Research Paper

Time allocation across travel modes

Policy influences and their mediators

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Abstract

The allocation of time across travel modes has implications for various dimensions of welfare and transport planning, including physical and mental well-being, environmental outcomes, and infrastructure investments. Urban planning paradigms – such as that of the "15-minute city" – have consequently endeavoured to tackle many of these aspects simultaneously through land-use planning that brings key services and amenities to residents within a walkable or cycle-able 15-20-minute distance. At the same time, our understanding of health outcomes in a 15-minute setting remains limited, as most authors measure travel behaviour in terms of mode choice or trips taken. In fact, time spent on different travel modes – including physically active travel modes like walking and cycling – are a more direct link to determining health outcomes. Drawing on a panel of household travel data from Germany covering 2005 to 2020, we estimate fractional response models to analyse the role of amenities in determining time allocated across motorized, non-motorized, and public transit modes. We do so with a view to sub-groups divided by income to glean variance in responses to policy measures. Overall, we find that people living within 15-20-minute cycling or walking distance of amenities spend around 4.5 more daily minutes in non-motorized travel, with low-income groups spending significantly more time in non-motorized travel relative to middle- and high-income groups. We connect this to health impacts using the WHO's Health and Economic Assessment Tool (HEAT).

Keywords

15-minute city, travel mode time, amenities, health impacts

1. Introduction

The formulation of policies that balance accessibility with environmentally benign travel modes is among the more pressing challenges confronting urban planners. This challenge is particularly evident in Europe, where even as total greenhouse gas emissions have decreased by nearly 25% since 1990, those from transportation are on the rise, increasing by almost 30% (European Commission, 2020). Over the past three decades, European countries have introduced a variety of demand-side and technological policy measures to curb the transportation sector's growing environmental footprint. One such collection of measures -- alternatively referred to as "new urbanism" or "smart growth" (Wey and Hsu, 2014) -- targets the integration of transportation and land use planning, with an eye toward combining compact design, mixed development, and the provision of public transport as a means of integrating neighbourhoods and reducing transport-related externalities. In recent years, these principles were refined further under the rubric of the "15-minute city," an urban planning model that places time as its focal point, the objective being to promote lifestyles that are low-emissions by situating urban amenities, infrastructures, and opportunities such that that people can walk or cycle to any given activity within a timeframe of 15-20 minutes (Allam et al., 2022). This idea is closely linked with the application of nature-based solutions to the extent that it relies on the sustainable management and restoration of both natural and modified ecosystems that benefit nature and people. The 15-minute concept, which we conceive of broadly to apply to both urban and non-urban areas, also supports increased physical activity (PA) as shorter distances are achieved through walking or cycling. As documented in a systematic review by Woodcock et al., (2011) and verified in subsequent scholarship, many studies have quantified a dose-response relationship between the time spent in non-vigorous PA and improved health, highlighting the potential for urban planners to positively influence health through land-use planning that encourages non-motorized modes (Stevenson et al., 2016).

Connecting consequences of the 15-minute city for PA and health outcomes is important but understudied. Existing literature has investigated to what extent policies like increasing fuel prices and transport infrastructure can affect peoples' choice of travel mode or number of trips taken by specific modes. However, connecting these outcomes to health impacts is difficult as the effect on health is the direct result of *time* spent on a travel mode, rather than the *choice* of mode or number of trips.

Thus, in this paper, we use a panel of household survey data from Germany that spans 2005 until 2020 to investigate how the central idea of the 15-minute city – proximate amenities – influences *travel time expenditures* across transportation modes. Making use of the rich, individual-level travel diary information recorded in the data, we subsequently present the results of fractional response models that distinguish between time spent at home, time spent out-of-home, and time spent traveling, with the latter further distinguished between motorized-, non-motorized-, and public transit modes. This set-up allows us to estimate how changes in each of these categories – expressed in terms of minutes – relate to various policy-relevant variables and connect to health outcomes.

