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## Do highway widening reduce congestion?

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TI 2022-010/VIII  
Tinbergen Institute Discussion Paper

# Do highway widenings reduce congestion?

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# Do highway widenings reduce congestion?

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## Abstract

Highway construction occurs nowadays mainly through widening of existing roads rather than building new roads. This paper documents that highway widenings considerably reduce congestion in the short run, defined here as 6 years. Using longitudinal microdata from highway detector loops in the Netherlands, we find substantial travel time savings. These savings occur despite strong increases in traffic flow. The welfare benefits in the short run already cover 40% of the widenings' investment costs. Our paper contributes to an explanation why countries invest in roadworks even when the fundamental law of congestion predicts that travel savings disappear in the long run.

JEL Codes: R3, R33, R4, R42, H4

Keywords: highway widenings; congestion; traffic flow; welfare effects; economic activity

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## 1 Introduction

Highway construction has occurred over the last decades largely through widenings – adding new lanes to existing roadways – rather than through construction of new greenfield highways in developed countries. In the Netherlands, for instance, very few new greenfield highways have been built after 1990, whereas highway lane kilometres have increased substantially, by about 25 percent. Furthermore, the construction of highway widenings has been planned to continue at the same rate as in previous decades, whereas there are very few new highways planned. Various other countries show a similar pattern of slowing down of new highway construction (e.g. US, but also West European countries such as Germany, France, Italy, UK, see [European Commission \(2018\)](#)).

There exists an important body of literature on the effects of greenfield highways, but much fewer papers study widenings. This is unfortunate because the size, timing and scope of the effects differ substantially between these two types of roadworks. The greenfield highways offer car travelers alternative routes, improving the road system’s coverage. The travel time savings may be large but also are varied as travel time reductions are not restricted to the congested hours only. Further, alternative routes may induce substantial changes in spatial structure — in terms of population and employment. These changes take time so that the effects of greenfield highways reveal themselves in a longer run only.

In contrast, widenings typically take place on congested highway segments. The direct (welfare) effect of this increase in road capacity arises due to local reductions in travel time, i.e. on the widened segment self, during congested hours. This further induces adjustments in travel demand within the day (e.g. from nonpeak to peak), over space (i.e. from adjacent highways to treated highways) and in overall travel demand.<sup>1</sup> Still, the major part of the effects of widenings can be observed on a much shorter term than is the case with green-

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<sup>1</sup>The effects of widenings therefore depend on whether treated highways are substitutes or complementary to adjacent highways. For example, parallel roads tend to be substitutes, but the roads may also feed into each other. Usually, except when Braess paradox exists, average travel time within the highway network will not increase, because of widenings.

field highways. As a result, in the case of widenings the short-run effects might be especially important. While there is evidence that the travel time reductions from roadworks disappear in the long run due to an induced increase in travel demand (see [Hsu and Zhang \(2014\)](#); [Garcia-Lopez et al. \(2021\)](#) for the widenings), the welfare benefits may still be substantial during the transition to this new long-run equilibrium. This is especially important for the policy, taking into account that widenings are much cheaper than greenfield construction.<sup>2</sup>

In the current paper, we aim to examine the short-run effect of widenings, ignored in the literature. We examine the welfare effects of highway widenings, mainly between cities, for the Netherlands. We include the effects on congestion (travel time) and travel demand (travel flow) up to 6 years after a widening. We study how these effects vary by year within this time interval. Furthermore, we study also the variation in the effects within the day, which is relevant because of trip rescheduling ([Arnott et al., 1990, 1993](#); [Small et al., 2005](#)), as well as over space (i.e. within a certain distance of the widening). Our (welfare) estimates complement studies that focus on the widenings in the long run ([Hsu and Zhang, 2014](#); [Garcia-Lopez et al., 2021](#)) and on greenfield highways ([Duranton and Turner, 2011](#); [Couture et al., 2018](#)) and therefore help us to get a more complete picture to gauge the welfare implications of highways investments.

A widening increases the number of lane kilometres for a certain area. Our identification strategy exploits the variation over time and space in the number of lane kilometres induced by widenings. We make use of information from individual induction loop traffic detectors for the Dutch highway network, which allows us to estimate the effects for several levels of aggregation.<sup>3</sup> Our focus is on a region defined by the geographical area within 20 km of a widening. Regions are therefore quite sizeable (about 630  $km^2$ ).<sup>4</sup>

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<sup>2</sup>Estimates for the Netherlands indicate that the cost of a lane kilometre of a widening is roughly 1/4 of the cost of a greenfield extension.

<sup>3</sup>In the literature, it is standard to use information for administrative regions. Using more fine-grained information is particularly beneficial for identification in small, high-density, countries such as the Netherlands.

<sup>4</sup>Regions are 1/5 of the median US county size, but with much higher levels of population

Additionally, we examine the effect of widenings locally, i.e. at the level of the highway segment, our smallest unit of analysis (a segment has an average length of 12 km). Analysis at this level is useful as it allows us to examine spatial variation in the effects of widenings within regions, including whether highways are substitutes or complements to each other. Importantly, analysis at this level is politically relevant, as the local effects of widenings are very pronounced and therefore visible.

We take several steps to account for endogeneity issues. To control for unobserved time-invariant heterogeneity, we use location fixed effects. This does not control for time-varying heterogeneity which may be problematic when time-varying location characteristics are correlated to highway widenings.<sup>5</sup> Furthermore, we focus solely on segments respectively regions where road capacity increased during the study period. This relaxes the identifying assumption for causal inference, as it only requires that, conditional on the widening, the exact timing of the widening is random. To justify this assumption, we discuss the Dutch transportation investment planning process and explain that it involves many phases of consulting with several layers of government and local residents which lead to unpredictable – and therefore arguably random – adjustments to the exact timing of the widening. For example only about 10% of the new lanes were opened in the planned year.

We focus on the dynamic effects of widenings, i.e. we employ an event study, to estimate the short-run effects we are interested in. Consequently, our identification strategy is based on the idea that widenings cause large *discrete jumps* in travel time as well as travel flow. The threat to identification from discontinuous confounding factors is then limited, because widenings vary considerably in opening year and geographical location. It is highly unlikely that all widenings were in the same way affected by the same confounding variable.

We first document that widenings are far from random and occur on highway and employment density.

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<sup>5</sup>Reverse causality is potentially an important threat to identification. For example, highways might be widened at locations where congestion is expected to increase. We address this issue by focusing on *sudden* changes.

segments that are highly congested particularly during peak hours. Widenings substantially increase road capacity: a widening increases the number of lanes of the widened segment by about 50%. This is also true at the regional level (in our study, regions have a 20 km radius): road capacity of regions that receive at least one widening increases, on average, by 10%.

We document considerable travel time reductions and travel demand increases after widenings on treated road segments, particularly during peak hours. The majority of these changes take place almost immediately after the widening. These results are important as they explain why widenings are politically attractive. We also find considerable reductions in travel time and increases in travel demand at the regional level within the first six years after a widening. Again, the majority of the effects take place immediately after the widening with stronger effects during peak hours.

To examine the welfare effects of widenings, we include four important components of welfare: (i) the time *losses* because of road construction just before the widening, (ii) the gains because of reduced travel times after a widening, (iii) the gains because of rescheduling and (iv) construction and maintenance costs of widenings. Our main conclusion is that 6 years after the widening, the accumulated welfare gains are substantial, and cover approximately 40% of the overall investment costs.

Finally, we investigate to what extent widenings cause local changes in economic activity (i.e. employment) and spatial structure (i.e. real estate). We provide evidence that highway widenings induce moderate redistributions of employment and commercial floor space within a range of 10 km, but the effects on population are too small to detect.

The structure of the paper is as follows. Section 2 deals with the literature. Section 3 describes the Dutch institutional setting of highway investments, which is essential for our identification strategy, and discusses the data on widenings. Section 4 examines the effect of widenings on travel outcomes, dealing consecutively with the traffic data, the empirical model and identification, and the results. Section 5 discusses the welfare effects and policy implications of the



effects of widenings on congestion. Section 6 goes into the effects of widenings on local economic activity and spatial structure. Section 7 concludes.

## 2 Literature

Our paper is connected to several streams of literature. The first one examines how urban traffic outcomes, such as vehicle kilometers travelled, travel flow, speed, congestion are *in the long run* affected by increases in road supply. The seminal paper by [Duranton and Turner \(2011\)](#) finds support for the 'fundamental law of congestion' introduced by [Downs \(1962\)](#): they document a unity elasticity of kilometers travelled in US metropolitan regions to their road infrastructure supply between 1980 and 2000. [Hymel \(2019\)](#) confirms this result on more recent data. [Couture et al. \(2018\)](#) support these findings by reporting a low (0.09) long-run elasticity of traffic speed to road supply for the US. [Hsu and Zhang \(2014\)](#) and [Garcia-Lopez et al. \(2021\)](#) demonstrate that long-run elasticity of vehicle kilometers for Japan respectively Europe is around one with higher estimates for greenfield road construction.

Our paper adds to this discussion by documenting for the Netherlands short-run dynamic effects after increases in road supply. We find that 6 years after the widening, the elasticity of travel flow with respect to road supply is about 0.50 (the difference from unit elasticity implied by the fundamental law is statistically significant). The elasticity of travel time with respect to road supply is then about  $-0.70$ .

Our study also indirectly relates to a growing literature studying the effects of changes in transport infrastructure on broader travel demand. [Gu et al. \(2021\)](#) and [Yang et al. \(2018\)](#) report increases in speed on Chinese highways following subway line opening adjacent to highways, [Gu et al. \(2017\)](#) documents a decrease in travel frequency following the introduction of driving restrictions. [Gendron-Carrier et al. \(2021\)](#), [Chen and Whalley \(2012\)](#) and [Davis \(2008\)](#) report a positive influence of urban transit rail and driving restrictions on air quality. [Anderson \(2014\)](#), [Adler and van Ommeren \(2016\)](#), [Bauernschuster et al. \(2017\)](#) document increases in car travel time during public transit strikes.

Another relevant body of literature deals with welfare benefits of transportation improvements (Gibbons and Machin, 2005; Duranton and Turner, 2012; Ossokina and Verweij, 2015; Teulings et al., 2018; Tsivanidis, 2018). By focusing on widenings and employing rich data on car travel time and travel flow, we are able to estimate the effects of widenings on travel demand and time savings, which are essential ingredients of a welfare analysis. We show that the benefits of the widenings in the first 6 years cover around 40% of the investment costs.

