How transport policies affect residential location choice, living space consumption and housing costs

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Abstract

One of the main challenges of spatial planning is to make the transport system more sustainable. While many studies examine the impact of transport policies on transport-related pollution or mode choice, impacts beyond transport aspects are much less frequently analysed. However, the implementation of transport policies may also have other long-term effects, in particular on housing.

We examined how the implementation of a transport policy aiming at a strict modal shift from cars to more sustainable modes of transport affects residential location choice, living space consumption and housing costs. Therefore, we combined a transport model with a model that, coupled with a synthetic population, iteratively determines residential location choice, living space consumption and housing costs, using Germanys Frankfurt region as a study area.

Our results show that transport policies aiming at a strict modal shift also affect housing markets. In terms of residential location choice, proximity to work becomes more important and centres and agglomerations become more attractive. This leads to higher population densities and housing costs in these areas. Our results highlight the need to take these effects into account when designing policies in both the housing and transport sectors.

Keywords: transport policy, location choice, living space consumption, housing costs, travel demand model

Introduction

Making regions more sustainable is a key challenge for planning authorities on different spatial levels. In the sense of a socio-ecologic transformation, mitigating greenhouse-gas emissions and the consumption of natural resources while enhancing social inclusion and equity as well as addressing disparities in access to services, housing, education, and employment opportunities constitute essential guiding principles for policy makers.

In Germany, where the study area of this article is located, two of sectors which clearly failed to meet the self-imposed greenhouse gas-saving targets, are both the housing and the transport sector (German Environment Agency 2023). Thus, both sectors are of high importance in Germany's efforts to do justice to its proclaimed pioneering role in global climate change mitigation. At the same time, access to the transport system as well as access to housing are essential determinants of social inclusion and therefore at the centre of discourses on housing affordability, public transport prices or the expansion and conversion of infrastructure, for example.

With regard to examining effects of transport policies, the focus seems to be primarily on environmental externalities or transport parameters, both in practice and in research. While many studies analyse the impact of transport policies on transport-related pollution or mode choice (see e.g. Buehler et al. 2017), impacts beyond transport aspects are much less frequently assessed. Some existing studies do, for example, analyse how specific transport measures such as congestion charging or improving access to bicycle infrastructure affect residential property values (Percoco 2014; Welch et al. 2016; Theisen 2020; Tang 2021; Dahir and Le 2025; Hearne and Yerushalmi 2025). However, these studies do not aim at investigating the effects of whole transport policies, consisting of sets of measures, on transport-related outcomes as well as housing outcomes.

Our study addresses this research gap by examining how the implementation of a transport policy aiming at a strict modal shift from cars to more sustainable modes of transport would affect residential location choice, living space consumption and housing costs in Germany's Rhine-Main region. Our article is structured as follows. First, we present relevant literature and existing findings; second, we outline our modelling approach and the methods applied in the respective modules of our modelling framework before we describe the design of a counterfactual used to model the effects of the transport policy. Finally, we present and discuss the modelling results.

Literature review and research questions

Literature review

Our study focuses on measures that improve public transport or bicycle infrastructure, calm traffic, or reduce congestion via charging, tolling, reducing speed limits, or closing roads, all of which can affect residential location choice or housing prices. First, we present research analysing the impact of transport measures on residential location choices or housing costs. Next, we review studies examining the effects on housing in general.

Effects of transport measures on residential location choice

Transport measures affecting travel times, such as reducing speed limits or improving infrastructure, could influence the choice of residential location via the accessibility of relevant locations, such as workplaces or supermarkets, as accessibility is a significant factor in this choice. However, accessibility is less important than neighbourhood or dwelling characteristics (Zondag and Pieters 2005; Baraklianos et al. 2020). Access to jobs, which is mostly described by commuting times, is often used as an independent variable in residential location choice models. As the car is the dominant means of transport for commuting, many studies have integrated car commuting time (Lee et al. 2010; Frenkel et al. 2013; Ibeas et al. 2013). However, several studies have considered commuting time by both car and public transport (Habib and Miller 2009; Guidon et al. 2019). In general, these studies found that the probability of choosing a location as a place of residence increases with lower commuting times. Focusing more on general accessibility, Yan (2020) found a significant positive correlation between public transport accessibility and residential location choice in three U.S. regions: Atlanta, Puget Sound, and Southeast Michigan. However, the importance of public transport accessibility when choosing a residential location varies depending on household characteristics. Good public transport accessibility is particularly important for low-income households (Hu and Wang 2019; Zhang et al. 2025), although another study found that it is less important for low-income households than for high-income households when buying a house in Oslo (Lunke and Böcker 2025). The same study also found that public transport accessibility is a more important factor for young, childless households than for older households and families with children.

In addition to travel times, transport measures can influence travel costs. For example, road pricing can increase travel costs, while discounted public transport tickets can reduce them. To estimate the influence of travel costs on residential location choice, studies typically use commuting costs for cars and public transport as independent variables. This shows that the lower the commuting costs, the more attractive a location is as a place to live (Pagliara et al. 2006; Salon 2009; Guo et al. 2020). Studies based on stated preference data which analyse the potential effects of road pricing come to the same conclusion (Tillema et al. 2010b; Andani et al. 2021). Studies from the Netherlands even found that 5–10% of households would consider moving if road pricing were introduced (Arentze and Timmermans 2007; Tillema et al. 2010a).

