km/km^2)	770	1.48	0.62	0.89	5.98

Source: Authors.