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Park & Ride facilities and suburban sprawl

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ABSTRACT

This study investigates the effects of Park & Ride (P&R) facilities, which aim to increase the attractiveness of commuting by public transport, on population growth in suburban areas. We employ a difference-in-differences approach to parking capacity extensions of seven P&R facilities outside the central business district of the city of Vienna between 2012 and 2016. Specifically, using fine-grained grid population data, we compare population growth in close distance to the P&R facility to population growth in surrounding municipalities. We find that the expansion of a P&R facility, which is located at least 20 min away from a main public transport station in Vienna, causes population growth of, on average, 1.6–1.9% in neighbouring municipalities compared to those where the P&R facility is located. This accounts for up to 15% of the total population growth in the respective regions between 2008 and 2019 and highlights the role of P&R facilities in fostering suburbanization and the suburban sprawl.

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1. Introduction and motivation

The improvement of traffic infrastructure tends to increase the accessibility of regions and thereby improves regional attractiveness. Thus, a better accessibility of a region may also attract population and firms, enhance labour market conditions and lead to a higher regional growth. The link between accessibility and population growth (e.g. Koopmans, Rietveld, and Huijg 2012; Kotavaara, Antikainen, and Rusanen 2011; Beyzatlar and Kustepeli 2011), and the link between accessibility and regional growth (e.g. Cascetta et al. 2020; Del Bo and Florio 2012) have been frequently investigated in the literature.

A review of existing empirical studies by Kasraian et al. (2016) finds that proximity to rail infrastructure is often associated with population growth. Proximity to road infrastructure tends to increase economic activity in terms of commercial and industrial development favouring the creation of jobs. Studying Norwegian regions, Aarhaug and Gundersen (2017) argue that the effectiveness of traffic infrastructure as a policy tool to promote sustainable regions depends on the population size of regions themselves. Regions with a population size above 10,000 inhabitants are likely to benefit from improvements in terms of population growth, while smaller regions benefit from different types of infrastructure investments.

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Thus, the literature highlights three essential factors determining the impact of traffic infrastructure on regional development. That is, the effects of traffic infrastructure vary by type of region, by mode of transport, and by type of infrastructure.

In this article, we investigate a specific type of traffic infrastructure that facilitates the combination of two modes of transport in commuting: train-based Park & Ride (P&R) facilities around the urban conglomeration of Vienna, the Austrian capital. The focus of this study is to identify the effects of P&R facilities on regional development, in particular on population growth. Between 2008 and 2019, the city of Vienna grew by more than 226.000 inhabitants, corresponding to a population growth of about 14% relative to its population of 1.67 million in 2008. At the same time, however, the city experienced a cumulative net outflow of about 59.000 inhabitants (3.5% of its population in 2008) to Lower Austria, the region surrounding Vienna. Thus, despite the city's remarkable growth, suburbanization continued.

This study aims to empirically investigate the role P&R facilities play in suburbanization. We, therefore, identify considerable parking capacity expansions of P&R facilities in proximity to Vienna and investigate whether these have an impact on regional population growth in areas surrounding these facilities. Such facilities increase the accessibility of these areas by public transport, and thereby improve the attractiveness of these areas.

This study can be seen as an empirical contribution to the literature on the monocentric city model (Duranton and Puga 2015), which is the standard model to study infrastructure effects in an urban context. A considerable number of studies has shown that highways and railway infrastructure cause suburbanization (Baum-Snow 2007a; Garcia-López 2012; Garcia-López, Hémet, and Viladecans-Marsal 2017; Garcia-López 2019; Cordera et al. 2019). Baum-Snow (2007b) extends the monocentric city model to account for heterogeneous commuting speeds, e.g. due to highways. As Duranton and Puga (2015, 486) point out, such non-monotonic gradients also need to be taken into account, if several modes of transport are combined. Different modes of transport as well as endogenous population densities are incorporated into the monocentric model by Xu et al. (2018). In the context of non-monotonicities caused by a better accessibility, P&R facilities can be seen as public transport infrastructure that amplifies such non-monotonicities in the monocentric city model. Overall, the model would predict that P&R facilities will foster suburbanization, as they lower the costs of commuting from the more remote regions around a city to the city centre. This prediction will be tested in this study.

This article is structured as follows: Section 2 discusses P&R facilities and their effects identified in the literature, Section 3 introduces the data sources and describes the applied methodology, Section 4 presents the main results of our study, and Section 5 concludes.

2. Characteristics and effects of P&R facilities

P&R facilities are a popular infrastructure policy instrument, in both Europe (Dijk and Montalvo 2011) and in the US (Noel 1988; Duncan and Cao 2020). Ideally, they enable a quick transition from individual transport by car to public transport by providing sufficient parking space close to public transport stations. The increasing trend of suburbanization, and as a consequence, increased traffic volumes in and outside city centres due to commuting, favoured the evolution of P&R facility systems, being in particular beneficial in less densely populated areas (Zhang, Wang, and Meng 2018).

The principal aim of P&R facilities is to reduce congestion in urban areas (OECD 2007) by providing a quick and easy access to public transport and thereby releasing pressures from urban road traffic. Recent surveys on the use of P&R facilities seem to confirm that people switch to commuting by public transport due to these facilities. Mingardo (2013) undertakes a survey in The Hague and Rotterdam and finds that P&R facilities increase the likelihood of switching to public transport by up to 23%. Tennøy, Hanssen, and Øksenholt (2020) find in a survey on Norwegian facilities that this likelihood amounts to 39%. Klementschitz and Grass (2019), investigating the effects of P&R facilities in Vienna, estimate the likelihood of switching to around 19%. Therefore, P&R infrastructure can reduce traffic in urban areas by a substantial amount as it enables persons living outside densely populated urban areas to switch to public transport at an early stage of their commute. Additionally, P&R facilities can be seen as interventions in the market for parking space. Following the discussion on the economics of parking by Inci (2015), P&R facilities can be seen as infrastructure reducing (or even eliminating) search costs for parking space and congestion around the railway station, which in turn may increase welfare.

However, P&R facilities do not necessarily reduce overall traffic. On the one hand, people are incentivised to switch to public transport outside city centres, which reduces congestion, traffic and pollution inside the city. On the other hand, there are opposing effects. Specifically, P&R facilities provide an incentive to take the car instead of public transport or a bicycle to the railway station. Moreover, if aiming to minimize overall commuting time, P&R facilities incentivise taking the car to a facility close to the city. Also, a P&R facility has no effect for commuters who already parked nearby the railway station before its existence. Lastly, P&R facilities are used for unintended purposes than commuting as well. Taking these effects into account, a number of studies (e.g. Tennøy, Hanssen, and Øksenholt 2020; Mingardo 2013; Meek, Ison, and Enoch 2010; Parkhurst 2000) argues that P&R facilities tend to increase the total number of kilometres travelled by motor vehicles. However, surveys by Duncan and Cao (2020) and Duncan and Cook (2014) find that P&R facilities reduce kilometres travelled by car in the context of the US. Moreover, Webb and Khani (2020) contribute to the literature by showing that commuters using a P&R facility in the US do not necessarily aim to minimize their overall commuting time, but their car driving time. This would dampen the opposing effects somewhat.