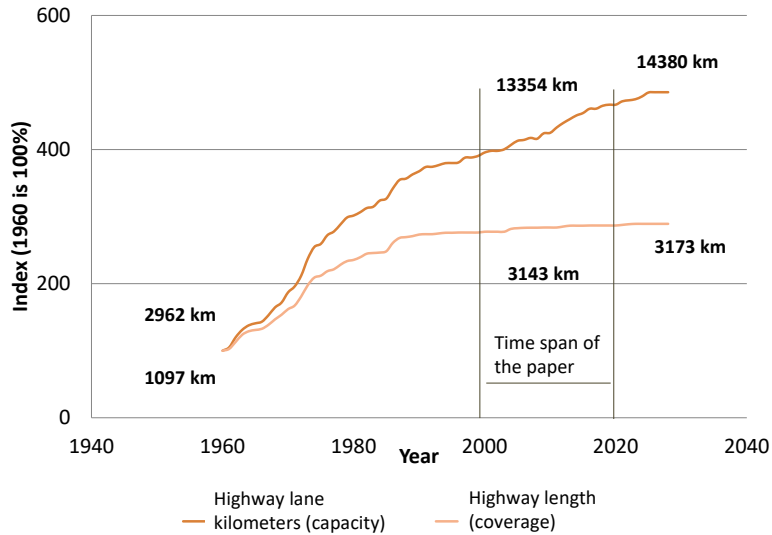
Finally, our paper is connected to studies that examine the impact of highways on urban development, and in particular the relocation of population and employment. Baum-Snow (2007, 2010) show for the US in 1950-1990 that additional highways passing through central cities led to suburbanization of population and employment. Garcia-López et al. (2016) reports that these effects have become smaller over the last decennia in Europe, likely because of the presence of a well-developed highway network. Levkovich et al. (2016) demonstrates that zoning policies influence how new highways affect population relocation in the Netherlands. Duranton and Turner (2012) shows for the US that new highways caused increases in employment and population in metropolitan areas in 1980-2000. Moeller and Zierer (2018) reports substantial effects of new highways on employment in German regions. Baum-Snow et al. (2020) shows for China that highways negatively affect hinterland population growth. We complement these studies by focusing on the short-run effects of widenings at a detailed spatial level and find mainly redistribution effects.

### **3 Background, Data and Sample**

#### **3.1 Highway investment, planning and functioning in the Netherlands**

The Netherlands has a high population density and a very developed and dense highway network (World Economic Forum, 2015). About 1% of GDP is spent on highway investment, mainly through widenings — adding new lanes — and maintenance (Ministry of Infrastructure and Water Management, 2018). Figure 1 shows highway length and lane kilometres. Highway length — i.e. cov-

Figure 1: Highway length and lane kilometres



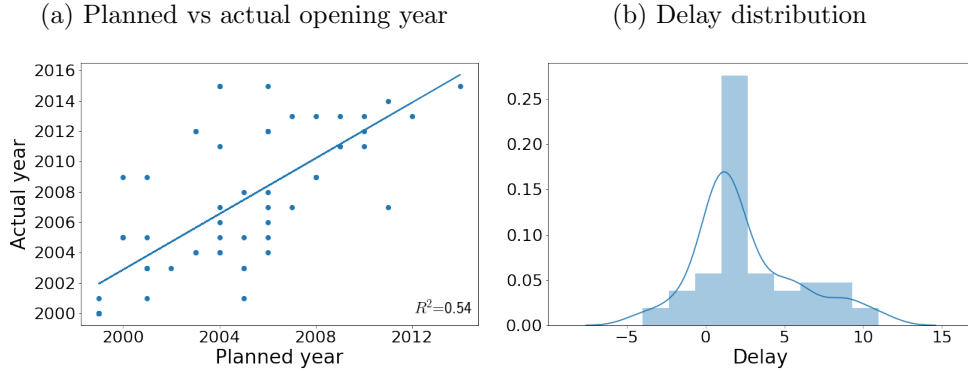
erage — grew with a factor of 3 between 1960 and 1990 but did not increase substantially after 1990. In contrast, the number of lanes (i.e. road capacity) — and thus the number of lane kilometres — kept steadily rising. This figure also shows future plans: capacity is expected to keep growing in the coming years, whereas coverage remains almost stable. In this paper we focus on widenings in the period from 2000 to 2018, as indicated in the figure.

The Dutch have a long history in spatial planning. Similar to other European countries (e.g. the UK), the political decision-making concerning highway investments is very involved. Usually many years pass between the time a new highway corridor or widening is first mentioned in policy documents and the year of construction. Many rounds of consultations within different layers of the government, and with local residents, take place to ensure that most costs and benefits of new developments have been included.

The decision-making process includes six main steps before the project is carried out.<sup>6</sup> Several steps take quite some time and allow for appeal. It is

<sup>6</sup>(1) An announcement of a new investment. (2) Initial research which examines the desirability of the widening. (3) An Initial Memorandum of Announcement is published which

Figure 2: Highway widenings 2000-2015



therefore essentially impossible for governments and other decision-makers (e.g. commercial developers) to predict the exact *location and year* in which a highway widening will be opened (see also Hansen and Huang (1997)). It appears that only 10 percent of the widenings were realised in the planned year.<sup>7</sup> 80% were delayed with up to 10 years and 10% were realised up to 5 years earlier than initially planned. Figure 2 shows a scatter diagram of the realised and planned opening years (the  $R^2$  of a linear relationship is only 0.54). We use this uncertainty surrounding the opening year for the purposes of identification.

Our study focuses on the Netherlands which has a dense highway structure with many ramps, so about 90 percent of Dutch households live within 2 km of a highway ramp.<sup>8</sup> As a result, the Netherlands has a high share of vehicle kilometres on highways (roughly 50 percent of overall vehicle kilometres)<sup>9</sup> and describes the need for and desirability of the investment. Local governments, interest groups and concerned citizens have the right to react. (4) The Memorandum is improved, in consultation with involved parties. A general Environmental Impact Report is produced discussing different alternatives. (5) A Draft Alignment Decision is developed that determines the project location. Public consultation takes place: lower governments, special interest groups and private citizens may offer input. (6) The Alignment Decision is announced. It is possible to appeal against this decision with the Council of State.

<sup>7</sup>We are able to demonstrate this for highway widenings realised in 2000-2015. For these widenings we know the realised and the planned opening year (as mentioned in the policy documents at the beginning of the decision-making process).

<sup>8</sup>We have calculated this using the geocoded location of residences sold in the Netherlands.

<sup>9</sup>We have calculated this using data from Statistics Netherlands.

a corresponding low share of vehicle kilometres within cities (e.g. in Amsterdam, the number of car kilometres does not even exceed the number of bicycle kilometres). Using a congested highway is almost always faster than using an alternative uncongested non-highway route (Emmerink et al., 1996), which implies that non-highway roads tend to be complementary to highways.<sup>10</sup>

In contrast to most other countries, there is not so much congestion within Dutch cities, which contain the bulk of non-highway roads, and congestion is predominantly on highways between cities. Congestion within cities is rather limited, because of high parking prices, combined with low car speed levels within cities due to the physical layout of roads, as over the last 40 years, road supply within cities has reduced for car users, whereas bicycle lanes have strongly increased.

In conclusion, highway widenings are unlikely to have a meaningful (negative or positive) effect on travel time on non-highway roads implying that the welfare gains or losses on these roads because of changes in congestion are of second order and can be ignored.<sup>11</sup> Furthermore, as it is plausible that non-highway roads are mainly complementary to highways, it is possible however that our welfare benefits of widenings are slight overestimates.

### 3.2 Data on highway lanes, segments and widenings

We exploit information on the Dutch highway network in 2000-2018 collected by the Dutch Ministry of Infrastructure and Water Management. In total, 260

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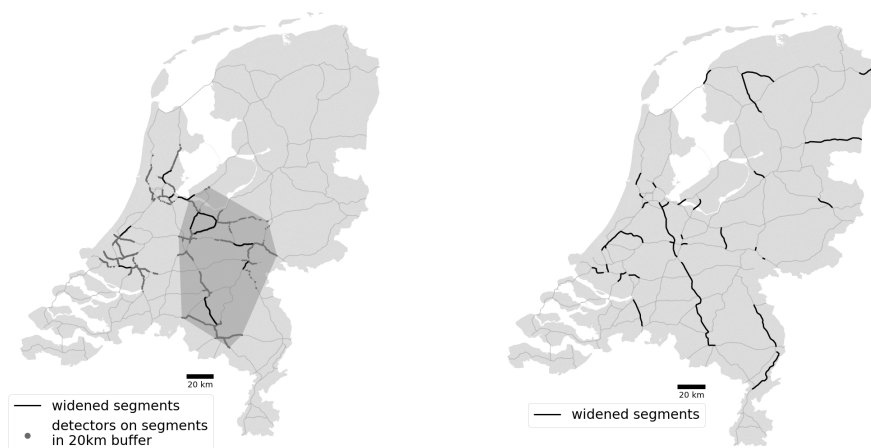
<sup>10</sup>This characteristic of the Netherlands is important, because the second-order welfare effects of highway widenings depend on the presence of time delays caused by car congestion on alternative routes to highways, which can be substitutes or complementary to highways. In case that roads are substitutes, travel time and travel flow on non-highway roads will be reduced by highway widenings, but if non-highway roads are primarily complementary, travel time and travel flow on non-highways will increase (Hsu and Zhang, 2014). These increases in travel time will typically lead to reductions in welfare, whereas the increases in flow will lead to increases in welfare, so the net second order effect is likely small and will be ignored.

<sup>11</sup>This includes other travel externalities such as noise, see Ossokina and Verweij (2015), which are typically much smaller in magnitude than those caused by congestion.

Figure 3: Widenings 2000-2018

(a) Traffic effect estimation

(b) Economic effect estimation



highway segments are distinguished in the network.<sup>12</sup> Within a segment, the number of lanes does not vary. We know for each segment its length (the average is 12 km), the number of lanes per year and therefore the year of the widening.

We focus on 48 widenings in the period from 2000 to 2018, which increased the total number of lane kilometres by almost 20 percent.<sup>13</sup> Most widenings have taken place in the west of the Netherlands, where most economic activity takes place. We have 16 widenings in 2013-2018 to study the effects on traffic outcomes.<sup>14</sup> For these widenings, we know the exact month of the widening. We also have information about another 32 widenings in 2000-2011 to study the effects on wider economic activity.<sup>15</sup> Appendix A contains a full list of the widenings and their opening dates.

Figure 3, left panel, shows in black the geographical location of the widen-

<sup>12</sup>A segment contains both driving directions.

<sup>13</sup>We have excluded a few segments that experienced more than one widening or that received another treatment - e.g. a peak lane opening.

<sup>14</sup>Almost all of these widenings are located on highway segments situated in between larger cities.

<sup>15</sup>We cannot use information on all 48 widenings to study their effects on traffic and economic activity outcomes, because the periods of observation of traffic and economic activity outcomes are both limited.

ings used in the analysis of the traffic effects. To capture the traffic effects of widenings, we focus on the increase in lane kilometres within a certain region surrounding the widening. In our main analysis, these regions include highway segments within 20 km of the widening.<sup>16</sup> Traffic detectors located within this 20 km buffer are depicted in the plot in grey.