A much-researched concept in the field of the relationship between residential location choice and travel behaviour is residential self-selection. van Wee and Cao (2022) define residential self-selection as "the tendency of people to choose residential locations based on their travel abilities, needs and preferences." This raises the question of whether it is more suitable to model residential location choice using household attitudes or travel-related location characteristics. Both Faber et al. (2021) and Klein et al. (2024) concluded that travel-related location characteristics were more effective predictors than attitudes.

Effects of transport measures on housing costs

If accessibility to amenities or the labour market, both of which are key determinants of residential property prices (Osland and Thorsen 2008), is affected by transport measures, this indicates that transport measures can also influence residential property prices and housing costs. Furthermore, the negative externalities of traffic, including congestion, noise and pollution, typically result in a decline in housing prices, particularly in urban and metropolitan areas, as evidenced by numerous studies (e.g. Larsen and Blair 2014; Jin and Rafferty 2018; Morawetz et al. 2024). Our study focuses on measures that improve public transport or bicycle infrastructure, calm traffic, or reduce congestion via charging, tolling, reducing speed limits, or closing roads, all of which can affect housing prices.

An extensive number of studies in different spatial context have investigated how access to public transport affects housing prices. Although meta studies report mixed findings (e.g. Debrezion et al. 2007), most studies generally find that proximity to public railway or bus stations correlates positively with housing prices and property values, with rail stations having a greater effect. However, possible counteracting effects include negative externalities (e.g. noise or rising crime rates) emitted by stations or means of transport (Bowes and Ihlanfeldt 2001). Analyses using European cities or regions as study area show similar results. Improved public transport accessibility, for example trough new lines or stations, have increased housing costs within catchment areas of stations (Song et al. 2019; Rojas 2024), these increases have not always been substantial (Gadziński and Radzimski 2016).

Existing literature also yields findings regarding the amenity value of bicycle infrastructure. While Dahir and Le (2025) found mixed effects of on-street and off-street bicycle facilities on nearby housing, empirical studies have found that proximity to the nearest bicycle network, or more broadly, to the nearest facility, is associated with higher residential property values (Welch et al. 2016; Liu and Shi 2017; Hearne and Yerushalmi 2025), as is the density of bicycle networks (Liu and Shi 2017; Conrow et al. 2021). The only analysis based on a European study area (the Greater Manchester region) was conducted by Hearne and Yerushalmi (2025).

Research on the effects on congestion charging on prices of residential property prices shows differing results. Tang (2021) found a premium for residential property values in London after congestion charging was introduced. Similar outcomes were observed in Kristiansand, Norway by Theisen (2020). In contrast, the implementation of congestion charging in Milan resulted in a decline in residential property values. (Percoco 2014). Agarwal et al. (2015) found no connection between congestion and residential property prices in Singapore. Road tolling can also influence property values, as studies showed for the Netherlands (Thissen et al. 2011) or the United Kingdom (Protopsalti and Skouralis 2024). Another branch of research focuses on haw traffic calming affects residential property values. Case studies find traffic-calming measures such as residential speed limit reductions or driving restrictions to increase housing prices in affected areas (Ossokina and Verweij 2015; Polloni 2019; Li and Yang 2023).

Joint analyses of the effects of transport measures on housing

While the aforementioned research is primarily empirical and uses econometric modelling to determine the effects of transport measures on housing location and costs in isolation, we would also like to present a couple of studies examining the interplay between transport systems and urban or regional systems more generally. These studies use city or regional models based on neoclassical economic theory to depict spatial and economic relationships and simulate the effects of changes in the urban or regional system by using counterfactuals.

Although housing outcomes are not the main interest of the article, Ahlfeldt et al. (2015) provide a framework that can be used to simulate changes in residential location choices and floor space prices in response to changes in the transport system. The authors show, for example, that changes in the transport system within Berlin, which increase travel times between spatial units, influence the distribution of jobs and the residential population, for whom proximity to the place of work becomes more important. Due to a migration of the working population, this would even lead to falling floor prices in Berlin (Ahlfeldt et al. 2015).

To our knowledge, only one study exists, that particularly investigates how changes in the transport system affect housing prices as well as residential space consumption. Larson et al. (2022) simulated the effects of transport-calming measures in Chicago, United States, which corresponded with a premium on residential property and a decrease in average dwelling size, especially in the CBD.

In transport research, land-use/transport interaction (LUTI) models analyse the interdependency between the transport system and land use. For a general overview, see Acheampong and Silva (2013). For an overview of LUTI applications in European cities, see Thomas et al. (2018). These models typically combine a travel demand model with several other models addressing location choice, land prices or accessibility. Possible outputs of a LUTI model are the variables on which our focus lies: housing cost level, living space per capita, and population distribution. Due to the large number of models involved, LUTI models often require detailed spatial and demographic data and are computationally complex.

Our Study

In urban and regional planning, the impact of transport measures is typically estimated using a traditional travel demand model. In this approach, the transport system does not interact with land use and vice versa (van Wee 2013). This issue has been addressed by LUTI models. However, these models are only applicable in limited situations. Developing and operating such a complex model framework requires financial and human resources. Against this background, our aim was to develop a transferable model framework depicting the interdependencies between the transport system and land use that could be used more easily by urban and regional planners. We reduced the complexity by reducing the number of models coupled to the travel demand model, defining the municipality as the unit of analysis, and focusing on the housing market while considering job locations to be exogenous. This approach ensured low data and computational requirements, as well as good data availability and the ability to output key indicators, such as housing cost levels and population size.