We focus specifically on the time allocation across travel modes for respondents who live within 15-20-minute walking/cycling distance of entertainment and service-related amenities. Indeed, key amenities like grocery stores may be critical in reducing car trips and encouraging active mobility (Elldér et al., 2022; Heroy et al., 2022). We compare this time allocation to that of more traditional policy tools like the fuel tax. To allow for differential effects in these variables across socioeconomic groups, we subset the estimation sample according to income level. Using the model estimates as input for the World Health Organization's Health economic assessment tool (HEAT) (Kahlmeier et al., 2020), we estimate health outcomes that would be associated with changes in the policy variables.

2. Background

Transportation policy is a cornerstone of efforts to make cities more sustainable. Falling within the UN's Sustainable Development Goal (SDG) 11 "Make cities and human settlements inclusive, safe, resilient and sustainable", access to safe, affordable, accessible and sustainable transport systems can create positive social, economic, and environmental impacts (SDG Target 11.2). Such a transformation will require moving away from car dependent lifestyles and associated negative externalities: pollution from tail-pipe emissions (Huang et al., 2020) death and injury from accidents, and obesity and cardio-respiratory disease from increased physical inactivity (Douglas et al., 2011). Encouraging active transportation can also result in positive physical and mental benefits. For example, physically active transportation has been shown to reduce various health impairments, including cardiovascular disease and diabetes (Woodcock et al., 2011; Maizlish et al., 2013; Stevenson et al., 2016), while outdoor PA contributes to mental well-being (Thompson et al., 2011; Lahart et al., 2019; Remme et al., 2021). While commuting, and especially longer commutes, can negatively impact subjective well-being (Chatterjee et al., 2020; Choi et al., 2013; Hansson et al., 2011; Hilbrecht et al., 2014), walking (Clark et al., 2016) and cycling (Crane et al., 2016) to work have been found to be linked to higher self-reported life satisfaction. Such activity has considerable health benefits: one systematic review found that 30 minutes of daily moderate activity five days a week was associated with reduced mortality risk by 19% compared to no activity (Woodcock et al., 2011).

One differentiating characteristic of the 15-minute concept from its price-based correlates is its ambition to achieve its goals equitably across sub-groups of the population. However, questions of mobility are foundationally difficult as mobility is experienced differently by sub-populations, e.g. men and women are affected by commuting differently (Roberts et al., 2011; Sandow, 2019; Sandow and Westin, 2010) and have a different relationship with public transit and active modes of transit (Maciejweska and Miralles-Guasch, 2020; Marquet and Miralles-Guasch, 2015). There are also questions as to how such policy changes can support groups with lower socioeconomic status (SES), as these groups have been found to engage less in recreational physical activity than their higher SES counterparts (Stalsberg and Pedersen, 2018; Kamphuis et al., 2009). Immigrants and ethnic minorities often face more commuting burden as a result of a "spatial mismatch" in residential location and employment opportunities (Kuttler and Moraglio, 2020; Gobillon and Selod, 2019; Blázquez et al., 2010). Moreover, phenomena like forced car ownership, wherein low-income groups are 'forced' to own and use cars to access necessary services, still exist in both rural and urban areas (Currie and Senbergs, 2007; Curl et al., 2018; Mattioli, 2017).

3. Data assembly and modelling approach

3.1. The data

The primary data source used in this research covers the 2005-2020 waves of the German Mobility Panel (MOP), a representative multi-year travel survey financed by the German Federal Ministry of Transport and Digital Infrastructure. Participating households are surveyed daily for a period of one week over each of three years in the autumn, after which they exit the panel. During the survey, household members over 10 years of age keep a travel diary that records the details of each trip, including the departure and arrival time, the mode used, the trip purpose, and the distance travelled. Based on these entries, we calculated the time spent traveling by mode, as well as the time spent at home and in out-of-home activities for all 1440 minutes of the day, from which we calculate the respective shares over the course of a 7-day week.