Our focus is now on an area (shaded dark grey) that excludes observations having greenfield highway construction in a radius of 20 kilometers within the period investigated. It appears that there are only 2 new greenfields, both of a short length (7 km and 4 km). In our sensitivity analysis, we include observations nearby greenfield construction.

Figure 3, right panel shows in black the geographical location of the widenings used in the analysis of the economic effects. Here we focus on smaller regions around widenings, i.e. on zip codes that experienced increases in lane kilometres within 10 km, where we distinguish between an increase of lane kilometres within 5 km as well as within 5-10 km from the widenings. Here we again remove zip codes that had greenfield construction in the 20 km radius.

## 4 The effect of widenings on travel outcomes

### 4.1 Data

To study the effects of highway widenings, we employ high-frequency NDW data on car speed and car flow between 5:00 - 21:00 hours obtained from individual induction loop traffic detectors on Dutch highways from July 2011 – November 2019.<sup>17</sup> Information is available on a minute basis for detectors. To reduce downloading and computation time, we use information for a representative day of the week (Tuesday), and focus on monthly averages.<sup>18</sup>

Given information on speed, car flow for traffic detectors combined with distances between traffic detectors, we compute *travel time per kilometre* and

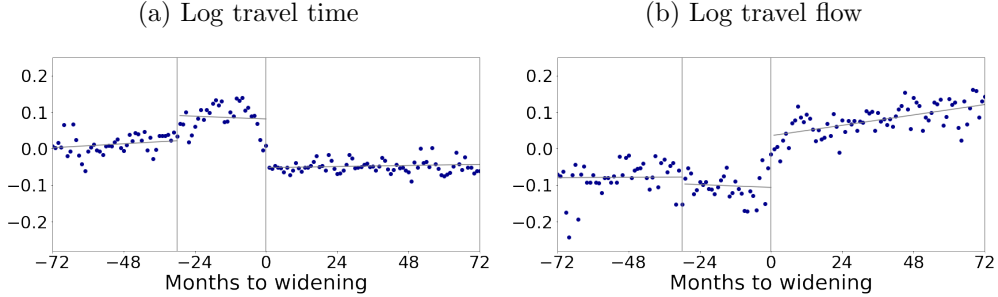
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<sup>16</sup>In the sensitivity analysis, we also show results for different geographical size.

<sup>17</sup>There is approximately one detector per 200m highway in our data. NDW is an acronym for National Data Warehouse for traffic information.

<sup>18</sup>Analysis based on weekly data generates almost identical results.

Figure 4: Time dynamics of traffic activity on widened segments



*traffic flow*, i.e. number of vehicles per traffic detector for specific areas (e.g. within 20 km of a widening) per specific time interval (e.g. per hour or per day).<sup>19</sup> In total we have information about 4500 detectors for 260 segments.

In our analysis, to reduce endogeneity issues, we focus on a subsample of some 250,000 monthly observations on travel time and travel flow for 2560 individual detectors on 122 segments that are all within 20 km of a widening.<sup>20</sup> For the 16 segments that are widened we have information from 193 traffic detectors.

## 4.2 Descriptive statistics

Figure 4 shows monthly averages of log travel time and log flow before and after the widening for treated segments.<sup>21</sup> This figure is helpful for our identification strategy. There are several messages in this figure.

First, due to road construction works, travel times increase and flow decreases temporarily for a period of about 2 years before the widening. Second, excluding the construction period, travel times are substantially lower after the widening. Third, before the widening but also after the widening, travel time is

<sup>19</sup>Traffic flow is proportional to the vehicle kilometres travelled, another measure which is used in this literature. As we will use detector specific information and use log transformations, our results for traffic flow can be interpreted as the results for vehicle kilometres travelled.

<sup>20</sup>Traffic detector data are not always available, e.g. because of malfunctioning. We require detectors to have at least 42 months of data. Furthermore, we only select detectors of widened segments for which we have at least 30 months of data before and at least 12 months of data after the widening.

<sup>21</sup>These variables are detector-demeaned.



approximately constant. For example, 6 years after a widening, the travel time is roughly the same as after 2 years. Fourth, ignoring the construction period, travel flow is approximately constant over time before the widening. It strongly increases in the first 2 years after the widening, whereas this increase seems to level off after 4 years.

Table 1 left panel reports descriptive statistics on the widened segments for two specific moments: 3 years before and 2 years after the widening.<sup>22</sup> Here we also distinguish between different time windows within the day. It shows that widenings imply a substantial increase in the number of lanes (from 4.4 to 6.5 lanes). This goes together with a 25% decrease in travel time during peak hours and a 10% decrease in travel time over the day. These travel time decreases go along with flow increases of 25% in the peak and 15% over the day.

These descriptives for widened segments also indicate that segments have not been randomly widened.<sup>23</sup> Road capacity was increased through widenings in order to reduce time delays due to bottlenecks present during peak hours: widened segments have higher travel times during peak hours before the widening (about 50 seconds per kilometre) compared to segments that have not been treated (about 44 seconds per kilometre), but this is not true for travel times averaged over the day, as daily travel times are about equal for widened and non-widened segments (equal to about 39 seconds per kilometre). This observation is key input for our welfare analysis. It suggests that the Dutch government has widened highway segments where the economic benefits of widenings are potentially the largest.

Table 1 middle and right panel reports descriptive statistics for traffic activity at the level of the region – for the main analysis as well as the analysis where we include observations nearby (within 20 km) two greenfield highways – for the

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<sup>22</sup>We focus on these specific moments, because only then we have full information for all widenings. For example, 6 years after the widening, we only have information about 5 of the 16 widenings.

<sup>23</sup>We have already noted that most widenings occur in the west of the Netherlands, where most economic activity takes place.

Table 1: Data descriptives traffic outcomes, 2011-2019

	Widened segments		Main analysis		Greenfields nearby	
	3 yr before	2 yr after	2011	2019	2011	2019
Number of lanes	4.39 (0.86)	6.51 (1.14)				
Lane kms radius 0-20km			622.45 (143.09)	689.02 (180.36)	735.02 (206.85)	810.88 (247.27)
Travel time 7:00-9:00h	50.60 (30.93)	37.50 (18.58)	44.28 (17.29)	43.55 (15.43)	44.62 (17.84)	43.92 (14.89)
Travel time 6:00-10:00h	45.04 (21.43)	36.91 (28.59)	41.55 (12.09)	41.00 (10.94)	42.01 (12.72)	41.50 (10.81)
Travel time 5:00-21:00h	39.88 (9.62)	36.33 (27.94)	39.11 (7.18)	39.33 (6.86)	39.78 (7.62)	40.14 (7.43)
Travel flow 7:00-9:00h	3.26 (1.00)	4.01 (1.34)	2.71 (1.14)	3.16 (1.35)	2.93 (1.35)	3.30 (1.45)
Travel flow 6:00-10:00h	2.87 (0.92)	3.40 (1.18)	2.39 (1.04)	2.82 (1.23)	2.59 (1.22)	2.95 (1.30)
Travel flow 5:00-21:00h	2.46 (0.85)	2.80 (0.96)	2.03 (0.81)	2.37 (0.96)	2.20 (0.96)	2.49 (1.04)
Number of segments	16		69		122	
Number of detectors	193		1401		2558	

*Notes:* We show means and standard deviations *per detector*. Number of lanes is in both directions. Travel time is measured in seconds per kilometer. Travel flow is measured in 1000 vehicles per hour.

beginning (2011) and the end of the observation period (2019).<sup>24</sup> It shows a strong increase in lane kilometres because of widenings: lane kilometers increase by about 10% between 2011 and 2019.<sup>25</sup>

<sup>24</sup>We focus on regions that may have received several widenings with substantial variation in the increase in lane kilometres. Therefore, it is insightful to provide descriptive information about the beginning (2011) and the end of the observation period (2019) and less informative to use "event study" types of figures such as Figure 4.

<sup>25</sup>This table also shows slight decreases in peak hour travel time over this period, with

### 4.3 Empirical model and identification

We denote our two traffic measures — log travel time per kilometer and log flow — at a (traffic detector) location  $l$  of an area  $s$ , in month  $t$  by  $V_{lst}$ . An area can either refer to a segment or a region (which contains locations within 20 km of location  $l$ ). To examine the dynamic effects of widenings on traffic within an area, we use a distributive lag specification:

$$V_{lst} = \sum_{L=-3}^6 \alpha_L H_{s,t-12L} + \delta_l + \phi(t) + \xi_{lst}, \quad (1)$$

where  $H_{s,t-12L}$  denotes the log of highway lane length in area  $s$  in the month  $t-12L$ , where  $L$  denotes a year;  $\delta_l$  denotes detector fixed effects;  $\phi(t)$  denotes year and month-of-the-year fixed effects and  $\xi_{lst}$  is an error term. We emphasise that the above specification allows the effects of widenings to depend on the elapsed number of years after the widening. The latter is important, because a *sudden* increase in traffic demand immediately after the widening makes the estimation strategy more convincing as it deals with reverse causality.<sup>26</sup> Note that in (1) we account for the effects of construction works in the three years before the widening by including lead variables:  $H_{s,t+12L}$ ,  $H_{s,t+24L}$  and  $H_{s,t+36L}$ .<sup>27</sup>

We are interested in the effect of widenings on travel time per kilometre *per motorist*. For that reason, the effect of widenings on travel time are estimated using a weighted regression, with weights based on the (time-invariant) average flow per traffic detector, where the average is taken over the whole study period.

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increases in travel time over the full day and considerable increases in flow particularly during the peak. Clearly, the latter information is not indicative of a causal effect of widenings, for example because it ignores autonomous time trends.

<sup>26</sup>In the absence of sudden increases in traffic demand, an alternative estimation strategy would be to rely on shift-share methodologies that exploit historic instruments, see e.g. [Baum-Snow \(2007\)](#) and, recently, [Garcia-Lopez et al. \(2021\)](#). These methodologies are particularly appropriate for large distinct geographical areas (e.g. countries within Europe, states within the US), but less so for small overlapping geographical areas such as observed in the Netherlands. The main advantage of our method is that we do not have to rely on assumptions regarding the exogeneity of instruments.

<sup>27</sup>We have attempted to identify the effects of nonlocal construction roadwork, but they appear too small to be detected, and are therefore ignored.

We will estimate  $\alpha_L$  which is the elasticity of the traffic outcomes with respect to highway lane length  $L$  years after the widening, conditional on highway length in other years. We are however mainly interested in the widenings' cumulative effect  $M$  years after a widening. For this purpose, we report  $\sum_0^M \alpha_L$  for values of  $M$  from 0 up to 6.<sup>28</sup> We report standard errors clustered at the segment level  $s$  and run robustness checks with HAC standard errors which allow for arbitrary correlation of residuals over space (both yield very similar results).

The above empirical strategy is essentially a two-way fixed effects, where we include year, month-of-the-year and location fixed effects, which rely on a common trends assumption. As highways are widened because of travel delays, it is possible that this assumption does not hold, i.e., it may be the case that the trend in travel delays and flow differs between widened and nonwidened highways. To deal with this, we will include only highway segments that are within 20 km of segments that are widened at least once. Hence, the identifying assumption of common trends is relaxed.