Despite the significant amount of literature on the effects of P&R facilities on the kilometres travelled, to the best of our knowledge no study investigated the effects of P&R facilities on population growth.

3. Data and methodology

In this study, we apply a difference-in-differences approach to evaluate the impact of an expansion of P&R facilities on population growth. According to the literature, railway infrastructure fosters population growth in municipalities where the railway station is located. In contrast, a P&R facility may make the area outside the central municipality more attractive and is more likely to attract population to neighbouring municipalities.

Therefore, our hypothesis is that the extension of a P&R facility causes an increase in population in neighbouring municipalities compared to the municipality the facility is located in.

Since not the whole area of the neighbouring municipalities will be affected by the construction and/or the expansion of a P&R facility, we limit our analysis to the areas accessible within a certain threshold from the facility, identified using grids of 250 × 250 m. On such a granular geographical basis, we unfortunately do not have access to socio-economic data, which limits our set of explanatory variables substantially. However, we argue that a difference-in-differences approach is able to allow for causal conclusions nonetheless.[1]

In general, for this approach to be valid, we have to assume that those areas in the municipality, where the facility is built or expanded, are affected by similar influences in explaining population growth than accessible areas in neighbouring communities, which is the common trend assumption. We argue that this is justifiable, since the choice to move to a specific region will depend on the commuting distance to the place of work as well as on local specialties, which vary across facilities but less within the region of a specific facility. Given that areas in the core municipality (where the facility is built) and the neighbouring facilities experience similar trends and determinants of population growth, we can test whether, after the opening or extension of a (larger) facility, the two areas evolve differently. Given our hypothesis, we would expect areas further away from the facility, i.e. the treated areas, to grow faster than areas immediately around a facility, i.e. the control group.

For a causal interpretation of a difference-in-differences estimation, it is crucial for the treatment to be exogenous. In the context of this study, the treatment is reflected in the capacity extension of a P&R facility. Taking the methodological approach of this particular study into account, the expansion of a P&R facility would be endogenous, if it is a reaction to an expected increase in population growth in the surrounding municipalities (outer isochrone), but not in the municipality the facility is located in (inner isochrone). However, exogeneity is given if the expansion depends on the population development in the whole region equally. Thus, the existence of common pre-treatment trends in the respective municipality and its neighbouring municipalities supports the treatment's exogeneity. As we explain later in this chapter, we select P&R facilities, for which common pre-treatment trends can be observed.

Moreover, we argue that the motivation behind extending P&R facilities in Lower Austria is not a reaction to an anticipated population growth. Rather, the motivation is to increase the attractiveness of public transport. This is emphasized in the Environment, Energy, and Climate Report 2014 as well as the Climate and Energy Program 2020 of the Federal Government of Lower Austria (2015, 2017). Both documents stress that the role of P&R facilities is to incentivise usage of public transport, thereby making traffic more sustainable. To further emphasize the exogeneity of extensions of P&R facilities with respect to population growth, several statements of the Federal Government of Lower Austria (2012, 2013, 2018, 2019) and of Vienna (2020) concerning P&R facilities can be analysed. The reasons to justify the construction or extension of P&R facilities in these statements are political, climatic or safety aspects but not, as mentioned, population growth or enhancing municipalities' attractiveness.

Nonetheless, it remains an assumption that the extension of P&R facilities is not motivated by attracting more population. But endogeneity concerns would only arise, if the extensions of P&R facilities aim to specifically attract population in the neighbouring municipalities only. However, we argue that this is not plausible, since the funding of a P&R facility is partly covered by the municipality that the P&R facility is located in, not by the surrounding municipalities. Also, tax revenues are allocated according to a (weighted) population key (Köppl-Turyna and Pitlik 2018). This supports the assumption, since the municipality building the P&R facility has no incentive to increase the allocated tax revenues for the neighbouring municipalities. A further endogeneity concern may be the presence of a different driving factor behind population growth. One may imagine that the policy of extending a P&R facility is linked to a public policy that makes a living in surrounding municipalities more attractive. However, to the best of the authors' knowledge, this is not the case.

Our central variable of interest is the development of population. We use fine-grained grid data, provided by Statistics Austria. For Lower Austria in total, population data for grids of a size of 250 m × 250 m is available from 2008 to 2019 on a yearly basis. To differentiate between the core area, which is immediately around a P&R facility, and the outer area around the core, we use Open Street Map data and create two types of isochrones[2] reflecting the accessible region by car within a certain amount of time. The time thresholds defining the two isochrones types are selected for each P&R facility separately, taking the settlement structure around the respective P&R facility into account. Laying the inner and outer isochrones on top of each other yields a core area and a belt around it. The polygon isochrones are afterwards intersected with the grid data.[3]

Due to data availability with respect to grid data, we have to restrict our analysis to P&R facilities in Lower Austria[4] that have been expanded between 2012 and 2016. In total, this amounts to 17 P&R facilities. Additionally, we take the main purpose of P&R facilities into account, i.e. to ease commuting. The city of Vienna is geographically embedded in Lower Austria and attracts a substantial amount of working population and students from Lower Austria. In 2018, more than 200,000 Lower Austrians (i.e. 12% of the total population of Lower Austria) commuted to Vienna on a regular basis. Moreover, 84% of those reach their working place in Vienna within one hour, according to data from Statistics Austria. Figure 1 displays the share of Lower Austrian commuters who work in Vienna.[5] It can be seen that the share is very high in municipalities close to Vienna. In some municipalities, up to 67% of all commuters work in Vienna. Also, the share quickly decreases, if moving farther away from the city.

In this study, we want to focus on P&R facilities, which ease the commute to the city of Vienna. Given that 84% commute less than one hour to their working place in Vienna, we restrict our analysis to P&R facilities from which this is in fact possible. Figure A1 in the Appendix shows the reachable area from the closest public transport hub in Vienna within 40 min by car. Taking possible time loss due to congestions as well as the fact that the overall commute to the working place may take longer than to the closest public transport hub into account, commuters from within the area can realistically reach their working place in Vienna within one hour. This includes ten P&R facilities, which have been expanded between 2012 and 2016. Additionally, we include the P&R facilities St. Pölten, Marchegg and Neunkirchen in our analysis, since fast train connections are