Study area

We tested our modelling approach using Germany's Rhine-Main region as study area. The region is one of Germany's most significant economic areas including major cities such as Frankfurt am Main, Wiesbaden, Mainz, Darmstadt, and Offenbach. Originally, the Rhine-Main region consists of 25 counties (‘Kreise’ and ‘kreisfreie Städte’) and stretches across three federal states (Hesse, Rhineland-Palatinate and Bavaria). Due to relevant commuting relations with the region, the counties ‘Lahn-Dill-Kreis’ and ‘Marburg-Biedenkopf’ were also added to the study area. In 2017, a total of 6.25 million people and 3.08 million households lived in the study area, spread across a total of 406 municipalities. Figure 1 shows the study area and its spatial structure according to RegioStaR7 typology (see Federal Ministry of Transport and Digital Infrastructure 2021).

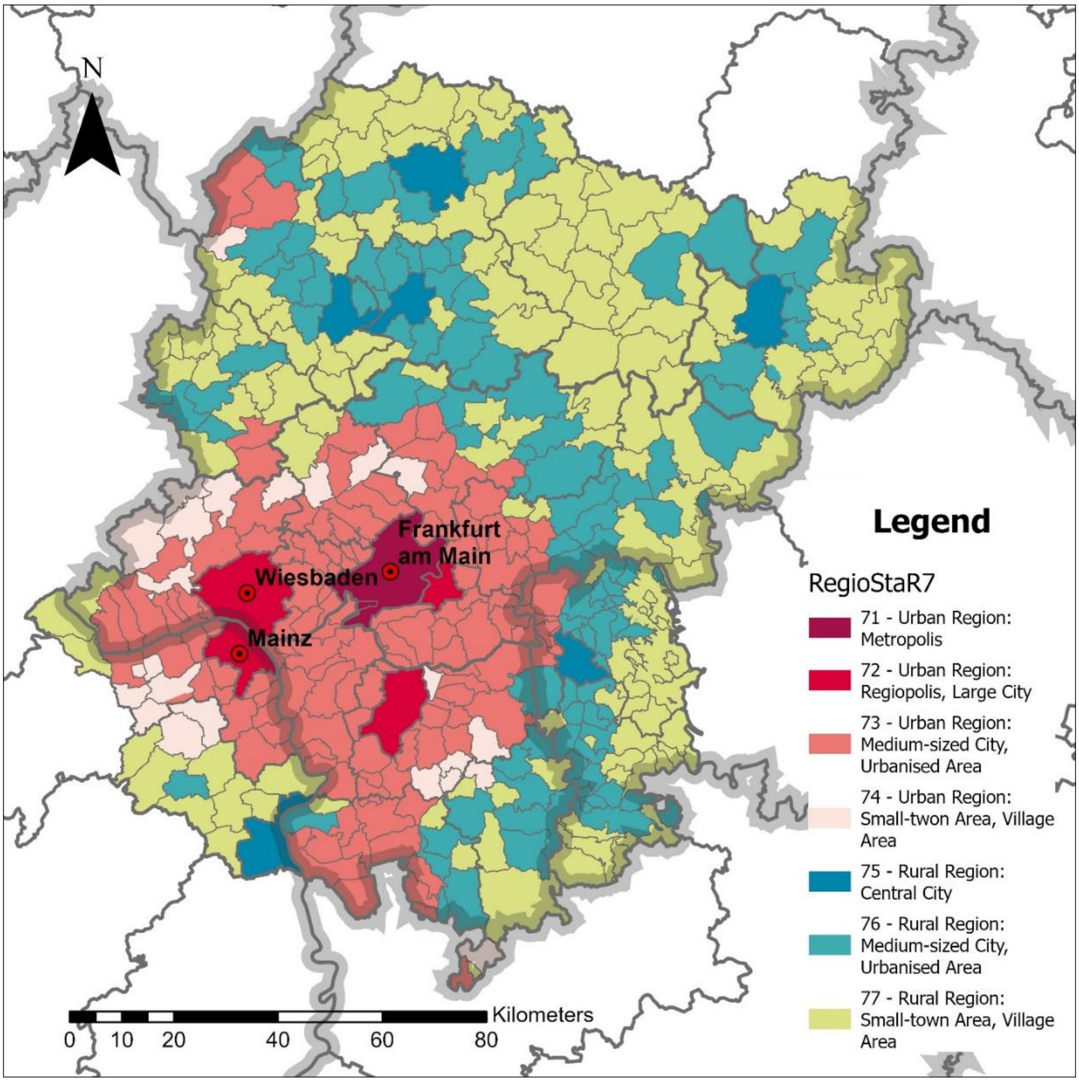

Figure 1: Study area and spatial structure according to RegioStaR7 typology (see Federal Ministry of Transport and Digital Infrastructure 2021). Source: BKG, BMVI

The Rhein-Main region is one of the main commuting regions in Germany, primarily due to its status as a significant economic hub and its extensive transport infrastructure. The major cities within the region, especially Frankfurt am Main, attract a large workforce. The region benefits from a well-connected public transportation network that includes S-Bahn trains, regional trains, buses, and trams. This connectivity allows residents from surrounding municipalities and rural areas to commute to cities like Frankfurt for work. While being extensive and generally efficient, the region's transport system also faces challenges. One significant issue is congestion; despite a robust public transportation network, road congestion remains a problem, particularly during peak commuting hours. Another challenge is capacity limitations within the S-Bahn and regional train systems.

Overall population growth is forecasted for the region (Maretzke et al. 2021), but spatial development and the housing system are characterised by major spatial disparities. Housing markets of the major cities and their suburban hinterland are very competitive which corresponds with the prevalence of housing affordability problems. Rural municipalities, on the other hand, struggle with out-migration and high vacancy rates. Fostering transit-oriented development, planning authorities are focussing zoning of new residential areas to medium-sized towns along the public transport corridors, also because the potential for redensification and land development in the major cities, especially in Frankfurt, is scarce (Dembski et al. 2021).