It is plausible that the effects of widenings strongly differ over the day: widenings are usually motivated by travel delays during peak hours, so they are expected to have the largest travel time reducing effects in the peak, and smaller effects during the rest of the day. Furthermore, given these reductions in travel time, one expects that motorists will substitute their chosen travel hour during the day towards the peak. We therefore distinguish between three time windows following definitions of the Ministry of Infrastructure and Water Management: 7:00-9:00 (narrow morning peak), 6:00-10:00 (broad morning peak), and 5:00-21:00 (whole day).

## 4.4 Empirical results

### 4.4.1 Local effects

We here focus on the local effects of widenings, so at the segment level. Table 2 reports the estimated results for the effect of a local increase in highway supply

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<sup>28</sup>The full results are reported in Appendix B.

on travel time as well as on flow in the  $L$ th year after the widening.<sup>29</sup>

The widenings have immediate large effects. For example, immediately after the opening, travel time during the narrow peak (7:00-9:00) decreases by about 50%, whereas travel demand increases by about 35%.

It appears that widenings also have persistent effects on local traffic. For the full day (between 5:00-21:00), the elasticity of travel time with respect to highway supply is  $-0.54$  after 6 years. During peak hours, the elasticity of travel time is approximately the same, but only for the first years after the widenings are the elasticities precisely estimated. We find also very strong effects of highway supply on travel flow with an elasticity of about 0.2 for the full day, and a somewhat larger elasticity during the peak. The latter estimated effects are highly statistically significant up to 5 years after the opening. Only in the last year, standard errors become large, because we do not have enough widenings to estimate the effects precisely.

These results provide insight into various behavioural substitution mechanisms that are at play. First, a strong increase in travel flow is in line with motorists' substitution from other routes (and potentially the overall increase in car travel demand). Second, the increase in out-of-peak flow is less than those during the peak, providing evidence for substitution within the day (Arnett et al. (1990, 1993); Small et al. (2005)). In other words, motorists reschedule their travel to the peak times as the latter become less congested.

Above estimates are also politically important. They show that highway widenings are *locally* extremely effective in reducing travel delays. This explains why highway widenings are a popular tool for politicians who aim to address congestion (Glaeser and Ponzetto, 2018), whereas road pricing is not popular at all, as most motorists are worse off (Russo, 2013).

To improve our understanding into the substitution effects within a day, we estimate the travel time and flow elasticity for each hour of the day. Figure 5, which shows these results for the 4th year after the opening, supports the above

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<sup>29</sup>Appendix B reports the  $\alpha_L$  of Equation (1). Appendix C reports a sensitivity analysis with HAC standard errors. Figure E1 reports the results by segment.

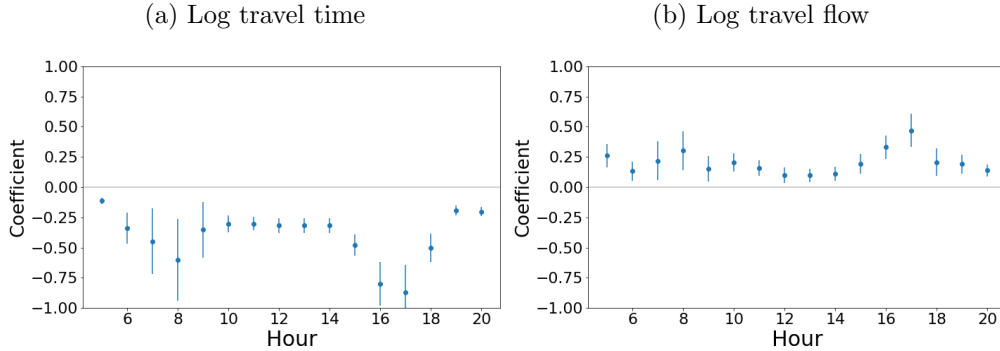
Table 2: Traffic effects on widened segments

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.543*** (0.094)	-0.444*** (0.066)	-0.319*** (0.041)	0.344*** (0.069)	0.263*** (0.059)	0.240*** (0.048)
1 yr after	-0.500*** (0.150)	-0.400*** (0.117)	-0.334*** (0.052)	0.322*** (0.081)	0.262*** (0.060)	0.230*** (0.056)
2 yrs after	-0.498** (0.199)	-0.428*** (0.166)	-0.379*** (0.075)	0.365*** (0.104)	0.298*** (0.073)	0.241*** (0.071)
3 yrs after	-0.531** (0.255)	-0.440** (0.209)	-0.419*** (0.090)	0.337*** (0.118)	0.267*** (0.087)	0.224*** (0.083)
4 yrs after	-0.511 (0.313)	-0.418 (0.266)	-0.450*** (0.108)	0.265* (0.154)	0.218** (0.110)	0.216** (0.098)
5 yrs after	-0.552 (0.389)	-0.479 (0.334)	-0.534*** (0.136)	0.327* (0.177)	0.262** (0.115)	0.223** (0.107)
6 yrs after	-0.434 (0.436)	-0.392 (0.381)	-0.541*** (0.162)	0.201 (0.223)	0.166 (0.150)	0.166 (0.120)
Detector FE (193)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	18761	18782	18780	18761	18782	18780
$R^2$	0.289	0.327	0.457	0.473	0.413	0.576

*Notes:* The independent variable is log lane kilometers. We cluster standard errors at the segment level. Standard errors are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

insights. All travel time elasticities are negative, and the effects are most pronounced during the (evening) peak. For flow, the variation in the effects over the hour of the day is less pronounced, but also here we see stronger increases during the (evening) peak.

Figure 5: Hourly elasticities, widened segments, 4 years after widening



#### 4.4.2 Regional effects

Table 3 reports the effects of widenings at the level of the region.<sup>30</sup> The results show large and persistent reductions in travel time in the region, with an elasticity of around  $-0.70$  in the 6th year after the widening. During peak hours, the travel time effects are the largest in the first year after the widening, and decrease by one third after, in line with the increasing travel demand. For the full day, the decrease in travel time is much less notable.

Widenings have a strong positive effect on travel flow. The size of the estimated effects increases in the first three years and then stays approximately the same. This result is consistent with the idea that induced demand is a gradual process, as it takes time for households and firms to re-optimize their location and travel patterns, for which we show evidence later on (Section 6). There are substantial increases in travel demand during the narrow peak, with an elasticity of about one (1.03) 6 years after the widening. Interestingly, the null hypothesis of a unit elasticity cannot be refuted already 1 year after the widening (with an estimate of 1.06). For the whole day, the effect is half as large with an elasticity of 0.52, so below one.

To improve our understanding of the substitution effects occurring within

<sup>30</sup>Appendix B reports the  $\alpha_L$  of Equation (1). We have also estimated models with other specifications, including linear models (see Appendix D.) Linear specifications yield similar implied elasticities. This result is relevant as for linear models, estimates at the individual detector level can be interpreted as estimates at the aggregate level.

Table 3: Traffic effects region

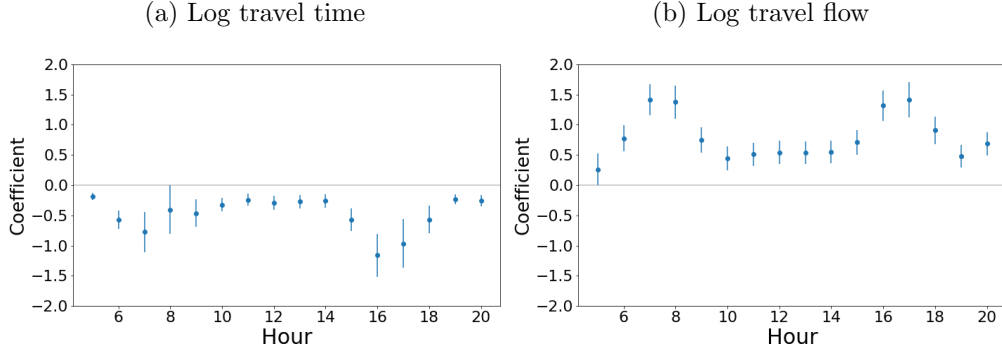
Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.930*** (0.359)	-0.814*** (0.268)	-0.500*** (0.161)	0.225 (0.155)	0.088 (0.130)	-0.001 (0.115)
1 yr after	-1.332*** (0.474)	-1.192*** (0.370)	-0.848*** (0.252)	1.064*** (0.257)	0.772*** (0.218)	0.560*** (0.182)
2 yrs after	-1.134** (0.525)	-1.036** (0.402)	-0.779*** (0.264)	1.267*** (0.298)	0.975*** (0.256)	0.699*** (0.219)
3 yrs after	-0.804 (0.555)	-0.786* (0.428)	-0.550** (0.242)	1.093*** (0.274)	0.826*** (0.234)	0.524*** (0.196)
4 yrs after	-0.846 (0.596)	-0.801* (0.451)	-0.564** (0.267)	1.119*** (0.300)	0.850*** (0.261)	0.625*** (0.220)
5 yrs after	-0.962 (0.596)	-0.903** (0.456)	-0.652** (0.269)	1.030*** (0.306)	0.763*** (0.261)	0.434* (0.222)
6 yrs after	-0.785 (0.589)	-0.781* (0.452)	-0.680** (0.293)	1.029*** (0.345)	0.774*** (0.295)	0.515** (0.252)
Detector FE (1403)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	140534	139789	140825	140534	139789	140825
$R^2$	0.109	0.119	0.162	0.162	0.168	0.179

*Notes:* The effects on travel time are estimated using a weighted regression, with weights based on the (time-invariant) average flow, where the average is taken over the whole study period. Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

a day, we again estimate the effects on travel time and flow elasticities by the hour of the day for the 6th year after the widening. The effects by hour of the day reported in Figure 6 support the insights from Table 3. The travel time elasticities are negative and statistically significant for all hours of the day, with the effect being more pronounced during the peak hours, particularly the evening peak. Correspondingly, the flow elasticities are positive, and much higher during



Figure 6: Hourly elasticities, region, 6 years after widening



the morning and evening peak.

We have argued above that highways within regions tend to be complementary, and not substitutes. To examine this, we have re-estimated the models at the regional level (i.e. within 20 km of the widening), where we exclude segments that have been widened. These results can be found in Table E1 of Appendix E. The estimated flow elasticities of widenings are shown to be positive, and somewhat smaller than those reported in Table 3. This indicates that highways within regions are highly complementary, so highways feed into each other.

Widenings aim to remove bottlenecks within networks, but they may induce new bottlenecks in other parts of the network where demand has increased. If this is the case, then travel times in other parts of the network should increase. In contrast, the removal of a bottleneck of a certain segment may reduce travel time of nearby segments when queues extend to other segments. We test for these hypotheses by examining the effects of widenings on travel time in nearby segments (see Table E1 of Appendix E). It appears that the effect of widenings is negative (and statistically significant for the first three years). This strongly suggests that widenings did not cause new bottlenecks in other parts of the network.