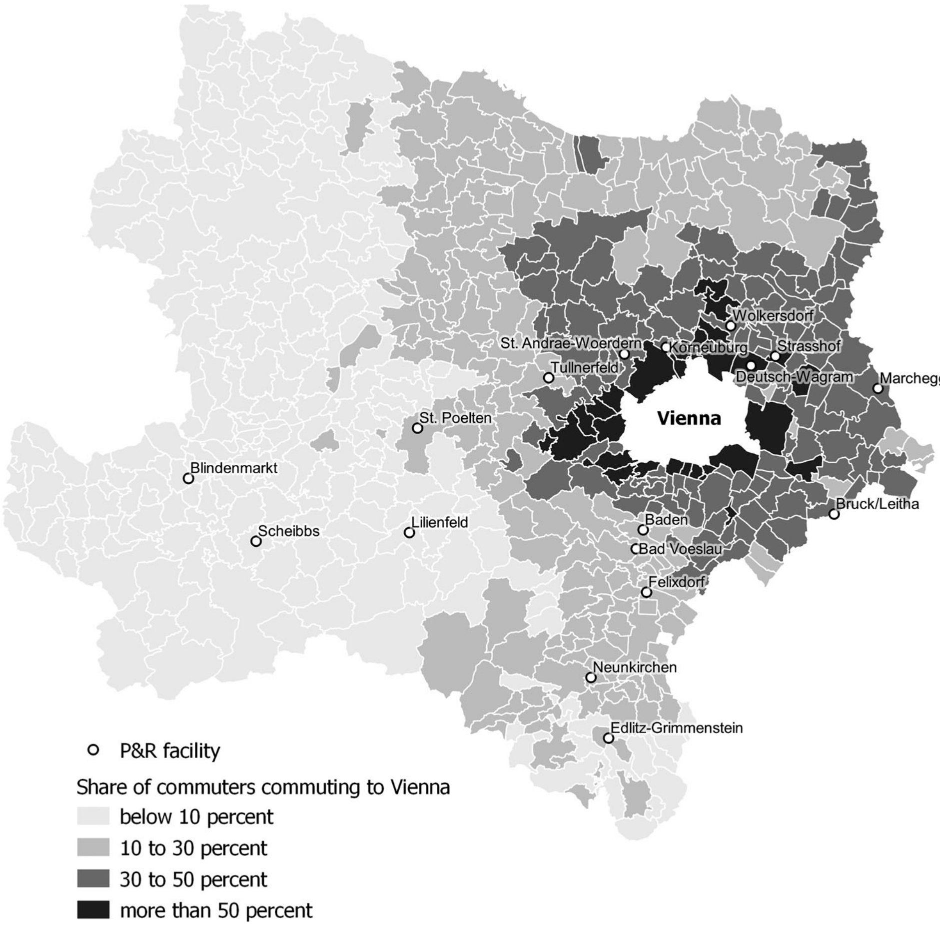

Figure 1. Share of commuters working in Vienna, 2018.

facilitating a commute to a public transport hub in Vienna within 21, 31, and 40 min, respectively. This makes them also relevant for our study, despite their larger distance if taking the car.[6]

For the selected 13 facilities, we generated isochrones as explained above, taking the settlement structure into account. As an example, Figure 2 displays the inner and outer isochrones of Baden and the inhabited grid cells. Similar depictions for the remaining P&R facilities are provided in Figures A4 and A5 in the Appendix. In the next step, we compared the evolution of the population in the core and outer areas using event plots. Due to missing common pre-treatment trends in the treated and non-treated groups, we had to omit six further P&R facilities. As a pre-treatment trend we define a population growth of similar magnitude in both the inner and outer isochrone. For the remaining seven P&R facilities, we identify common pre-treatment trends in the core and outer areas. Specifically, these are the P&R facilities in Baden, Deutsch-Wagram, Felixdorf, Korneuburg, St. Andrä-Wördern, St. Pölten, and Strasshof. The events plot for the selected and omitted P&R facilities are displayed in the Appendix in Figures A2 and A3, respectively.

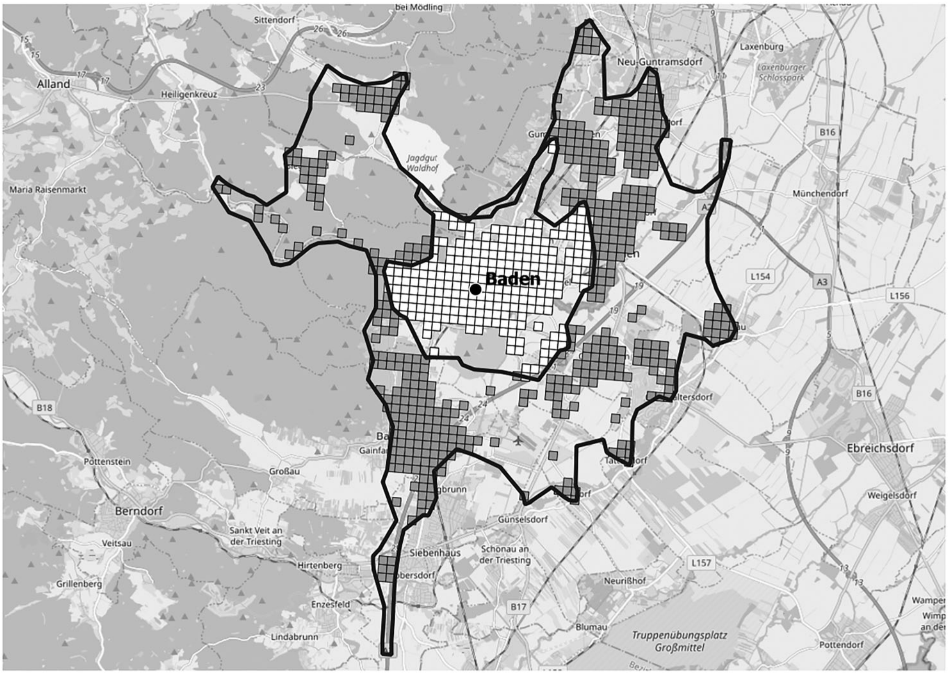

Figure 2. P&R facility in Baden, inner and outer isochrones and inhabited grid cells.

Table 1 summarizes the seven selected P&R facilities with respect to the size of the isochrones, the absolute number of inhabitants within the isochrones and the pre-treatment trend, the year of the respective P&R facility extension and the extension's size, as well as the driving time from the P&R facility to the closest public transport hub in Vienna.

Table 1. Investigated P&R facilities.

ID	P&R facility	Inner/ outer isochrone	Year of extension	Population in inner and outer isochrone in the year of extension	Cumulative population growth in the 3 years prior to extension	Capacity before extension	Size of extension	Driving time to closest hub in Vienna
P&R 1	Baden	7/13	2016	76,541	3.3%	446	+430	28
P&R 2	Deutsch-Wagram	5/13	2014	23,787	3.6%	362	+207	18
P&R 3	Felixdorf	5/8	2016	20,892	3.7%	315	+260	36
P&R 4	Korneuburg	6/10	2016	22,956	3.8%	600	+105	17
P&R 5	St. Andrä-Wördern	12/17	2015	20,915	2.9%	91	+85	33
P&R 6	St. Pölten	7/15	2015	67,513	1.4%	1.283	+565	49
P&R 7	Strasshof	5/10	2012	16,338	3.7%	7	+370	25

Notes: The extension volume is defined as the ratio of newly built parking spaces to the number of parking lots before the extension. The size of isochrones is depicted in minutes of car driving time, extending from the location of the respective P&R facility. The absolute population refers to the population in the inner and outer isochrone, as shown in Figure 2 and Figure A4. Thus, it does not reflect administrative borders. The depicted population growth refers to the cumulative growth of the number of inhabitants in both the inner and outer isochrone in the three years before the respective extension. Driving times to the closest public transport hub in Vienna are also denoted in minutes. As a hub, we define a public transport station that connects subway and regional train lines.