Modelling approach, methods and data

In our study, we developed a modelling approach that depicts the relationships between the transport system, residential location choice, and housing outcomes. We then used these models, which were fitted to data from 2018 (travel demand model and OD commuting matrix) and 2017 (remaining data), representing our base, to investigate the treatment effects of a transport policy aiming for a strict modal shift from cars to more sustainable modes of transport, using a counterfactual analysis.

Modelling approach

Our modelling approach combines two models iteratively: a regional travel demand model and a residential location choice and living space consumption model. The travel demand model estimates travel times between spatial units, differentiated by mode, which we then use to model residential location choice. Our residential location choice and living consumption model distributes the population of our study in space, synthesises it and estimates housing outcomes at the level of the spatial units used — municipalities, in our case. By feeding an adapted origin-destination (OD) commuting matrix and socio-economics (*via* the synthetic population) back to the travel demand model, interdependencies between the transport system, residential mobility and housing can be mapped - something that conventional travel models are incapable of. The iterative back-and-forth modelling converges to a state, where changes in travel costs and times due to changes in the choice of residential location and in the socio-economic composition of the population in the spatial units become negligible (and vice versa). Figure 2 and Figure 3 stylise our modelling approach as well as the modules of the residential location choice and living space consumption model.

The residential location choice and living space consumption model itself consists of various modules. Module 1 (M1) allocates a residential location to all employed individuals based on their place of work. The model incorporates data on commuting times, housing cost level, housing supply and accessibility. The result is an OD commuting matrix at a municipal level for the whole study area.

As only aggregated information on the number of employed persons at places of residence and work is obtained as result of M1, Module 2 (M2) creates a mesoscopic synthetic population. This means that specific households with attached information (e.g. number of household members, ages of household members, household income) are allocated to each municipality while adhering to constraints such as age and household sizes distributions throughout the entire study region. A car ownership model subsequently allocates probabilities of owning no car, one car, or several cars to households based on their characteristics and the accessibility of their place of residence.

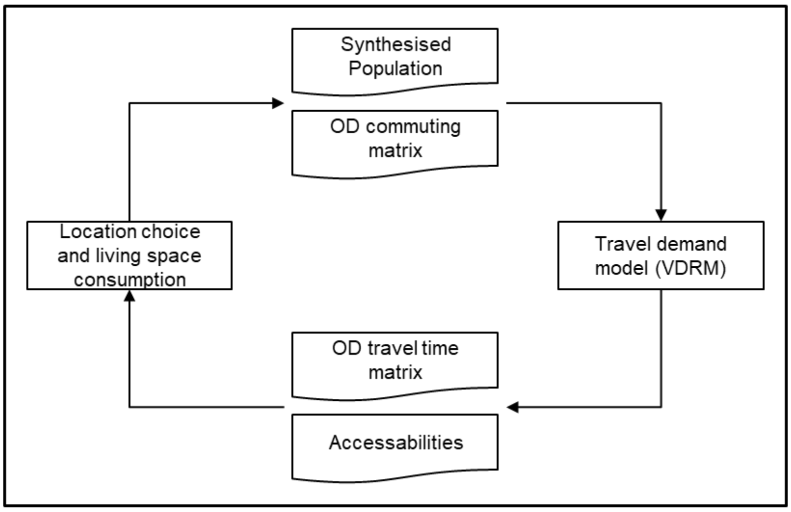

Figure 2: Model framework with in-and-output interfaces

Module 3 (M3) predicts the size of living space of each household based on household composition, household income, housing cost level at the place of residence, and the number of household members who work from home subsequently aggregating the predictions to living space consumption at the municipal level.

If the predicted consumption of living space in at least one municipality exceeds the housing supply, Module 4 (M4) will adjust the housing cost level for each municipality. These updated housing cost levels will then be used as input variables in the next iteration. If the predicted consumption of living space in each municipality matches the housing supply, the computation will stop and the OD commuting matrix and the synthetic population from the final iteration step will be forwarded to the travel demand model.

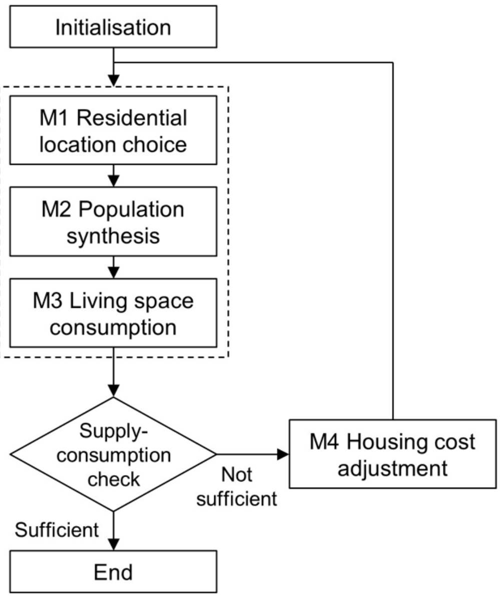

Figure 3: Modules of the residential location choice and living space consumption model

In addition to various transport parameters, we can use the approach to model residential location choice, level of housing costs (measured as average rental prices per square metre) and living space consumption (total and per capita) at the municipal level, with housing outcomes being the main emphasis hereafter.