Summarizing, our results imply that widenings reduced congestion in the short run (within 6 years). This reduction occurred on the widened segment by resolving the bottleneck, but also improved traffic conditions on complementary highways. Although the widenings induced an increase in traffic, this was by

far not strong enough to eliminate the travel time benefits. This insight is important and compliments previous studies that focus on the long run effect of highways showing that highways do little or nothing to reduce travel time. Our results suggest the presence of short-run benefits that may justify the widenings investment costs, even if the time savings should disappear in the long run. In Section (5), we will discuss the size of the welfare cost of widenings, allowing us to calculate the welfare effects of widenings.

#### 4.4.3 Sensitivity analyses

We have subjected our results to a range of sensitivity analyses such as the calculation of the standard errors, the functional form, the definition of the region, the chosen subsample, the inclusion of additional time trend control variables and including detectors that lie within 20 km distance from the two greenfield highway links.

In Appendix C, we re-estimate models with HAC standard errors. It appears that standard errors are very similar. In Appendix D, we re-estimate the effects using a linear specification of regional travel time and number of kilometres rather than a log-log specification. It appears that specifications yield similar implied elasticities, if we use the means of the variables. This result is relevant as for linear models, estimates at the individual detector level can be interpreted as estimates at the aggregate level, whereas this result does not hold for log-log models. Consequently, our estimates seem to hold at different levels of aggregation.

We have re-estimated all models using a different definition for region (Appendix F). To be more precise, in Table F1 we have examined the effects on traffic outcomes within 10 km of a widening (rather than within 20 km of a widening). The flow elasticities of widenings within 10 km are the same, but the travel time elasticities are larger.

We have also re-estimated all models by including the full sample for the Netherlands, rather than a sample of detector observations within 20 km of a widening, almost quadrupling the number of observations. The results are

reported in Table F2 of Appendix F. Point estimates of the effects on flow are somewhat larger and of travel time somewhat smaller. However, they do not show a statistically significant difference with the baseline results.

Assumptions about the underlying time trend are fundamental to our analysis. We have therefore re-estimated the models by including a linear time trend interacted with province (in the Netherlands there are 12 provinces, but treated areas include only 6 provinces), see Appendix E. It appears that the results for the first 4 years after the widening are extremely robust, but point estimates for the years after are noninformative, because of large standard errors. This makes sense as we have fewer observations after 6 years. Both, the results for the detectors within 20 kilometers from the treated segments and the results for the whole country, are robust.

Table E3 reports the effects of widenings when also including the detectors that lie within 20 km distance from the two greenfield highway links (see Figure 3, left panel). The results show large and persistent reductions in travel time in the region, with an elasticity of around  $-0.6$  in the 6th year after the widening. The elasticity is very close to that obtained before, also the dynamic effects are the same. During peak hours, the travel time effects are the largest in the first year after the widening, and decrease by one third after, in line with the increasing travel demand. For the full day, the decrease in travel time is much less notable. The point estimate of the effect on flow is now larger, but the difference is not statistically significant. Furthermore, we do not reject anymore the null hypothesis of unity elasticity for the full day. Finally, we have repeated all previous sensitivity analyses for the latter sample. It appears that we come to the same conclusion when we include observations of these greenfield highway links (results can be received upon request).

## 5 Welfare effects

In this section, we apply the results of the above analysis to compute the welfare effects of the widenings that opened between 2013 and 2018. We focus on the short-run benefits, i.e. benefits that occur during the first 6 years after the

widenings. So we limit our calculation to provide an estimate of which share of the widenings costs is covered by the short-run benefits.

In the cost-benefit calculation, we account for investment and maintenance costs, travel time benefits and the benefits from rescheduling. Further, we include the travel time losses on widened segments during construction and allow for the benefits from improved reliability of the travel time (Small et al., 2005).<sup>31</sup>

## 5.1 Theory

Let us compute the daily consumer surplus effect per detector  $l$  due to *travel time gains* in year  $y$  after a widening within the region (i.e. within 20 km of  $l$ ), denoted by  $\Delta W_l(y)$ . For now, we ignore rescheduling within the day, consequently we ignore differences between peak and nonpeak hours demand. We assume that the daily demand function can be approximated by a linear function, which allows for the following approximation:

$$\Delta W_l(y) = [V_{l0}(y)(t_{l0}(y) - t_{l1}(y)) + 0.5(V_{l1}(y) - V_{l0}(y))(t_{l0}(y) - t_{l1}(y))]VOT, \quad (2)$$

Here  $t_{l0}$  and  $t_{l1}$  refer to observed (before widening) and counterfactual (with widening) travel times respectively.  $V_{l0}$  and  $V_{l1}$  refer to observed respectively counterfactual daily travel flows multiplied with the highway length in kilometers covered by a specific detector. Counterfactual variables are calculated in the year of the widening ( $y=0$ ) and each of the six subsequent years, using the point estimates. VOT refers to the value of time per car.

The first term  $V_{l0}(y)(t_{l0} - t_{l1})$  reflects the welfare benefits due to shorter travel times, for motorists who used the route before the widenings. The second term,  $0.5(V_{l1} - V_{l0})(t_{l0} - t_{l1})$  reflects the (smaller) travel time benefits due to the

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<sup>31</sup>We exclude the effect of widenings on local environmental quality. An increase in highway travel generally suggests a negative welfare effect. Note that previous studies on greenfield highways shows that this needs not necessarily be the case, as new highway construction may yield substantial benefits from relieving local streets from through traffic (Ossokina and Verweij, 2015). We also ignore the travel time losses during construction which may occur on adjacent segments as these are likely small.

widenings-induced increase in travel demand.<sup>32</sup>

One may extend the above calculation by allowing for *hourly* rescheduling within the day, as we have hourly observations. However, it appears that the additional benefits of rescheduling within the day are almost negligible, so this issue is further ignored.

The annual welfare effect is then calculated by multiplying  $\Delta W_l$  with the number of days in a year, denoted by  $d$ , and by summing the effects over all detectors. We will discount the future at the discount rate  $\rho$ . The present value of the total welfare effect,  $\Delta W$ , is therefore calculated as follows:

$$\Delta W = \sum_y \frac{1}{(1 + \rho)^y} \Delta W(y) = \sum_y \frac{d}{(1 + \rho)^y} \sum_l (\Delta W_l(y)). \quad (3)$$

## 5.2 Numerical assumptions

We calculate the present value of the welfare effects of the widenings using a discount rate of 2.25%, which is the prescribed discount rate in the Dutch cost-benefit analyses of transportation investments. We allow for an autonomous increase in flow as implied by the estimates in Table 3.<sup>33</sup> Construction cost per lane are assumed to be 5 million euro per lane kilometer.<sup>34</sup> After the opening of a widening, yearly maintenance costs are equal to 2% of the investment costs (according to the rules used by the Ministry of Infrastructure and Water Management). The time savings and induced demand for the first 6 years after the widening are calculated based on the estimated effects from Table 3. Finally, we assume that the welfare benefits of the widenings only apply to working days, thus ignoring the benefits in the weekends. As congestion in the weekends is

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<sup>32</sup>Given a linear demand curve, these benefits are valued to be equal to a half of the benefits from time savings. See for derivation e.g. TRB (2017), Appendix A.

<sup>33</sup>It appears that there is growth in each year; over the period 2011-2019, the accumulated growth is about 15%.

<sup>34</sup>The costs per lane kilometer are derived from two-lane widening estimates provided by the Ministry of Infrastructure and Water Management for 110 km that are planned for the coming years. Note that widenings are much cheaper than greenfield construction. The cost of a lane kilometre of a widening is roughly 1/4 of the cost of a greenfield extension.

Table 4: Descriptives of observed (before widening) and counterfactual outcomes

	Before widening		6 y. after widening	
	(observed)		(counterfactual)	
	mean	st. dev.	mean	st.dev.
Lane kms within 20km	727.37	(210.66)	780.54	(226.89)
Travel time per km	41.33	(5.04)	40.06	(4.91)
Vehicles per hour	2.18	(0.73)	2.27	(0.83)

*Notes: Descriptives per detector. Vehicles in thousands. Travel time in seconds.*

much less than during workdays, this is unlikely to be fundamental. The number of working days in a year is assumed to be 256.

To translate time savings into welfare benefits, a value of time per car of 20 euro/hour is used (similar to [Adler and van Ommeren \(2016\)](#), average over different travel motives). We also include reliability benefits (see e.g. [Small et al. \(2005\)](#)), arising due to a decrease in variation in expected travel time after the widening. Based on the values of the reliability ratio reported in several Dutch Cost-benefit analysis of highway investments, we approximate the reliability benefits to be equal to 10% of the time savings. For the calculation of the benefits, we take a time horizon of 6 years. Finally, we assume that the excise duties and other indirect fuel taxes are set optimally, so that the marginal excise tax on gasoline exactly equals the external effect of an additional kilometer travelled.<sup>35</sup> Furthermore, we ignore other tax distortions, such as subsidies to company cars, free parking et cetera.

### 5.3 Welfare outcomes

Table 4 reports the descriptives of the observed traffic outcomes (“before widening”) and counterfactual traffic outcomes (“6 years after a widening”) per loop detector. It shows that the widenings resulted in an increase from 727 to 780

<sup>35</sup>Existing Dutch Cost-benefit Analyses of highway investments suggest that the excise duties are higher than the external effects of kilometers travelled in the Netherlands, this would imply that we underestimate the benefits.

Table 5: Welfare effects widenings after 6 years.

(i)	Travel time savings	836
(ii)	Reliability benefits	84
(iii)	Benefits from rescheduling	25
(iv)	Time losses due to construction	-35
	Total travel time benefits after 6 years	909
(v)	Investment cost	1970
(vi)	Maintenance cost	250
	Total cost after 6 years	2220
	Total benefits minus costs after 6 years	-1311

*Notes: Net present value in mln euro is reported.*

lane kilometres within a 20 km radius per detector, so by about 7%. In total, about 400 new lane kilometres were constructed, resulting in an investment of about 1970 million euro. This leads to a counterfactual 3% decrease in the travel time (from 41.3 seconds per kilometer to 40.1 seconds per kilometer) and a counterfactual induced demand of 4% (from 2180 to 2270 cars per hour).

Table 5 reports the welfare effects from widenings, based on the estimated effects from Table 3. The maintenance costs over 6 years are calculated to be about 250 million euros, so the total investment and maintenance costs are about 2220 million euros. The accumulated benefits after 6 years are worth about 909 million euros, which predominantly consist of time savings. This implies that about 40% of the investment and maintenance costs are recovered within the first 6 years after the widening.<sup>36</sup>

<sup>36</sup>We can only speculate about the welfare implications in the long run. One plausible scenario is to assume that the fundamental law of road congestion holds in the long run, e.g. 20 years, such that the time savings disappear and induced-demand increases in proportion to the extended road lanes. Given this scenario, our estimates imply that the average widening has not been welfare beneficial. Another, arguably less plausible, scenario is to assume that the estimates do not change after 6 years. In that case, the average widening is welfare beneficial after about 20 years.