These shares serve as the dependent variable of the econometric model. The variables *home* and *away* measure the share of time spent at home or at an out-of-home destination, while *motorized*, *nonmotorized*, and *transit* measure the share of time spent traveling by mode. Specifically, motorized transport is by private car, non-motorized is by foot or bike, and transit is by any mode of public transportation. Of note is that the category *away* includes trips such as Rundgänge, which are walks or cycling trips that begin and end at home with no intermediate stop, i.e. walks, jogs and cycling tours.

We also include explanatory variables related to other parts of urban infrastructure. The variables *bike path density* and *park density* are externally obtained from Open Street Map (OSM) (Open Street Map, 2017) and merged with the data using QGIS. This merge was facilitated by using indicators recorded in the MOP for the 3-digit zip code and the county in which the household resides.

Three additional policy variables are derived from the data recorded in the MOP. The variables *high outlet* and *low outlet* indicate proximity to various retail and entertainment outlets. *high outlet* is coded as one if the respondent is within a 15-minute walk of the cinema, a clothing store, a supermarket, and a bar, and zero otherwise. *low outlet* is recorded as one if the respondent can reach none of these outlets within a 15-minute walk, and zero otherwise. An excluded base category measures intermediate versions of these two extremes. Importantly, high outlet areas are distributed across urban and suburban settings and data depicts sizeable shares of cross-cases: roughly 9% of urban respondents are beyond a 15-minute walk of any of the outlets while 13% of suburban respondents are within a 15-minute of all of the outlets.

Our final policy variable is the *fuel price*, which is collected in a separate survey of the MOP -- the "Tank survey" – carried out in the spring, when respondents maintain a log of each visit to the gas station over a

6-week period. During this time, they record the price paid for fuel and the odometer reading for each car in the household. We use this data to calculate the average price paid for petrol and/or diesel fuel for each household and car. About 10% of the sample households own a mix of petrol and diesel cars, so that prices for both are recorded.

For such households, we assign the diesel price to *fuel price*, noting that results change negligibly if the petrol price is assigned. Using a household identifier, we merge the *fuel price* with the main data. To account for the changes in the price level between the spring timing of the Tank survey and the preceding fall, we apply a weight constructed from a time-series of monthly fuel prices published by the fuel company Aral. The price series is additionally deflated using a consumer price index for Germany obtained from the German Federal Statistical Office.

The remaining variables comprise controls for the socioeconomic attributes of the respondent and household in which they reside.

The data was pruned along three dimensions. First, we limit the sample to car owners, which comprise about 83% of German households. We also eliminate households who reported having taken a vacation over the survey period, about 6% of the sample. Last, respondents under 18 were excluded from the data. The resulting sample comprises 13,348 respondents from 8,199 households. 5,636 respondents participate in one survey year, 4,152 in two, and 3,560 in all three, yielding 24,620 observations in total.

3.1. The model

Recognizing that the dependent variable comprises shares that sum to one for each observation, we estimate the correlates of time allocation using a fractional response model (FRM):

$$E\left[y_{ij}|x_i\right] = \frac{\exp(x_i\beta_j)}{\left[1 + \sum_{h=1}^{J}\exp(x_i\beta_h)\right]}\ , j = 1 \ldots J - 1$$

where y_{ij} is the share of time allocated by person *i* to activity *j*, the vector x denotes the explanatory variables, and β denotes the estimated coefficients. We demean the explanatory variables by state and year, which effectively serves to control for time-varying unobservable variables across each of Germany's 16 states. The model is estimated using quasi-likelihood estimation with a multinomial logit link function for multiple proportions, and with robust standard errors (Mullahy, 2015).