4. Results

In a first step, we estimate the following difference-in-differences models, defining the dependent variable, i.e. population, in logarithmic and absolute terms

$$log(pop_{i,j,t}) = \alpha_i + \beta_i T_j + \gamma P_t + \delta(T_j * P_t) \quad (1)$$

$$pop_{i,j,t} = \alpha_i + \beta iTj + \gamma Pt + \delta(Tj * Pt) \quad (2)$$

The subscript i denotes the individual P&R facility, subscript j denotes the treatment group, i.e. either the inner or outer isochrone, and subscript t denotes the respective year. α_i accounts for unobserved characteristics of P&R facilities. T_j takes on value one (zero) if the observed population lies in the outer (inner) isochrone. P_t takes on value one (zero) if year t is after (before) the expansion of the respective P&R facility. The coefficient δ is of utmost importance, since it captures the causal difference-in-differences effect.

For a consistent estimation of δ, the assumption of common trends in the treated and non-treated groups in the absence of a treatment is necessary. A crucial indication for this assumption is the presence of common pre-treatment trends. As mentioned above, Figure A2 in the Appendix shows the event plots for those seven P&R facilities with common pre-treatment trends.[7] Moreover, the later conducted placebo tests present a more formal indication of common pre-treatment trends.

In general, we assume that the inner and outer regions are economically similar. There is a high probability that an idiosyncratic shock hitting the inner region affects the outer region either directly or over spill-over effects, and vice versa. However, the detection of common pre-treatment trends is a necessary condition for the validity of this argument and our empirical analysis.

The results for this basic difference-in-differences estimation are shown in columns (1) and (2) in Table 2. It can be seen that the effect of P&R facilities on population is positive but insignificant.

However, the pull-effect of a P&R facility strongly depends on the proximity to Vienna. If it is close to Vienna, a P&R facility may not enhance the attractiveness of the outer region around it. Imagine a suburban town 15 min driving time away from a public transport hub inside a large city, which entails a P&R facility itself.[8] Then, if having to commute to the city, it is rational to take the car to the public transport hub and continue the commute from there. Hence, we include a dummy in the difference-indifferences model to distinguish between P&R facilities which are within and beyond a certain threshold of driving time to the closest public transport hub in Vienna.

That is, we estimate the following models

$$log(pop_{i,j,t}) = \alpha_i + \beta_i T_j + \gamma(P_t * sub_i) + \delta[(T_j * P_t) * sub_i] \quad (3)$$

$$pop_{i,j,t} = \alpha_i + \beta_i T_j + \gamma(P_t * sub_i) + \delta[(T_j * P_t) * sub_i] \quad (4)$$

The dummy sub_i denotes whether a P&R facility i is within or beyond a certain threshold distance to the closest public transport hub. We define 20 and 30 min as thresholds. The driving time to the closest hub in Vienna is shown in Table 1. For 20 min, only two facilities are within the threshold, while for 30 min, four out of seven facilities are within the threshold.

Table 2. Main results.

	Dependent variable					
	log(*pop*)	*pop*	*log*(*pop*)	*pop*	*log*(*pop*)	*pop*
	Without differentiation		Within and beyond 20 min		Within and beyond 30 min	
	(1)	(2)	(3)	(4)	(5)	(6)
γ	0.036***	549.345***				
	(0.003)	(147.915)				
$\gamma \times$ *beyond*			0.034***	604.7***	0.032***	646.7**
			(0.003)	(189.5)	(0.002)	(270.2)
$\gamma \times$ *within*			0.008	−193.8	0.007	−170.3
			(0.007)	(271.5)	(0.006)	(314.7)
δ	0.009	283.679				
	(0.007)	(251.166)				
$\delta \times$ *beyond*			0.016**	329.8	0.019*	66.7
			(0.007)	(306.3)	(0.011)	(278.2)
$\delta \times$ *within*			−0.024	−161.5	−0.018	379.7
			(0.018)	(496.6)	(0.014)	(476.0)
Observations	98	98	98	98	98	98
R^2	0.633	0.540	0.645	0.559	0.641	0.550
Adjusted R^2	0.566	0.456	0.570	0.465	0.565	0.455

Note: All regressions include standard errors accounting for heteroskedasticity. *p <0.1; **$p < 0.05$; *** $p < 0.01$.

Columns (3) to (6) of Table 2 display the estimation results. We find a positive and significant effect of P&R facilities, which are more than 20 or 30 min from the closest public transport hub in Vienna, on population growth in the outer isochrone. Specifically, the results imply that the expansion of P&R facilities leads to an increase in the number of inhabitants in surrounding municipalities of 1.6–1.9%, compared to the population development immediately around the P&R facility. Between 2008 and 2019, the cumulative population growth in all outer isochrones of the investigated P&R facilities amounted to 12.4%. Hence, the estimated effect of 1.6–1.9% accounts for up to 15% of the overall population growth in these areas. Estimated in absolute terms, the effect is positive, but insignificant. In contrast, for P&R facilities close to Vienna, we find no significant effect of expanding P&R facilities on population growth.

Robustness. In the following, several robustness checks are provided. First, we perform placebo tests to establish that the expansion of P&R facilities is indeed the driving factor. Specifically, we estimate the model described in equation (3) but artificially shift the treatment, i.e. the extension of a P&R facility, to an earlier point in time. We conduct these tests for both thresholds, 20 and 30 min. These tests can be interpreted as tests for the presence of a common pre-treatment trend in the treated and non-treated groups.

Table 3 depicts the placebo results. Columns (1) to (4) show the results for the sub_i threshold of 20 min, columns (5) to (8) for 30 min. For both specifications, the size of the effect decreases when shifting the treatment to an earlier point in time. Moreover, the effect becomes insignificant. For the threshold of 30 min, the placebo test becomes immediately insignificant, if shifting the treatment by one year.[9] For the threshold of 20 min the coefficient $\delta \times$ *beyond* is only insignificant, if shifting the treatment four years in the past. As only observations of three years before and after the treatment are included in the regression, *t−4* is the first placebo test, where the actual treatment is completely out of the respective sample.

Table 3. Placebo tests.