## 6 Economic activity and spatial structure

Widenings are thought not only to reduce travel time, but also affect wider economic activity and therefore spatial structure of employment and population. These effects have been ignored in the above welfare analysis, which was essentially based on a partial equilibrium assumption of a given spatial structure of employment, ignoring for example economic advantages related to agglomeration (Lucas and Rossi-Hansberg, 2002).

We emphasise here that the widenings examined above are at locations *between* large employment centres, and hardly within large employment centres. In such a setting, reductions in travel time provide incentives to households to move to these locations (to take advantage of low house prices as commuting times have dropped) inducing local population growth. Furthermore, these reductions in travel time, as well as these relocations of population, give incentives to firms to relocate to these locations inducing local employment growth. Due to these relocations, widenings will reduce economic activity further away from widenings, particularly at (competing) locations that are relatively nearby, so changes in agglomeration will occur (Lucas and Rossi-Hansberg, 2002; Teulings et al., 2018).

A priori, one expects that the effects of widenings on wider economic activity and spatial structure will be quite different from the effects of *greenfield* highways which has been studied intensively starting with the seminal studies by Baum-Snow (2007, 2010). In particular, as emphasised in the introduction, one expects these effects to be much smaller, and to occur mainly locally. To verify this, we will also aim to estimate the (short-run) effects of widenings on economic activity and spatial structure (employment, population, commercial floor space, residential floor space) at a low aggregation level (four-digit zip code areas which cover about one square kilometre, on average).

To account for possible endogeneity, we focus only on locations that experienced a widening in their proximity (within 10 km). Our main threat to identification is that widenings occur at locations where governments expect changes in



economic growth. To deal with this, in the regression analyses, we shall control for spatial trends at a low level of aggregation, to account for continuous shifts in local transportation demand. More importantly, although governments may be aware at which locations the economy will grow, and may even plan the building of certain housing stock commercial space at certain locations, it is impossible for governments to control the exact year of highway openings, so the exact year of the widening can be considered as good as random.

### 6.1 Empirical model and identification

We examine the effect of widenings on economic activity within vicinity using annual information on employment, population, commercial floor space and residential floor space per zip code area. Zip code areas are small and part of larger regions. Hence, for each zip code area  $i$ , located in region  $j$  in year  $t$  we observe economic activity, denoted by  $Q_{ijt}$ . The changes in highway supply within vicinity of an area induced by widenings are captured by increases in lane kilometres within a given radius. Here, we will focus on changes within 10 km of the area.

To examine the effects of widenings in the year  $t - L$  on economic activity in the year  $t$ , we use a dynamic specification similar to (1):

$$Q_{ijt} = \sum_{L=-4}^6 \alpha_L^0 H_{it-L}^{0-10} + \gamma_i + \theta_t + \tau_j t_t + \epsilon_{ijt}, \quad (4)$$

where  $H_{it-L}^{0-10}$  denotes the log of highway lane kilometres within 10 km.  $Q_{ijt}$  refers to the logarithm of employment, population, commercial and residential floor space respectively. We let  $L$  vary from -3 until +6 years.<sup>37</sup>

Furthermore, we will distinguish between changes within 10 km, as well as nearby – within 5 km – of the area, as well as further away – between 5 and 10

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<sup>37</sup>As an alternative, one may use residential and firm market access, as used for example in Tsivanidis (2018), which can speak to the welfare implications more directly. The main advantage of our approach is that we do not have to specify the travel time gains between locations (which differ from the travel time gains measured by us for regions), the size of the geographical market as well as the distance decay within this market. Consequently, we impose less structure on the data.

km. Hence, we estimate:

$$Q_{ijt} = \sum_{L=-4}^6 \alpha_L^1 H_{it-L}^{0-5} + \sum_{L=-4}^6 \alpha_L^2 H_{it-L}^{5-10} + \gamma_i + \theta_t + \tau_j t_t + \epsilon_{ijt}, \quad (5)$$

where  $H_{it-L}^{0-5}$  and  $H_{it-L}^{5-10}$  denote the log of highway lane kilometres within 5 km and between 5 to 10 km, respectively.

We are mainly interested in the effects of  $\alpha_L^i$ ,  $i = 0, 1, 2$  for  $L \geq 0$ . We concentrate here on the cumulative effect 6 years after the widening,  $\sum_{L=0}^6 \alpha_L^i$ , and the effect in the 3 years before the widening to test for the presence of pre-trends.<sup>38</sup>

The main underlying assumption of the above approach is that the timing of the widening is exogenous, i.e. not correlated with  $\epsilon_{ijt}$ , and is not accompanied by other confounding factors occurring at the same moment. Therefore, similar to (1), we also include year dummies  $\theta_t$  and zip code fixed effects  $\gamma_i$ . As explained in Section 2, the Dutch institutional setting implies that precisely timing of widenings is not possible, which suggests that the estimates are causal. Nevertheless, one relevant additional control variable we include here is that we also include *region-specific* time trends  $\tau_j t_t$ , where a region contains, on average, only 3 zip codes. This control variable is important, if one is still worried that highways are widened because regions are expected to grow. Finally, the error term is denoted by  $\epsilon_{ijt}$ .

Another possible concern is the presence of alternative policies that came into effect during our sample period, or other confounding factors. Because in our data there are more than 30 widenings, varying considerably in terms of the opening year and the geographical location, it is very unlikely that all the widenings were in the same way affected by the same confounding variable.

We believe that the main threat to identification is unobserved time-varying variables that positively covary with the widening. We will however show that within 10 km none of the estimated effects is statistically significant, despite that

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<sup>38</sup>The coefficients for 3 years before are reported in Appendix G, together with the full estimates.

we estimate 8 coefficients. This strongly suggests, that within 10 km, this threat to identification is likely not of concern. In contrast, we find evidence of positive effect within 5 km and negative effects between 5 to 10 km. In particular the latter is difficult to explain by the presence of unobserved time-varying variables.

## 6.2 Data on economic activity

To estimate the effect of widenings on broader economic activity, we use a range of annual data from different sources all available per (4-digit) zip code area for the period 2000-2011. These areas are quite small and cover, on average, approximately 1 square kilometer.<sup>39</sup> Economic activity data include *employment* (provided by LISA, a company collecting firm level data) and *population* (provided by Statistics Netherlands). We also have information on *real estate floor space* and *residential floor space* (which is derived from BAG micro data provided by Statistics Netherlands). We restrict our analysis to areas within 4 kilometres of a highway ramp (we also experimented with other distances).

Table 6 reports descriptive statistics of the sample. We focus on the period between 2000 and 2011. During this period, areas in question observed an increase of about 15% additional lane kilometres within a radius of 5 km and 10% within a radius of 5 to 10 km, due to widenings. It is further noted that employment, measured in number of employees, as well as commercial floor space, measured in square metres, experienced a much stronger increase than population and residential floor space.

## 6.3 Results

We now discuss the effects of widenings on economic activity. Tables 7 and 8 summarise the estimates of (4) and (5), showing the accumulated effects six years after the widening. Appendix G reports the results for the three years before. It appears that there are no statistically significant trends in economic activity before the widening, supporting the underlying assumption of no trends.

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<sup>39</sup>A 4-digit zip code area contains about 2000 dwellings.

Table 6: Descriptive statistics economic activity, 2000-2011

	Employment, commercial floor space				Population, residential floor space			
	2000		2011		2000		2011	
	mean	st.dev.	mean	st.dev.	mean	st.dev.	mean	st.dev.
Lane kms 0-5km	77.35	(40.9)	89.84	(44.22)	74.71	(40.44)	86.91	(43.85)
Lane kms 5-10km	161.35	(81.58)	178.74	(86.77)	155.6	(81.0)	172.58	(86.45)
Lane kms 0-10km	238.7	(110.03)	268.57	(115.8)	230.3	(109.79)	259.47	(116.36)
People (x1000)	3.05	(3.85)	3.45	(4.27)	5.54	(4.39)	5.77	(4.48)
Floor space (m <sup>2</sup> x1000)	104.07	(147.45)	131.56	(189.44)	251.86	(190.45)	282.81	(210.46)
Number of zip codes	559		559		596		596	

Table 7: Elasticity of employment and commercial floor space

Dependent	Log commercial floor			Log employment		
	0-10 km	0-5 km	5-10 km	0-10 km	0-5 km	5-10 km
6 yrs after	0.137	0.273*	-0.215	0.066	0.236**	-0.207
	(0.142)	(0.147)	(0.144)	(0.136)	(0.105)	(0.163)
Zip code FE	559		559	559		559
Year FE	12		12	12		12
Observations	6707		6707	6707		6707
$R^2$ within	0.36		0.36	0.24		0.24

*Notes:* Standard errors are in parentheses. \*, \*\*, \*\*\*, indicate 10%, 5%, 1% significance, respectively.

Our results imply that, after a widening, there is no statistically significant overall effect on economic activity within a 10 kilometre radius of the highway. In contrast, we document a positive highway lane supply elasticity of employment and commercial real estate within 5 kilometers and an opposite, negative, impact, with an elasticity of comparable size (in absolute value) at a further away distance. This strongly suggests that commercial space and employment relocate to the direct vicinity of the highway (0 to 5 km) from somewhat further away locations (5 to 10 km). Hence, this suggests a local relocation of employment to

Table 8: Elasticity of population and residential floor space

Dependent	Log residential floor			Log population		
	0-10 km	0-5 km	5-10 km	0-10 km	0-5 km	5-10 km
6 yrs after	0.081 (0.071)	-0.022 (0.071)	0.117 (0.118)	0.091 (0.112)	0.071 (0.189)	-0.007 (0.205)
Zip code FE	596		596	596		596
Year FE	12		12	12		12
Observations	7130		7130	7130		7130
$R^2$ within	0.31		0.31	0.18		0.18

*Notes:* Standard errors are in parentheses. \*, \*\*, \*\*\*, indicate 10%, 5%, 1% significance, respectively.

places with lower travel times (better accessibility).

Our results seem to differ from estimates obtained for greenfield highways. For example, Moeller and Zierer (2018) find for Germany that a one-standard-deviation increase in the growth of autobahn length between 1937 and 1994 led to employment growth of between 2.7 and 3.4% in the region where the highways were realised. In contrast to their findings, we do not document any effect for regions of 10 kilometers around the highway, but only evidence for substitution *within* the region. For population and housing, we do not find any statistically significant effects.

In summary, we do provide evidence that highway widenings restructure local employment, but we do not have any support for the claim of employment growth at a more aggregate level. We do not find any effects for population.