Beyond their sign and statistical significance, the coefficients of the FRM are not immediately interpretable. We therefore focus our discussion on the average partial effects (APEs), calculated as:

$$PE_{ijk} = \frac{\partial E\left[y_{ij}|x_i\right]}{\partial E_{ik}} = E\left[y_{ij}|x_i\right] * \left[\beta_{jk} - \frac{\left[\sum_{h=2}^{J}\beta_{hk}\exp\left(x_i\beta_j\right)\right]}{\left[1 + \sum_{h=2}^{J}\exp(x_i\beta_h\right]}\right] * 1440$$

The multiplication by 1440 ensures that we can interpret the APEs in terms of the change in daily minutes resulting from a unit change in the explanatory variables. The APEs of a given explanatory variable across categories of the dependent variable logically sum to zero, reflecting the constraint of 24 hours in the day.

3.1. Health impacts

To explore the implications of the model results for health outcomes, we use the Health economic and assessment tool (HEAT) (Kahlmeier et al., 2020; Kahlmeier et al., 2017) of the World Health Organization. HEAT is an online application that allows impact assessments of habitual changes in walking and cycling on the mortality of the adult population. HEAT is country-specific and applies a comparative risk assessment in which the health outcome of interest is the difference in premature mortality between two cases: a reference case and a comparison case. The difference in mortality is obtained by comparing the difference in levels of active travel. The tool takes into account the all-cause mortality for walking and cycling in the selected country.

4. Results

4.1. Temporal trends

We begin our analysis with an overview of trends in time allocation, thereafter turning to the model estimates. Figure 1 shows the average daily time spent traveling, broken down by mode, along with the 95% confidence intervals. On average, people spent almost 50 minutes daily on motorized travel, about 10 minutes on public transit, and between 10 and 18 minutes on non-motorized travel prior to COVID. Time allocation on all modes is relatively stable through 2019 until COVID, demonstrating the scope for a drastic re-adjustment in response to an exogenous shock. The non-motorized mode was also the only one not discernibly affected by COVID, holding steady at about 10 minutes in 2020 while the others dropped substantially. While not portrayed in the figure, the data indicates that time allocation on travel mode exhibited differences across income groups. High income respondents spent almost 15 minutes more on average for traveling across modes than low-income respondents, while low income respondents spent more time on non-motorized travel and public transit.

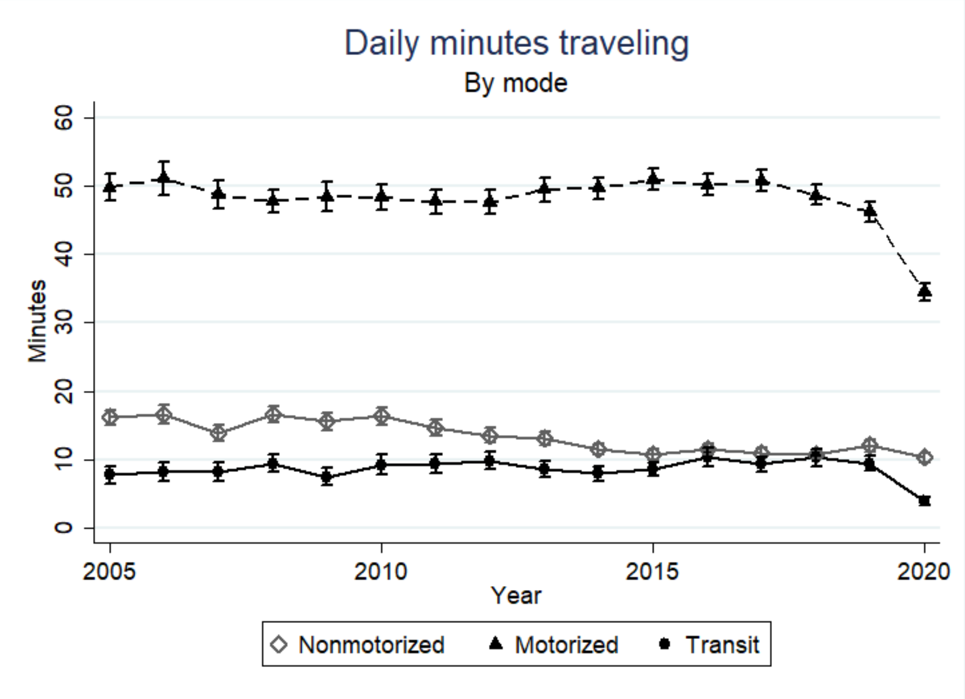

Figure 1 Daily minutes traveling on nonmotorized, motorized and public transit for years 2005-2020