	Dependent variable: log(pop)							
	Within and beyond 20 min				Within and beyond 30 min			
	(1) t-1	(2) t-2	(3) t-3	(4) t-4	(5) t-1	(6) t-2	(7) t-3	(8) t-4
$\gamma \times$ *beyond*	0.030***	0.023***	0.019***	0.017***	0.028***	0.022***	0.018***	0.018***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.004)	(0.004)	(0.004)
$\gamma \times$ *within*	0.008	0.013***	0.013***	0.010**	0.007*	0.009*	0.009*	0.004
	(0.006)	(0.004)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)	(0.006)
$\delta \times$ *beyond*	0.013**	0.013**	0.012*	0.008	0.013	0.011	0.010	0.006
	(0.006)	(0.006)	(0.006)	(0.007)	(0.010)	(0.009)	(0.009)	(0.009)
$\delta \times$ *within*	−0.021	−0.020	−0.011	−0.006	−0.009	−0.007	−0.004	0.002
	(0.015)	(0.012)	(0.012)	(0.010)	(0.013)	(0.012)	(0.011)	(0.011)
Observations	98	96	94	90	98	96	94	90
R^2	0.636	0.608	0.574	0.543	0.628	0.601	0.570	0.537
Adjusted R^2	0.559	0.523	0.478	0.435	0.549	0.514	0.474	0.427

Note: All regressions include standard errors accounting for heteroskedasticity. $*p < 0.1$; $**p < 0.05$; $*** p < 0.01$.

Secondly, we estimate equation (3) iteratively omitting one P&R facility. The results for both thresholds of sub_i are shown in Table A1 in the Appendix. The coefficient $\delta \times beyond$ remains positive for all specifications. However, the effect of P&R facilities on population in the outer isochrone is not significant if removing P&R 3 or P&R 5 from the sample. For the remaining five specifications, the effect remains significant.

Furthermore, we provide regression results for all single P&R facilities in Table A2. The upper panel shows the results for *log*(*pop*) as dependent variable, the lower panel for *pop*. We find positive and significant difference-in-differences coefficients for three P&R facilities with respect to *log*(*pop*), ranging from 3.1% to 4.7%. Only the estimation for P&R 4 (Korneuburg), which is the closest to Vienna (see Table 1), is significant and negative.

5. Conclusion and discussion

We present a difference-in-differences approach to study the effects of P&R facilities on population growth in suburban municipalities around the city of Vienna. We find that the expansion of train-based P&R facilities, which are, by car, more than 20 min away from a public transport hub inside the city of Vienna, increases population in the neighbouring municipalities on average by 1.6–1.9% relative to the municipality in which the P&R facility is located. Between 2008 and 2019, the cumulative population growth in all outer isochrones of the investigated P&R facilities amounted to 12.4%. Hence, the estimated average effect of 1.6–1.9% accounts for up to 15% of the overall population growth in these areas. This points towards a positive externality on neighbouring municipalities: Since the Austrian fiscal constitution allocates tax revenues to municipalities according to a (weighted) population key (for a description, see Köppl-Turyna and Pitlik 2018), revenues for neighbouring municipalities increase as their population increases. Currently, however, these municipalities do not have to provide funds for the construction or expansion of P&R facilities, indicating a free-rider problem.[10]

Significant and positive population effects are found for P&R facilities in municipalities located more than 20 min by car from a major public transport hub in Vienna, whereas no significant effect is found for facilities in municipalities closer to Vienna. Whether these results hold for other comparable regions in Europe has to be further investigated. We also perform several robustness checks. While placebo tests strongly support our findings, the omission of certain single P&R facilities from the regression results in insignificant, but still positive coefficients.

The findings of this study support the theoretical predictions of the monocentric city model with non-monotonicities such as different modes of transport or heterogeneous commuting speeds (Xu et al. 2018; Baum-Snow 2007b). That is the prediction of increased population growth following a higher accessibility to the central business district. While we find positive population effects of P&R facilities, we cannot say where the additional population comes from. In the setting studied here, we would expect people to move from the city of Vienna to suburban areas and beyond while retaining their workplace in Vienna. This is comparable to the effects of highway or railway infrastructure fostering suburbanization (Baum-Snow 2007a; Garcia-López 2012; Garcia-López, Hémet, and Viladecans-Marsal 2017; Garcia-López 2019; Cordera et al. 2019). That is, the results of this study show that the construction or extension of P&R facilities can be viewed as an additional step in the process of suburbanization after providing railway infrastructure, by making neighbouring municipalities around a subcentre more attractive.

The empirical approach in this study can also be used to analyse other types of local infrastructure on economic variables of interest, not necessarily traffic infrastructure only. Expanding infrastructure or building new infrastructure is increasing the attractiveness of certain municipalities and enabling them to attract new inhabitants but might also create externalities on other (neighbouring) municipalities. This can provide an indication for the financing of infrastructure in a regional context.

Notes

1. Alternatively, we considered to use a propensity-score matching algorithm comparing regions around a certain P&R facility with similar areas along a railway line without a P&R facility. However, there are no (major) railway stations around Vienna without a P&R facility. Therefore, this approach is not feasible.
2. An isochrone in the context of this study is defined as the area around a P&R facility, which can be reached by car within a certain amount of time. This takes the road infrastructure and the allowed speed limits into account and yields a polygon shape that can be projected on a map.
3. The intersection is based on the centroids of the single grids. That is, a grid cell is assigned to a specific isochrone, if its centroid, i.e. its central point, lies within the polygon shape.
4. In 2018, 257 P&R facilities were located in Lower Austria. Their size ranges between 10 and 1.908 slots per facility. The average (median) size of a P&R facility was 148 (50) slots per facility.
5. In this context, a commuter is defined as an employee who works in a different municipality than he is living in.
6. In contrast, the P&R facilities in Edlitz-Grimmenstein and Lilienfeld are not included in our analysis, since the commuting time of one hour to a working place in Vienna in total is not credible in these cases. The fastest train connections take 52 and 65 min to the closest public transport hub, respectively.
7. Figure A3 in the Appendix shows the event plots for those P&R facilities, which are not included in the regressions due to a missing common pre-treatment trend.
8. As a public transport hub we define a public transport station that connects subway and regional train lines.
9. The number of observations decreases in Table 3 from 98 to 90 for $t-4$. The reason for this is that observations covering P&R 7 (Strasshof) are shifted out of the sample. It was expanded in 2012. Hence, in the basic regression the years 2009–2015 are included. However, we do not have any population grid-data before 2008, which reduces the sample if shifting the treatment to an earlier point in time. However, we argue that the results of the placebo tests are not driven by this, since omitting P&R 7 in the basic model from the sample completely, gives significantly positive results (see Table A1, column 7).
10. See Mun (2019) for a two-region model on the joint provision of transport infrastructure.