Methods

Modelling residential location choice (M1)

We estimated a multinomial logit model based on OD commuting data from the Federal Employment Agency in order to model employees' choice of residential location. The 2018 data contains the number of commuters of all OD relations at the municipal level within the study area. We then added characteristics relating to commuting and the municipality that influence people's choice of where to live. The commute-related independent variables were commuting time by car and public transport, and a dummy variable indicating whether the places of residence and work were in the same municipality. The independent variables characterising the municipality were housing supply in the form of total living space, and median rent per square metre as a proxy for housing costs, and travel time by car to the nearest regional centre. The travel times were obtained from the travel demand model. Total living space was taken from the German regional database, and housing cost data was based on advertisements on the Immobilienscout24 platform and provided by CBRE. All independent variables were alternative specific and generic coefficients were estimated with the mlogit package for R (Verweis Croissant). We calibrated the model by computing fixed effects for each OD relation, based on a comparison of surveyed OD commuting matrix and the model predictions.

As a result, the model calculates an OD commuting matrix and the number of employees living in a municipality under the condition of exogenous workplaces. However, as the commuting data used to estimate the model only includes employees subject to social security contributions (approximately three-quarters of the German workforce), the results had to be converted for transfer to the synthetic population and traffic demand model. As we had no information on how the remaining employees were distributed, we allocated them in the same proportion as those subject to social security contributions.

Population synthesis (M2)

The population was synthesised in several stages. First, we generated an initial household sample, allocating households drawn from the 'Mobility in Germany' (MiD) survey to each municipality in the study area. This population's household size and age distribution roughly corresponded to the German average.[1] The initial sample comprised approximately 350,000 households, corresponding to around 10% of the actual population in the study area. Each household was given a weight, initially set to one. We applied iterative proportional fitting (IPF) to adjust the household weights so that the reweighted sample matches the actual distribution of employed persons and persons by age at municipality level, and the household size distribution at the county level (Kreise).

To model the effects of our transport policy counterfactual, we adjusted the household weights via IPF to fit the initial synthetic population to the number of employed persons residing in each municipality as estimated in M1 while keeping the age distribution of individuals, and the household size and income distribution within the study region before treatment. The travel demand model and the living space consumption module use this re-fitted synthetic population as input directly.

Meraner et al. (2016) describe the IPF algorithm which we applied in more detail. We used R's „surveysd" package for implementation (Gussenbauer et al. 2019).

Modelling living space consumption (M3)

In order to estimate how much living space the households of the synthetic population consume per municipality, we fitted a linear regression model with household size of livings space as response. Being fitting on data of the German Socio-Economic Panel (GSOEP), the model incorporates the number of

[1] The households were drawn from the 'Mobility in Germany' (MiD) survey and basic socio-economics (household size, age of household members, income and employment status) were adopted. The methodology could just as easily be applied on the basis of other micro data sets such as the German Socio-Economic Panel (GSOEP) or German micro census.

household members by age, household income and housing cost level at the place of residence as independent variables. We then applied the model to the households of the synthetic population, estimating housing consumption at municipality level using the same housing cost levels as in M1. We calibrated the model via municipality-specific fixed effects.

Within the modelling of our counterfactual, the calibrated model predicts the living space consumption at municipality level in each iteration step and passes the predictions on to the housing costs adjusting mechanism using the synthetic population from step *i* and the housing cost levels from step *(i-1)* as input data.

Adjusting housing cost levels (M4)

The basic approach is to adjust housing cost levels in all municipalities as long as demand exceeds supply in at least one of them. In our study, the vacancy rate in a municipality reflects the balance between supply and demand. Therefore, a negative vacancy rate – which is practically impossible – would indicate that demand exceeds supply. In the current version of the adjustment mechanism, we assume a linear relationship between the vacancy rate in iteration *i* and municipality *j* (L_{ij}) and the adjustment factor (F_{ij}). Additionally, we define a globally applicable vacancy rate, L_{th}, at which housing costs are not adjusted. If the vacancy rate is lower than this threshold, housing cost levels increase, and vice versa. To minimise the risk of the iteration not converging, the adjustment is damped by a factor of 1000 (if the vacancy rate is expressed as a percentage). This results in the following equation for the adjustment factor: $F_{ij}=(L_{ij}–L_{th})/1000+1$. The housing cost levels used as input for the next iteration are therefore given by $HC_{(i+1)j} = F_{ij}*HC_{ij}$.

We calibrated the mechanism by selecting Lth to best reflect our 2017/2018 base, initially setting the housing costs of all municipalities at 7.5 EUR/sqm. All other input variables corresponded to those of the base. We tested 19 variations of Lth between 1 and 10 in increments of 0.5. Using the residential location choice and living space consumption model, we predicted housing cost levels and population for each municipality at each level of Lth, and compared these with the actual values. Using Root Mean Squared Error (RMSE), we selected $L_{th}=4.5$ *%*. Figure 4 shows that the modelling results are consistent with the 2017/2018 base.