4.2. Model estimates

To allow for differential effects in the explanatory variables by socioeconomic attributes, we estimated the model in Equation 1 on a subset of the data distinguished by income. We present the point estimates of the APEs and their 95% confidence intervals graphically in Figures 2-4. Our discussion focuses on two of the policy variables, outlet accessibility and fuel prices.

Figure 2 presents the marginal effects and 95% confidence intervals of the dummy *High outlet*, distinguished by income group. While the differences across income levels are more pronounced, their confidence intervals overlap in virtually all cases. Respondents from low- and middle-income households who are in high outlet areas spend more time away and less time at home than those from high-income households, for whom the effects are statistically insignificant. All three groups spend more time using non-motorized and less time using motorized modes, with low-income groups spending significantly more time on non-motorized travel relative to the other groups. The effects for public transit are roughly zero.

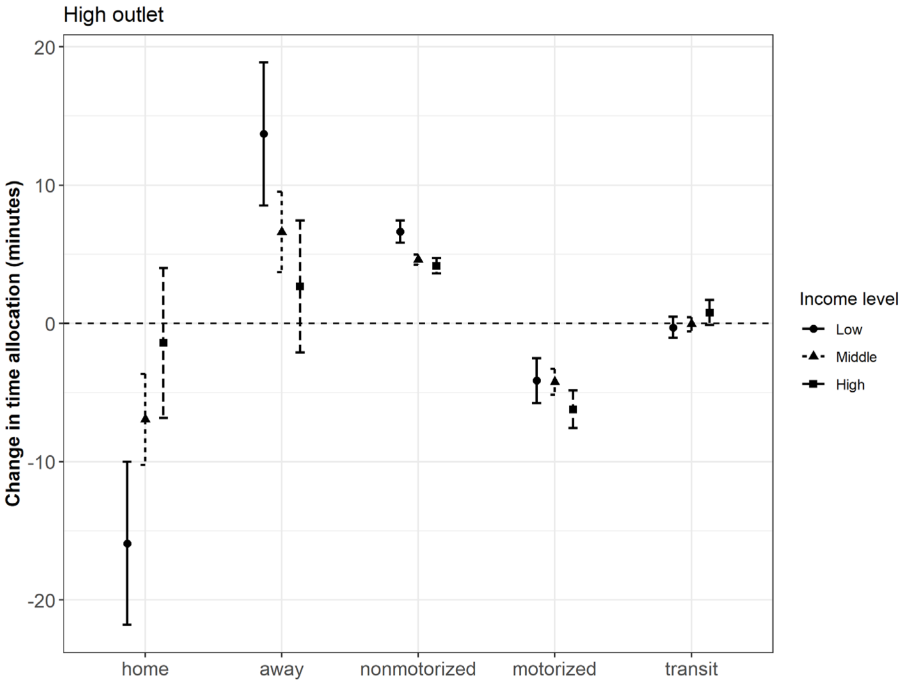

Figure 2 Daily time allocation: High amenity outlet

To gauge the impact of moving to a densely serviced neighbourhood among the roughly 80% of the German population that lives elsewhere, we assumed an average increase of 4.5 minutes in non-motorized travel based on the econometric estimates (see Figure 2). Using this estimate in the HEAT tool yields an estimate of 4035 premature deaths prevented per year across the German population. However, the impact of the increase in non-motorized travel on low-income populations may be more formidable as this sub-population typically suffers from SES-related stress and poor health.