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Appendix

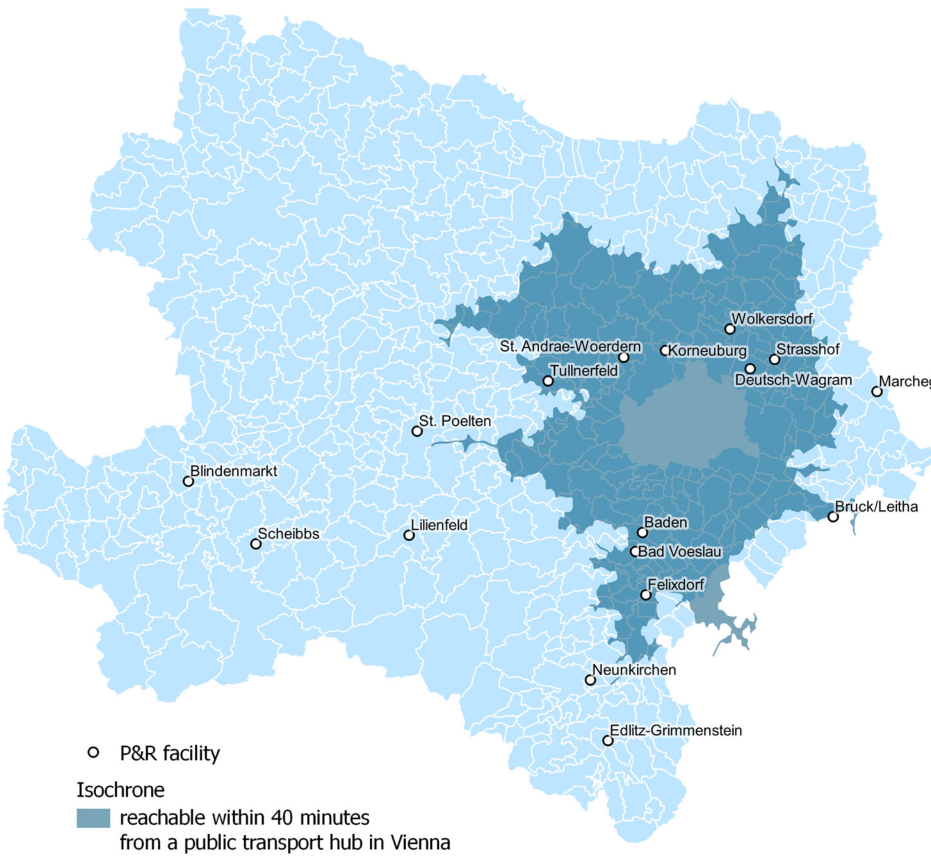


Figure A1. Accessible Lower Austrian municipalities within 40 min from a public transport hub in Vienna by car.

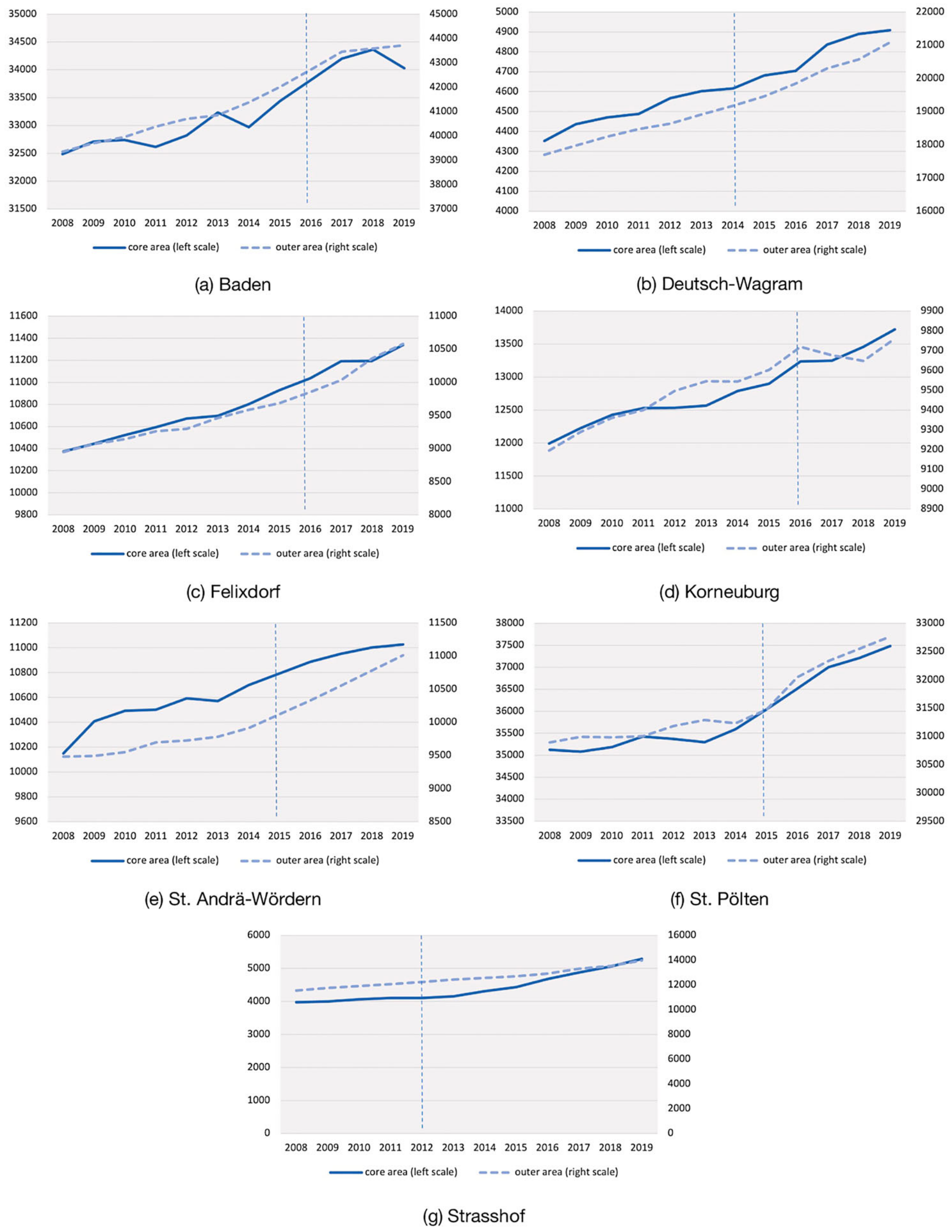


Figure A2. Event plots for all investigated P&R facilities.