## 7 Conclusions

This paper analyses the short-run effects of highway widenings – adding new lanes to existing corridors – on congestion and traffic demand. We document that in the Netherlands highway widenings take place on most congested corridors and immediately and substantially reduce travel times both on the widened segment and in the wider region. The effect turns to be persistent up to 6 years after

a widening and takes place despite the strong increase in travel demand which we also document. Widenings furthermore induce changes in trip scheduling, as the proportion of motorists travelling during the peak strongly increases. We provide evidence that the time saving benefits induced by widenings cover about 40% of the widenings' cost within 6 years. Our paper is the first to shed light on the short-run effects of the widenings and provides a possible explanation of why the widenings are a frequent policy measure chosen to deal with congestion. Our findings on the presence of short-run time saving benefits complement the literature by enriching the existing knowledge that documents the fundamental law of congestion for the long run ([Duranton and Turner, 2011](#); [Garcia-Lopez et al., 2021](#)).

Our welfare analysis is based on the assumption that spatial restructuring of the economy due to widenings is minor, i.e. agglomeration effects of widenings are small, hence the main welfare effects are through changes in travel demand and time savings. This assumption is supported by our data. We do not find any evidence that economic activity increases within 10 km of a widening. However, we provide evidence that highway widenings induce a local restructuring of economic activity: employment within 5 kilometres of the highway rises, while employment further away, between 5 and 10 kilometres, is reduced.

It is important to point out that our study focuses on widenings only, and our welfare results are unlikely to hold for greenfield highway construction. Widenings have two important characteristics which make them different from greenfield highway construction. First, the construction costs of widenings are much lower than of greenfield highways. Second, highway widenings are typically constructed to remove bottlenecks, which can be easily identified, and where latent demand is likely substantial. This makes it plausible that the return on investment of widenings that remove bottlenecks tends to be larger compared to greenfield construction where latent demand is more difficult to measure by public authorities.

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## A Appendix List of widenings

Table A1: Widenings (2013-2018) used to estimate effects on travel outcomes

Highway	Location	Opening date	Lanes before widening	Lanes added
A1	Eemnes	September 2018	4	4
A27	Utrecht Noord	September 2018	4	2
A4	Leidschendam	September 2018	6	2
A6	Muiderberg	January 2018	6	4
A1	Diemen	September 2016	8	2
A12	Maanderbroek	June 2016	4	2
A7	Zaandam	December 2015	4	2
A15	Rotterdam Benelux	December 2015	6	4
A8	Coenplein	September 2015	7	1
A15	Hoogvliet	September 2015	6	2
A1	Eembrugge	July 2015	4	6
A2	Vught	September 2013	4	2
A10	Amsterdam Amstel	September 2013	6	2
A28	Utrecht Uithof	July 2013	4	2
A28	Den Dolder	June 2013	4	2
A50	Valburg	May 2013	4	4

Table A2: Widenings (2000-2011) used to estimate effects on economic activity

Highway	Location	Opening year	Lanes before widening	Lanes added
A2	Oudenrijn	2011	7	1
A2	Nieuwegein	2011	6	2
A2	Everdingen	2011	4	2
A2	Holendrecht	2010	6	2
A2	Vugt	2010	4	4
A2	Empel	2010	6	2
A2	Ekkersweijer	2010	6	2
A9	Diemen	2010	4	2
A2	Leenderheide	2010	4	6
A2	Batadorp	2010	4	6
A2	Zaltbommel	2010	4	2
N31	Midlum	2008	2	2
N73	Ulingshiede	2008	2	2
N31	Werpsterhoek	2008	2	2
N37	Holsloot	2007	2	2
N35	Wierden	2007	2	2
A50	Schaarsbergen	2006	4	2
A50	Kampen	2006	2	1
A12	De Meern	2006	8	2
A2	Holendrecht	2005	6	2
A16	Zonzeel	2004	4	2
A16	Princeville	2004	4	2
A16	Klaverpolder	2004	4	2
N11	Bodegraven	2004	2	2
N30	Barneveld	2004	2	2
A15	Vaanplein	2003	8	2
A9	Raasdorp	2003	4	6
A4	Kethelplein	2002	4	5
A37	Oosterhesselen	2002	2	2
A37	Hoogeveen	2000	2	2
A4	Badhoeverdorp	2000	10	2
N11	Alphen aan de Rijn	2000	2	2

## B Appendix Full estimation results

Tables B1 and B2 report yearly coefficients from the main model.

Table B1: Yearly (incremental) elasticities, widened segments

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
3 yr before	0.205*	0.143*	0.023	-0.094	-0.064	-0.062
	(0.109)	(0.086)	(0.053)	(0.059)	(0.044)	(0.050)
2 yr before	0.096*	0.102**	0.061**	-0.103**	-0.059	-0.010
	(0.052)	(0.046)	(0.025)	(0.051)	(0.047)	(0.044)
1 yr before	-0.060	-0.037	-0.021	-0.026	-0.048	-0.095*
	(0.056)	(0.047)	(0.027)	(0.075)	(0.067)	(0.055)
yr widening	-0.543***	-0.444***	-0.319***	0.344***	0.263***	0.240***
	(0.094)	(0.066)	(0.041)	(0.069)	(0.059)	(0.048)
1 yr after	0.043	0.044	-0.015	-0.021	-0.001	-0.010
	(0.086)	(0.072)	(0.024)	(0.040)	(0.028)	(0.027)
2 yrs after	0.002	-0.027	-0.045	0.043	0.036	0.012
	(0.063)	(0.056)	(0.028)	(0.031)	(0.023)	(0.028)
3 yrs after	-0.033	-0.013	-0.039*	-0.028	-0.031	-0.017
	(0.059)	(0.047)	(0.020)	(0.032)	(0.026)	(0.021)
4 yrs after	0.020	0.023	-0.032	-0.072	-0.049	-0.008
	(0.073)	(0.062)	(0.026)	(0.046)	(0.035)	(0.025)
5 yrs after	-0.041	-0.062	-0.084***	0.062*	0.044*	0.007
	(0.081)	(0.072)	(0.032)	(0.035)	(0.026)	(0.016)
6 yrs after	0.118	0.087	-0.007	-0.125**	-0.096**	-0.056***
	(0.098)	(0.073)	(0.037)	(0.056)	(0.041)	(0.019)
Detector FE (193)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	18761	18782	18780	18761	18782	18780
$R^2$	0.289	0.327	0.457	0.473	0.413	0.576

Notes: Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table B2: Yearly (incremental) elasticities, region

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
3 yr before	-0.097 (0.363)	-0.176 (0.264)	-0.111 (0.160)	0.179 (0.179)	0.014 (0.154)	-0.134 (0.137)
2 yr before	0.643* (0.385)	0.421 (0.284)	0.148 (0.172)	-0.274 (0.234)	-0.292 (0.196)	-0.254 (0.174)
1 yr before	-0.181 (0.221)	-0.060 (0.173)	0.035 (0.104)	0.041 (0.166)	0.047 (0.152)	0.025 (0.139)
yr widening	-0.930*** (0.359)	-0.814*** (0.268)	-0.500*** (0.161)	0.225 (0.155)	0.088 (0.130)	-0.001 (0.115)
1 yr after	-0.402* (0.211)	-0.379** (0.171)	-0.348** (0.146)	0.839*** (0.207)	0.684*** (0.180)	0.561*** (0.146)
2 yrs after	0.198* (0.112)	0.156* (0.087)	0.069 (0.055)	0.203** (0.097)	0.203** (0.091)	0.139* (0.083)
3 yrs after	0.330** (0.155)	0.250* (0.131)	0.229*** (0.071)	-0.174* (0.102)	-0.149* (0.081)	-0.175*** (0.067)
4 yrs after	-0.041 (0.158)	-0.015 (0.113)	-0.014 (0.076)	0.026 (0.120)	0.024 (0.105)	0.102 (0.088)
5 yrs after	-0.116 (0.100)	-0.102 (0.079)	-0.088** (0.037)	-0.089 (0.080)	-0.087 (0.068)	-0.191*** (0.063)
6 yrs after	0.177 (0.135)	0.122 (0.107)	-0.028 (0.057)	-0.001 (0.090)	0.011 (0.078)	0.081 (0.063)
Detector FE (1403)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	140534	139789	140825	140534	139789	140825
$R^2$	0.109	0.119	0.162	0.162	0.168	0.179

Notes: Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

## C Appendix HAC standard errors

Tables C1 and Table C2 re-estimate models with HAC standard errors.

Table C1: Cumulative elasticities, widened segments, HAC errors

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.543*** (0.081)	-0.444*** (0.052)	-0.319*** (0.045)	0.344*** (0.084)	0.263*** (0.073)	0.240*** (0.061)
1 yr after	-0.500*** (0.149)	-0.400*** (0.115)	-0.334*** (0.055)	0.322*** (0.090)	0.262*** (0.069)	0.230*** (0.070)
2 yrs after	-0.498** (0.199)	-0.428*** (0.164)	-0.379*** (0.074)	0.365*** (0.111)	0.299*** (0.080)	0.241*** (0.084)
3 yrs after	-0.531** (0.250)	-0.440** (0.202)	-0.419*** (0.083)	0.337*** (0.126)	0.267*** (0.093)	0.224** (0.089)
4 yrs after	-0.511* (0.297)	-0.418* (0.251)	-0.450*** (0.099)	0.265 (0.174)	0.218 (0.133)	0.216* (0.121)
5 yrs after	-0.552 (0.362)	-0.479 (0.311)	-0.534*** (0.124)	0.327* (0.193)	0.262* (0.136)	0.223 (0.137)
6 yrs after	-0.434 (0.377)	-0.392 (0.334)	-0.541*** (0.152)	0.201 (0.238)	0.166 (0.169)	0.166 (0.154)
Detector FE (193)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	18761	18782	18780	18761	18782	18780
	0.289	0.327	0.457	0.473	0.413	0.576

*Notes:* We use a range of correlation of 20 kilometers. Standard errors are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table C2: Cumulative elasticities, region, HAC errors

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.930*** (0.331)	-0.814*** (0.236)	-0.500*** (0.108)	0.225** (0.110)	0.088 (0.060)	-0.001 (0.066)
1 yr after	-1.332*** (0.352)	-1.192*** (0.221)	-0.848*** (0.099)	1.064*** (0.013)	0.772*** (0.051)	0.560*** (0.094)
2 yrs after	-1.134*** (0.405)	-1.036*** (0.240)	-0.779*** (0.0132)	1.267*** (0.161)	0.975*** (0.152)	0.699*** (0.138)
3 yrs after	-0.804* (0.460)	-0.786*** (0.287)	-0.550*** (0.087)	1.093*** (0.096)	0.826*** (0.110)	0.524*** (0.115)
4 yrs after	-0.846* (0.437)	-0.801*** (0.289)	-0.564*** (0.106)	1.119*** (0.092)	0.850*** (0.094)	0.625*** (0.072)
5 yrs after	-0.962** (0.381)	-0.903*** (0.258)	-0.652*** (0.119)	1.030*** (0.106)	0.763*** (0.123)	0.434*** (0.095)
6 yrs after	-0.785* (0.414)	-0.781*** (0.303)	-0.680*** (0.113)	1.029*** (0.199)	0.774*** (0.187)	0.515*** (0.132)
Detector FE (1403)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	140534	139789	140825	140534	139789	140825
$R^2$	0.109	0.119	0.162	0.162	0.168	0.179

*Notes:* We use a range of correlation of 20 kilometers. Standard errors are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.