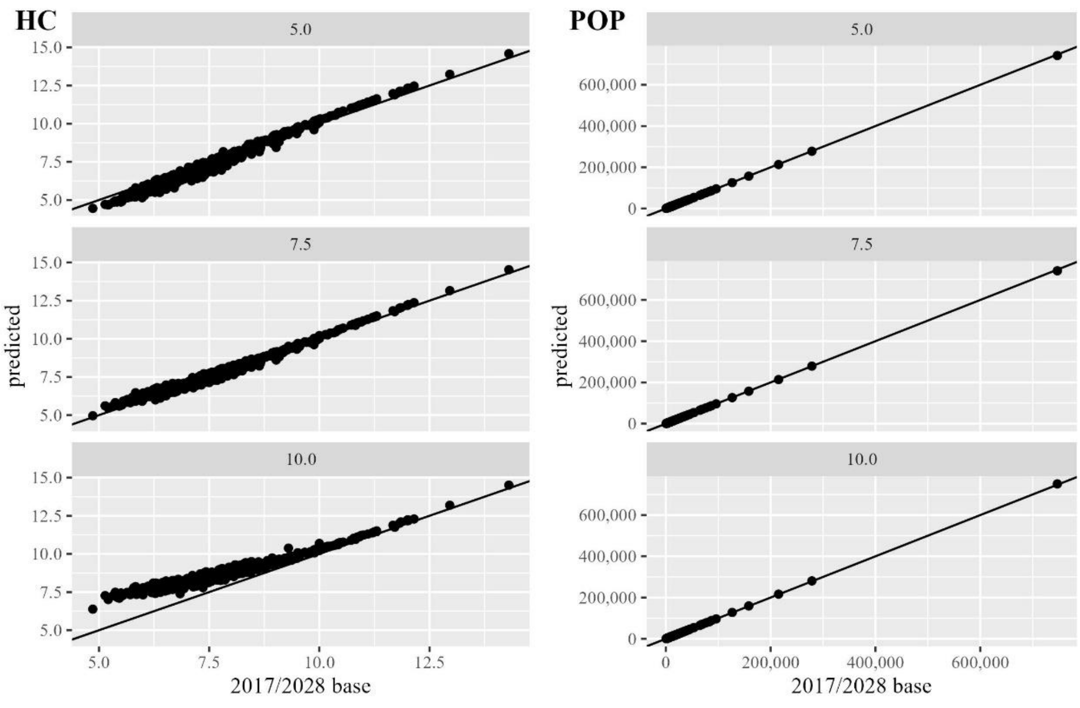

Figure 4: Comparison of the 2017/2018 base (x-axis) and the predicted results (y-axis) for housing cost levels (HC) and population (POP), categorised by the initial housing cost levels that were used as inputs in the residential location choice and living space consumption model (5.0, 7.5, 10.0 EUR/sqm)

Since we calibrated our Lth using initial housing cost levels of 7.50 EUR/sqm, the predicted results are most similar to the actual values. However, even with initial housing cost levels of 5.0 and 10.0 EUR/sqm, the model produces favourable results for the population in each municipality. In terms of housing cost levels, the model tends to underestimate costs in cheaper municipalities with initial cost levels of 5 EUR/sqm. The opposite tendency is observed for initial cost levels of 10 EUR/sqm. Overall, it can be concluded that the model satisfactorily reproduced the base in terms of both housing costs and population at a municipal level. However, there is some uncertainty regarding housing cost levels in cheaper municipalities.

Adjusting travel times and workplace accessibilities

To assess the impact of transport policy changes on workplace accessibility, a travel demand model for the Frankfurt region is applied. The model is based on the VDRM (Verkehrsdatenbasis Rhein-Main – Rhine-Main Transport Database), a fully synthetic, macroscopic four-step model that incorporates all relevant transport modes (walking, cycling, public transport, and car), as well as the road and public transport networks (PTV AG 2021). Travel demand is calculated using a mode and destination choice model, based on travel times derived from network assignment. The model includes a calibrated and validated baseline version for 2018 and a projection for 2035, which accounts for population development and structural data. The region is divided in ~2,000 traffic analysis zones, with a higher spatial granularity in the densely populated areas such as Frankfurt.

While the base model serves as a valuable source of mobility data for the region, certain modifications were necessary to adapt it for use in the context of residential location choice under policies promoting a strict modal shift. To simulate a variety of measures, the VDRM's choice model was extended to include travel costs. This was achieved by converting cost changes resulting from monetary measures into their time equivalents, using value-of-time estimates from Ehreke et al. (2015) (4.66 EUR/h for car trips and 4.83 EUR/h for public transport). The perceived change in travel time was then added to the actual travel time, making a given mode appear virtually faster or slower, thereby influencing travel behaviour.

Lastly, the model was extended with several steps to establish the link to the residential location choice model. First, the changes in population per municipality from the synthetic population are used to adjust the model population. Next, travel demand is calculated for this adjusted population, with the OD commuting matrix from the location choice model used to modify the weighting factors for inter-municipal work trips. Once travel demand has been calculated, the final step in the model interface is the computation of workplace accessibility for car and public transport users. Accessibility is calculated by aggregating the perceived travel times – including changes in costs – for all work trips for the relations between municipalities, using the modelled travel demand as a weighting factor.

Counterfactual and results

Counterfactual

To encourage a significant shift toward active modes of transport and public transport, several policy measures were incorporated into the transport model. The counterfactual includes both pull measures, which aim to enhance the supply and attractiveness of public transport and active modes, and push measures, which restrict and reduce the convenience of car travel. It does not represent a policy that is likely to be implemented in the region in the near future. Rather, the modelling results should stimulate discourse for discourse on key strategies for future regional for regions. The measures and their implementation are detailed in Table 1. All remaining input variables within the model framework were left unchanged at the 2017/18 base.