It is of interest to contrast the estimates of *High outlet* with the mirror-like image of *Low outlet* presented in Figure 3. Individuals living in households that are not within a 15-minute walk of *any* of the outlets captured by the dummy spend more time at home and less time away. These estimates are again particularly pronounced among low-income households, who spend roughly 25 more minutes at home on a daily basis than their counterparts who live within 15 minutes of *some* of the outlets captured by the dummy, the base case. This potential loss in time spent on non-motorized travel may negatively affect health outcomes, though conclusive statements may be difficult to make as people may remain active in their homes e.g. doing more sports in the home, being actively engaged in chores.

Figure 4 depicts the impact of increases in fuel prices as a comparison point for amenities. An increase in fuel prices indicated reduced time spent on motorized transit for all income groups, though this reduction was smaller for the lowest income group. Further, residents of middle-income and high-income households reduce time spent away and increase time spent at home, while the estimate for the low-income group is statistically insignificant. An increase in fuel prices is also associated with a marginally higher time spent on non-motorized travel across income groups. Using the HEAT tool, the 10-cent increase and resulting increase in non-motorized travel yields an estimated 622 prevented premature deaths among the German population.

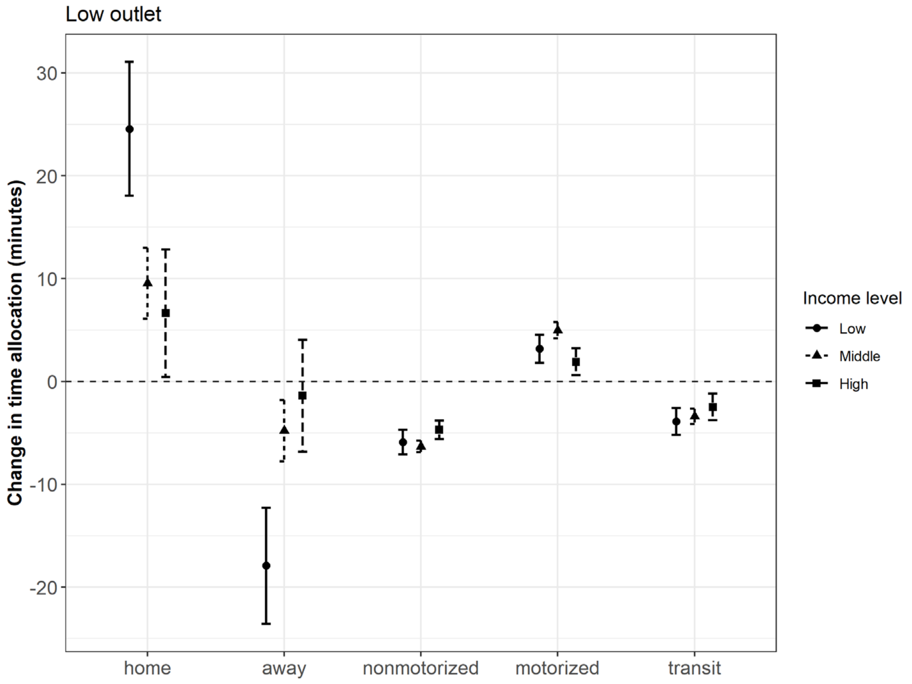

Figure 3 Daily time allocation: Low amenity outlet

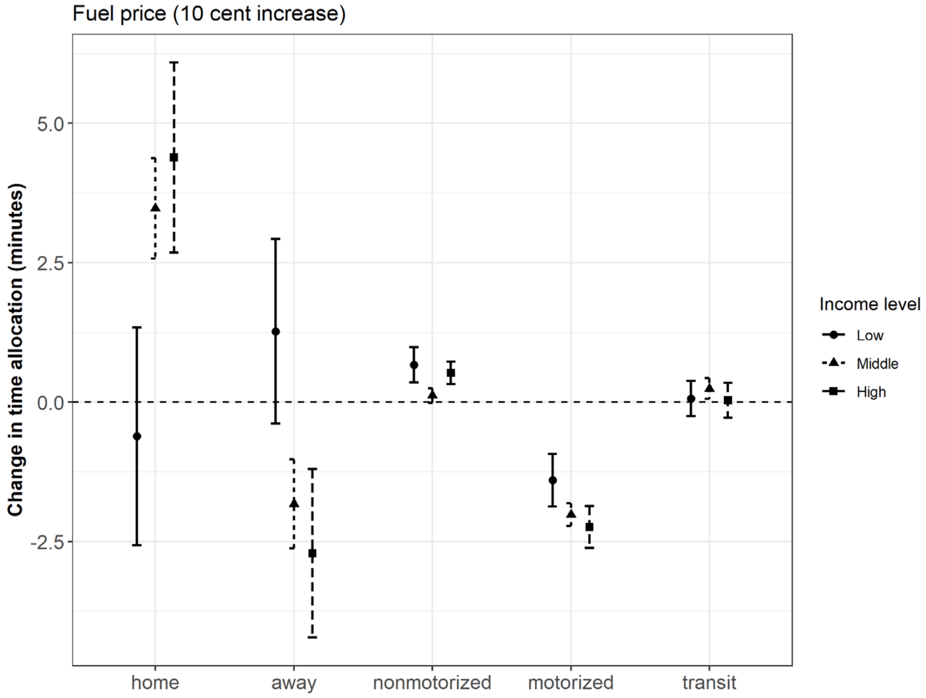

Figure 4 Daily time allocation: Increase in fuel price

5. Discussion and conclusion

The goal of this study was to explore the influence of different policy levers on time allocation on various modes of transit, specifically focusing on proximate amenities and fuel prices. In closing, we discuss the results as whole and their implications for policy.

Overall, we echo other studies that find that the built environment (Handy et al., 2005; Stevenson et al., 2016; Soltani and Allan, 2006) and fuel prices (Frondel and Vance, 2017) are effective policy levers in reducing the time spent with motorized- while increasing time spent with non-motorized modes. With reference to the 15-minute city concept, the results of our study support the idea that proximate amenities in the form of retail outlets and entertainment might encourage less time spent on motorized transit and more time spent on non-motorized forms of transportation. These findings support those