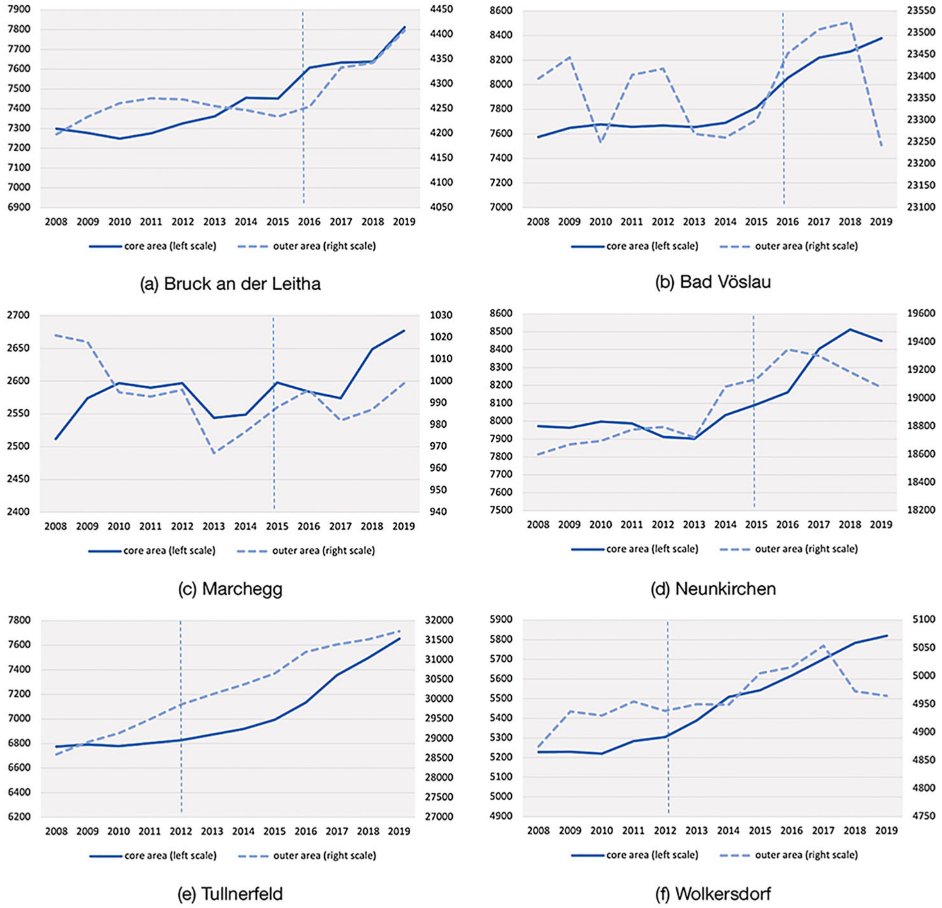


Figure A3. Event plots for omitted P&R facilities.

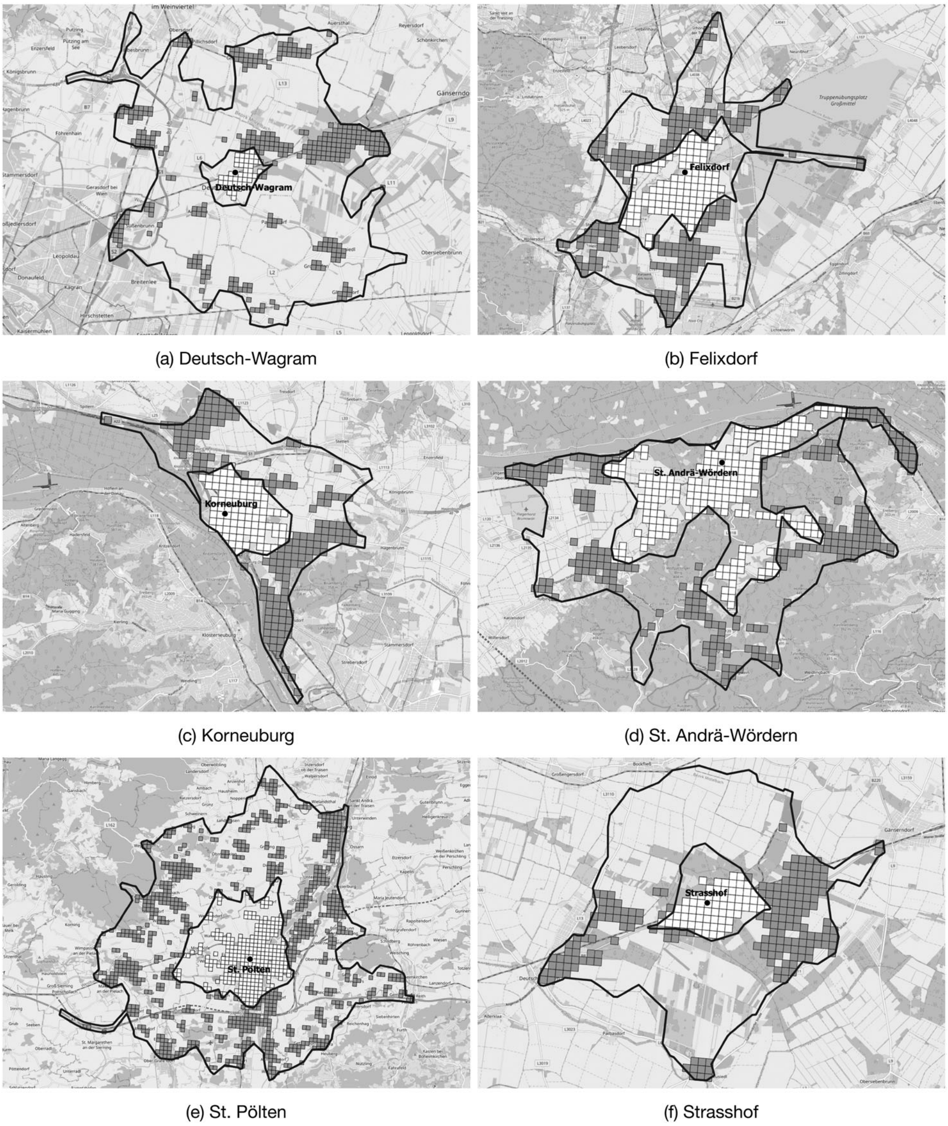
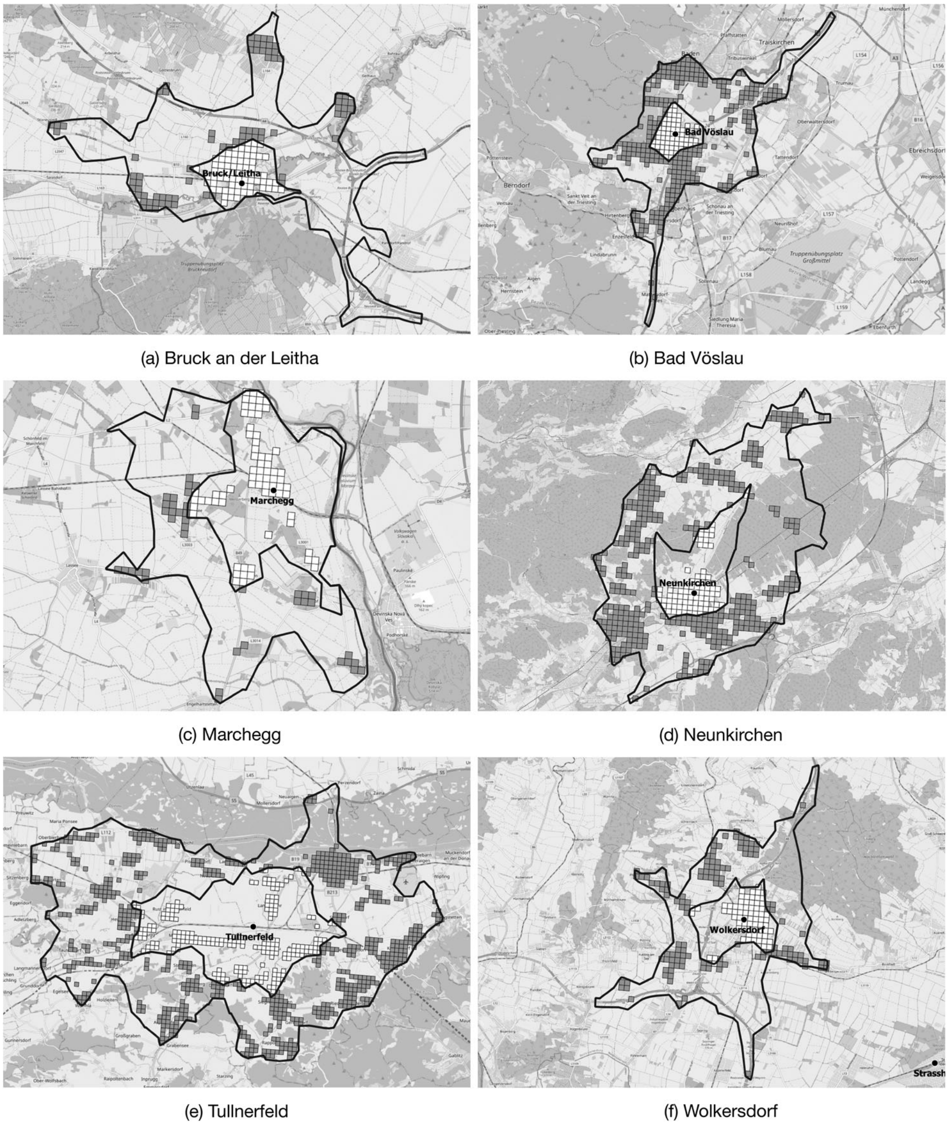