Table 1: Description of transport policy measures in the counterfactual

Measure	Model implementation
Improving public transport	Reduction of public transport travel time by 20% on all relations
Mandatory affordable job ticket (public transport)	30% increase in employees with job ticket, 50% fare reduction for job tickets
Demand-responsive transport (DRT) in suburban and rural regions	DRT as access mode for rail outside of Frankfurt as part of the public transit supply, access time to stations like private cars with a detour factor of 1.2
	Door-to-door DRT service in suburban and rural areas with a base fare of 3€ per ride, and an additional fare of 0.50€ per km. Detour factor to car travel time of 1.2
Investments in bike infrastructure	20% increase in bike travel speed on all relations, and up to 30% on relations between urban and suburban or rural areas
Speed reductions on city streets	Speed limit of 30 kph in larger cities in the model region (Frankfurt, Darmstadt, Mainz, Wiesbaden) except for superordinate road network
Congestion charge	10€ congestion charge for entering Frankfurt city centre by car
Distance-based toll	Additional 0.04€ fee per driven kilometer for all car trips
Road closures in residential neighbourhoods	5 min additional access and egress times for car trips for all central city areas with high population and low workplace density

Modelling results

The implemented transport policy measures have a strong impact on mode choice behaviour, with a noticeable shift from car trips to sustainable modes. Especially for commuting, public transport is now almost as attractive as the private car, with 29 % of trips (from 14 %), compared to 33 % car trips (from 63 %, including car passengers). Walking and cycling are also more popular for work trips, which also correlates with the changes in trip distances – there is a 34 % decrease to an average distance of 9.1 km. Overall, trips become shorter and the traffic volume for trips within the model region decreases by 14 %.

These severe changes in transport outcomes correspond with large effects on housing. Major cities and regional centres (RegioStaR7 types 71/72 and 75), where most jobs are located, are much more attractive, which corresponds with larger population in the counterfactual. In contrast, fewer people live in more remote municipality types (especially RegioStaR7 types 74 and 77) (see Table 2). Frankfurt am Main would experience severe effects, with its population set to increase by about 150,000 inhabitants (20%), although housing supply is inelastic. Generally, orientation of residential location towards the supply of jobs is much more pronounced, when the transport policy is implemented which does not only affect major cities and regional centres within the study area. Some neighbouring municipalities of these job hubs also have a larger population, whereas the modelled populations for most remote municipalities are noticeable lower in the counterfactual.

Table 2:Absolute values of population (POP), housing cost levels (population weighted mean) (HC), and living space consumption per capita (LS) for the base 2017/2018 (base) and counterfactual (cf) and deviations between base and cf (dev), categorised by the RegioStaR7 Combined Regional Statistical Spatial Type

RegioStaR7 type	POP base	POP cf	POP dev	HC base	HC cf	HC dev	LS base	LS cf	LS dev
71/72	1,525,657	1,792,498	0.17	12.0	14.2	0.18	37.9	31.2	-0.18
73	2,371,160	2,208,950	-0.07	9.6	8.6	-0.11	44.8	45.5	0.02
74	162,417	120,744	-0.26	7.9	5.3	-0.33	50.4	58.3	0.16
75	437,274	489,386	0.12	8.9	10.5	0.18	40.9	37.0	-0.10
76	991,961	977,289	-0.01	7.4	7.0	-0.07	46.8	46.5	-0.01
77	766,058	665,656	-0.13	6.4	4.9	-0.25	49.8	53.0	0.06

Deviations in the spatial distribution of the population also correspond with deviations in living space consumption of residents. While people in the municipalities with high centralities consume more living space overall (with lower consumption per capita), considerably less living space is occupied in more remote municipalities.

However, the differences in living space consumption between the counterfactual and the base case do not proportionally reflect the changes in municipal population figures. In some municipalities, the model results predict remarkably higher levels of average per-capita living space. In major cities and regional centres, more residents and more households share the same amount of space. In Frankfurt am Main, for example, this would result in an average of about 30 square metres of living space per capita, which is well below the actual value of 37 square metres referenced to our base, but roughly equivalent to that of other European metropolises such as Paris, London, Budapest and Warsaw (see Kholodilin et al. 2020). In contrast, fewer people and households live in rural communities, but consume more living space per capita. In the Taunus municipality of Glashütte, people live on an average of 75 m² per person representing the maxim um value of the model results.

The modelled effects of the counterfactual on population distribution and living space consumption are quite severe, but at the same time remain within a range that is already a reality in other European places today. However, due to our model's inelasticity assumption regarding housing supply, the modelled number of households residing in Frankfurt am Main, for example, would correspond with an average dwelling size of 60 square meters assuming that households do not share apartments. In the base case, the average dwelling size in Frankfurt am Main was approx. 71 square metres (Statistical Offices of the Federation and the Länder 2025). Keeping the inelasticity assumption, the average dwelling size would therefore have to decrease by 11 square meters requiring major interventions in the housing stock (e.g. dividing up dwellings) and smaller new-build apartment sizes than at present.

Drastic interventions in the transport system would also affect housing prices and housing costs in the study area, as the modelling results of the counterfactual suggests. Aggregating to RegioStaR7 categories, the results show that the level of housing costs in the major cities and regional centres is generally higher after treatment, while rural municipalities have lower housing cost levels (see Figure 5). The results also show that higher housing costs can also be expected in some neighbouring municipalities of regional centres and major cities.