of other authors who have studied the role of amenities on trips made by car and trips made by bicycle or walking (Heroy et al., 2022; Elldér et al., 2022; Dargay and Hanly, 2004). The resulting changes in travel time were linked to health outcomes using the HEAT tool, indicating that residents near proximate amenities who spend more time on non-motorized travel can reap considerable annual reductions in premature deaths.

Further, we find that while fuel price increases may be an effective instrument in reducing motorized travel, they may lack the same effectiveness in inducing greater PA. A 10-cent increase was associated with considerably more time spent at home for all sub-groups aside from the lowest-income group, while having minimal effect on time spent on non-motorized travel. Low-income groups that suffer from “spatial mismatch” may continue to drive even with fuel price increases in order to reach necessary services or employment. On the other hand, those living in proximate distance of high amenity outlets spent almost 5 minutes more on non-motorized travel – almost 7 extra minutes for the low-income group – and increased in time spent away from the home, including time spent for leisurely walks or cycling. For low-income groups, too, a complete lack of proximate amenities significantly reduced time spent away from the house. One nuance is that while low-income respondents may spend more time on non-motorized travel, it may be out of necessity - policy makers may need to consider how to induce walkability while mitigating the negative health outcomes associated with lower socioeconomic status (Kitchen et al., 2011).

The novelty of our work lies in showcasing how measuring travel outcomes in time per mode can allow for more direct linkages to health outcomes. At the same time, our study is subject to several caveats. Most prominently, despite the inclusion of a wide range of control variables, we cannot definitively ascribe a causal interpretation to the estimates. This particularly applies to the estimates associated with the urban form variables. To the extent that people settle in neighbourhoods based on their transportation preferences, the estimates of *High outlet*, for example, may be subject to endogeneity bias. One way to address this in future studies is to investigate the effect of urban form measures on travel mode longitudinally. Finally, differentiating between the purposes of trips and understanding more precisely whether people are engaging in Rundgänge or spending more time at their destination could be the focus of future work.

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