Figure A4. Respective isochrones and inhabited grid cells for remaining investigated P&R facilities.



(a) Bruck an der Leitha

(b) Bad Vöslau

(c) Marchegg

(d) Neunkirchen

(e) Tullnerfeld

(f) Wolkersdorf

Figure A5. Respective isochrones and inhabited grid cells for omitted P&R facilities.

Table A1. Robustness check – omitting one P&R facility at a time.

	(1) w/o P&R 1	(2) w/o P&R 2	(3) w/o P&R 3	(4) w/o P&R 4	(5) w/o P&R 5	(6) w/o P&R 6	(7) w/o P&R 7
				Within and beyond 20 min			
γ × beyond	0.036^{***}	0.034^{***}	0.034^{***}	0.034^{***}	0.036^{***}	0.034^{***}	0.031^{***}
	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)	(0.004)	(0.002)
γ × within	0.006	0.017^{***}	0.009	−0.00004	0.007	0.009	0.012^{*}
	(0.007)	(0.003)	(0.008)	(0.003)	(0.007)	(0.008)	(0.007)
δ × beyond	0.014^{*}	0.016^{**}	0.012	0.016^{**}	0.010	0.021^{***}	0.019^{**}
	(0.009)	(0.007)	(0.008)	(0.007)	(0.008)	(0.006)	(0.008)
δ × within	−0.023	-0.052^{***}	−0.021	0.004	−0.019	-0.030^{*}	−0.028
	(0.018)	(0.007)	(0.018)	(0.007)	(0.018)	(0.017)	(0.018)
Observ.	84	84	84	84	84	84	84
R^2	0.629	0.673	0.641	0.658	0.634	0.657	0.665
Adjusted R^2	0.547	0.601	0.562	0.582	0.553	0.582	0.591
				Within and beyond 30 min			
γ × beyond	0.032^{***}	0.032^{***}	0.031^{***}	0.032^{***}	0.035^{***}	0.031^{***}	0.032^{***}
	(0.002)	(0.002)	(0.003)	(0.002)	(0.0002)	(0.003)	(0.002)
γ × within	0.012^{**}	0.009	0.009	0.004	0.005	0.009	0.005
	(0.005)	(0.007)	(0.006)	(0.006)	(0.005)	(0.006)	(0.007)
δ × beyond	0.019^{*}	0.019^{*}	0.014	0.019^{*}	0.011	0.033^{***}	0.019^{*}
	(0.011)	(0.011)	(0.014)	(0.011)	(0.014)	(0.003)	(0.011)
δ × within	−0.025	−0.025	−0.014	−0.006	−0.010	-0.032^{***}	−0.018
	(0.015)	(0.016)	(0.017)	(0.012)	(0.017)	(0.010)	(0.016)
Observ.	84	84	84	84	84	84	84
R^2	0.630	0.648	0.635	0.658	0.628	0.660	0.657
Adjusted R^2	0.548	0.570	0.555	0.583	0.546	0.585	0.581

Note: The dependent variable in these regressions is *log*(*pop*). All regressions include standard errors accounting for heteroskedasticity. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A2. Results for single *P*&R facilities.

	(1) P&R 1	(2) P&R 2	(3) P&R 3	(4) P&R 4	(5) P&R 5	(6) P&R 6	(7) P&R 7
				Dependent variable: log(pop)			
β	0.209***	1.407***	−0.133***	−0.281***	−0.082***	−0.127***	1.075***
	(0.009)	(0.014)	(0.012)	(0.011)	(0.010)	(0.003)	(0.014)
γ	0.037***	0.062***	0.051***	0.071***	0.042***	0.043***	0.130***
	(0.005)	(0.014)	(0.009)	(0.013)	(0.008)	(0.008)	(0.036)
δ	0.031**	0.029	0.041*	−0.043**	0.047**	−0.007	−0.039
	(0.012)	(0.024)	(0.023)	(0.015)	(0.020)	(0.011)	(0.042)
Intercept	10.400***	8.409***	9.271***	9.433***	9.258***	10.472***	8.303***
	(0.004)	(0.009)	(0.007)	(0.009)	(0.007)	(0.002)	(0.009)
Observ.	24	24	24	24	24	24	24
R^2	0.986	0.999	0.915	0.988	0.863	0.980	0.989
Adjusted R^2	0.984	0.999	0.902	0.987	0.843	0.977	0.987
				Dependent variable: pop			
β	7664.875***	13,836.670***	−1322.875***	−3066.125***	−825.143***	−4215.286***	7783.000***
	(355.307)	(202.236)	(118.832)	(122.080)	(969.955)	(959.951)	(129.883)
γ	1225.000***	286.500***	560.625***	921.250***	444.400***	1552.857***	578.500***
	(182.174)	(67.492)	(99.661)	(171.132)	(85.468)	(296.731)	(167.799)
δ	1604.875***	1461.167***	340.125	−649.625***	452.943**	−400.314	560.750*
	(458.966)	(381.926)	(233.458)	(181.578)	(207.031)	(393.326)	(308.442)
Intercept	32,876.500***	4486.167***	10,629.120***	12,495.500***	10,488.000***	35,297.140***	4034.750***
	(121.509)	(40.183)	(69.739)	(109.627)	(71.428)	(73.816)	(34.738)
Observ.	24	24	24	24	24	24	24
R^2	0.984	0.997	0.918	0.987	0.860	0.979	0.990
Adjusted R^2	0.982	0.997	0.905	0.985	0.839	0.976	0.989

Note: All regressions include standard errors accounting for heteroskedasticity. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.