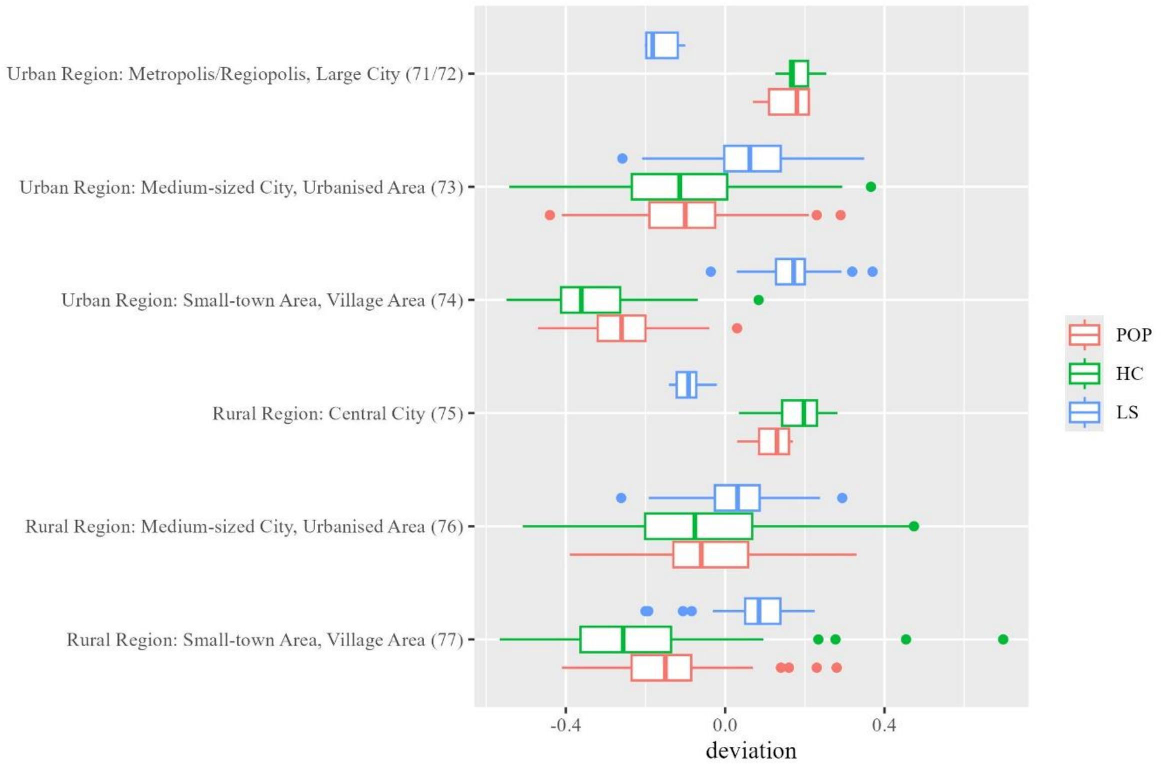

Figure 5: Percentage deviation between the scenario and the status quo for housing cost level (HC), population (POP) and living space consumption per capita (LS), categorised by the RegioStaR7 Combined Regional Statistical Spatial Type

As a result of the implementation of the counterfactual transport policy, affordability problems in the major cities of the study area are expected to worsen. In Frankfurt am Main in particular, a sharp increase in demand for housing is to be expected, leading to more people living with smaller living space per capita and rising housing costs. In rural areas, on the other hand, the modelling suggests that out-migration problems would intensify, vacancy problems would increase, housing prices would fall and housing markets would destabilise as a result.

Discussion

Our study contributes to existing literature by showing how to combine a travel demand model and a residential location choice and living space consumption model in order to investigate effects of transport measures on transport-related outcomes as well as on housing outcomes. Using a counterfactual, we want to highlight the prevalence of interdependencies which have – to our knowledge – little presence in practice discussions on how to make the transport system more sustainable.

However, our study has limitations. Although the equilibrium equation is a rough simplification, it is also an important element of our modelling approach determining the output. For our study, which was developed in the mindset of a proof of concept, it demonstrates that an equilibrium mechanism can be incorporated into our framework. However, we are aware that urban models already exist that can map complex economic relationships much better at this point (see Ahlfeldt et al. 2015). The results of our counterfactual should therefore be understood as indicators of the directions and the qualitative magnitude of the effects on housing rather than as exact quantitative predictions.

Since the residential location choice model does not include the individual characteristics of the decision maker, we cannot account for residential self-selection. Consequently, we assign people and households to residential locations regardless of their travel preferences. In our counterfactual, people tend to live in larger cities, which become denser as a result. However, some people – particularly captive car users – may choose to live in rural areas despite the higher commuting costs, because this enables them to realise their desired travel pattern. Conversely, captive public transport or bicycle users could consider well-connected residential locations outside larger cities.

In our 2017/2018 base, the car is the dominant means of commuting. However, as our counterfactual involves rigorous measures that would significantly increase the cost of travelling by car while improving public transport, it is possible that the estimated coefficients of the residential location model may not align perfectly with it. It is reasonable to assume that locations with good public transport accessibility to jobs outside large cities will become more popular places to live.

In our counterfactual, we assume that housing and labour supply are inelastic. However, the supply of housing and labour also depends on demand. If demand were to shift as significantly as in our results, the construction of new housing and the labour supply would also adapt to this shift. This could also affect housing costs (see e.g. Ahlfeldt et al. 2015).

Conclusions

The modelled counterfactual shows large effects on the choice of residential location, housing costs, residential space consumption and traffic patterns. Transport policies aiming at a strict modal shift from cars to more sustainable modes of transport can reduce commuting distances between home and workplace. Assuming an inelastic job and housing supply, the attractiveness of large cities and regional centres as place of residence will increase. The high costs of car trips as a consequence of rigorous push measures result in residential locations outside the centres often no longer being an acceptable alternative, even though housing costs in major cities increase. This can exacerbate existing affordability problems in the centres and at the same time weaken the attractiveness of rural areas resulting in vacancies or an increase in existing vacancy problems.

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