## D Appendix Traffic effects region: linear specification

Table D1: Cumulative marginal effects region

Dependent	Travel time			Travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.059** (0.028)	-0.047** (0.019)	-0.030*** (0.009)	1.195* (0.660)	0.566 (0.474)	0.029 (0.371)
1 yr after	-0.093*** (0.032)	-0.073*** (0.022)	-0.051*** (0.013)	4.804*** (1.160)	3.151*** (0.892)	1.832*** (0.595)
2 yrs after	-0.071** (0.035)	-0.057** (0.024)	-0.045*** (0.014)	5.938*** (1.396)	4.094*** (1.093)	2.470*** (0.781)
3 yrs after	-0.044 (0.038)	-0.037 (0.027)	-0.027** (0.013)	5.063*** (1.208)	3.507*** (0.941)	1.968*** (0.680)
4 yrs after	-0.052 (0.043)	-0.040 (0.029)	-0.027* (0.015)	5.102*** (1.291)	3.515*** (0.970)	2.250*** (0.701)
5 yrs after	-0.064 (0.043)	-0.050* (0.029)	-0.034** (0.015)	5.055*** (1.282)	3.479*** (0.950)	1.833*** (0.698)
6 yrs after	-0.034 (0.039)	-0.029 (0.026)	-0.031** (0.015)	4.402*** (1.382)	3.021*** (1.034)	1.942*** (0.753)
Detector FE (1403)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	140534	139789	140825	140534	139789	140825
$R^2$	0.091	0.106	0.165	0.212	0.216	0.237

*Notes:* Dependent and independent variables in levels. Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

## E Appendix Other sensitivity checks

Figure E1: Effect per segment, widened segments

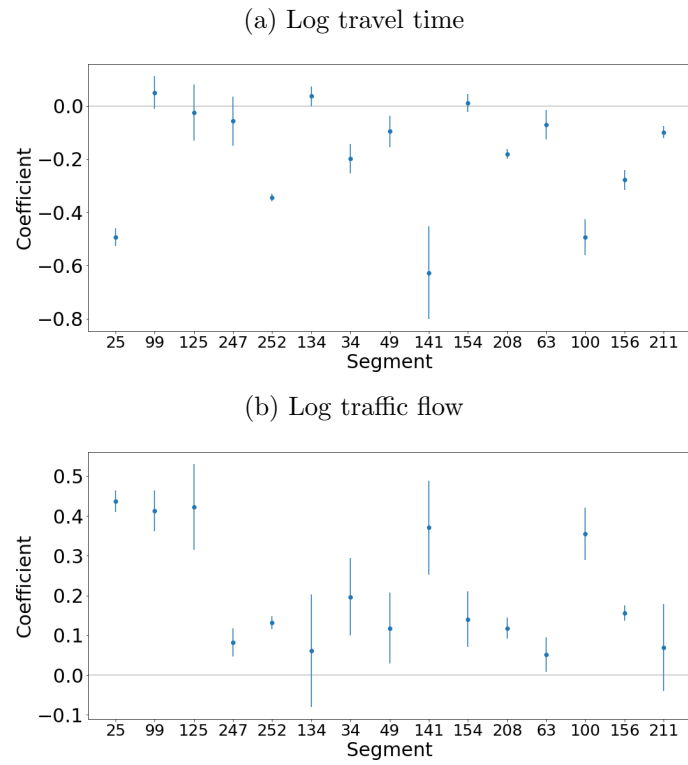


Table E1: Cumulative elasticities region, non-widened segments only

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.492 (0.304)	-0.475** (0.234)	-0.269** (0.122)	0.205 (0.150)	0.126 (0.133)	0.038 (0.128)
1 yr after	-0.766* (0.393)	-0.739** (0.311)	-0.408** (0.165)	0.770*** (0.245)	0.546** (0.218)	0.372* (0.190)
2 yrs after	-0.602 (0.465)	-0.610* (0.357)	-0.335* (0.180)	0.928*** (0.256)	0.716*** (0.230)	0.483** (0.204)
3 yrs after	-0.292 (0.523)	-0.377 (0.404)	-0.140 (0.173)	0.786*** (0.249)	0.592*** (0.222)	0.329* (0.189)
4 yrs after	-0.148 (0.504)	-0.282 (0.389)	-0.095 (0.174)	0.851*** (0.281)	0.644** (0.257)	0.450** (0.223)
5 yrs after	-0.262 (0.489)	-0.370 (0.383)	-0.176 (0.171)	0.724*** (0.272)	0.526** (0.244)	0.230 (0.214)
6 yrs after	-0.088 (0.485)	-0.268 (0.386)	-0.171 (0.182)	0.740** (0.301)	0.573** (0.269)	0.336 (0.233)
Detector FE (1199)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	120123	119858	120238	120123	119858	120238
$R^2$	0.121	0.132	0.184	0.155	0.175	0.164

*Notes:* Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table E2: Cumulative elasticities region, linear province-specific time trend

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.862*** (0.277)	-0.755*** (0.213)	-0.522*** (0.133)	0.380** (0.153)	0.143 (0.130)	0.002 (0.123)
1 yr after	-1.434*** (0.491)	-1.186*** (0.367)	-0.813*** (0.274)	0.992*** (0.312)	0.746*** (0.249)	0.525*** (0.202)
2 yrs after	-1.033** (0.484)	-0.899** (0.354)	-0.685*** (0.254)	1.198*** (0.315)	0.891*** (0.251)	0.614*** (0.204)
3 yrs after	-0.766 (0.509)	-0.656* (0.373)	-0.473* (0.260)	1.103*** (0.319)	0.820*** (0.250)	0.516** (0.201)
4 yrs after	-0.648 (0.596)	-0.580 (0.428)	-0.441 (0.294)	1.217*** (0.347)	0.899*** (0.279)	0.647*** (0.223)
5 yrs after	-0.425 (0.626)	-0.401 (0.457)	-0.370 (0.314)	1.020*** (0.385)	0.796** (0.311)	0.524** (0.250)
6 yrs after	-0.119 (0.626)	-0.179 (0.457)	-0.271 (0.335)	0.939** (0.443)	0.740** (0.364)	0.499* (0.302)
Detector FE (1403)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (1)	YES	YES	YES	YES	YES	YES
Observations	140534	139789	140825	140534	139789	140825
$R^2$	0.113	0.116	0.164	0.144	0.144	0.159

*Notes:* Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table E3: Traffic effects region including segments nearby greenfield construction

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.637*** (0.173)	-0.567*** (0.135)	-0.394*** (0.081)	0.427*** (0.105)	0.291*** (0.094)	0.212** (0.085)
1 yr after	-1.072*** (0.266)	-0.987*** (0.210)	-0.750*** (0.136)	1.100*** (0.178)	0.785*** (0.157)	0.588*** (0.135)
2 yrs after	-0.983*** (0.278)	-0.903*** (0.221)	-0.706*** (0.146)	1.374*** (0.215)	1.033*** (0.191)	0.793*** (0.168)
3 yrs after	-0.693*** (0.262)	-0.691*** (0.206)	-0.532*** (0.132)	1.316*** (0.201)	0.981*** (0.179)	0.713*** (0.161)
4 yrs after	-0.573* (0.330)	-0.589** (0.253)	-0.507*** (0.153)	1.387*** (0.206)	1.081*** (0.185)	0.850*** (0.162)
5 yrs after	-0.860** (0.361)	-0.834*** (0.280)	-0.683*** (0.169)	1.336*** (0.227)	1.006*** (0.201)	0.732*** (0.179)
6 yrs after	-0.542 (0.356)	-0.622** (0.288)	-0.619*** (0.180)	1.403*** (0.260)	1.106*** (0.232)	0.898*** (0.209)
Detector FE (2561)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	257029	257003	257163	257029	257003	257163
$R^2$	0.085	0.093	0.156	0.150	0.152	0.159

Notes: Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

## F Appendix Estimations with smaller and larger region definition

Table F1: Cumulative elasticities, region 10km

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.630*** (0.167)	-0.528*** (0.134)	-0.383*** (0.092)	0.245* (0.125)	0.138 (0.105)	0.069 (0.095)
1 yr after	-1.279*** (0.308)	-1.081*** (0.227)	-0.944*** (0.180)	0.943*** (0.255)	0.710*** (0.221)	0.517** (0.204)
2 yrs after	-1.277*** (0.320)	-1.080*** (0.241)	-0.943*** (0.186)	1.038*** (0.294)	0.803*** (0.255)	0.576** (0.239)
3 yrs after	-1.145*** (0.346)	-0.975*** (0.262)	-0.843*** (0.195)	0.939*** (0.288)	0.725*** (0.250)	0.496** (0.233)
4 yrs after	-1.231*** (0.370)	-1.034*** (0.277)	-0.895*** (0.220)	0.943*** (0.306)	0.726*** (0.270)	0.542** (0.249)
5 yrs after	-1.335*** (0.384)	-1.111*** (0.291)	-0.975*** (0.229)	0.918*** (0.317)	0.721** (0.281)	0.495* (0.258)
6 yrs after	-1.336*** (0.407)	-1.120*** (0.311)	-1.020*** (0.248)	0.948*** (0.349)	0.757** (0.308)	0.550** (0.280)
Detector FE (1003)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	100340	99778	100271	100340	99778	100271
$R^2$	0.131	0.153	0.233	0.133	0.153	0.168

*Notes:* Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table F2: Cumulative elasticities whole country

Dependent	Log travel time			Log flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.637*** (0.160)	-0.557*** (0.120)	-0.376*** (0.072)	0.179* (0.108)	0.092 (0.093)	0.081 (0.080)
1 yr after	-1.069*** (0.203)	-0.927*** (0.164)	-0.635*** (0.109)	0.886*** (0.177)	0.608*** (0.157)	0.464*** (0.138)
2 yrs after	-0.906*** (0.219)	-0.799*** (0.175)	-0.545*** (0.116)	1.173*** (0.207)	0.867*** (0.187)	0.677*** (0.167)
3 yrs after	-0.673*** (0.197)	-0.625*** (0.154)	-0.372*** (0.104)	1.193*** (0.194)	0.893*** (0.177)	0.673*** (0.161)
4 yrs after	-0.599** (0.239)	-0.597*** (0.178)	-0.396*** (0.113)	1.326*** (0.187)	1.053*** (0.170)	0.850*** (0.153)
5 yrs after	-0.813*** (0.240)	-0.750*** (0.185)	-0.493*** (0.124)	1.228*** (0.199)	0.952*** (0.178)	0.731*** (0.161)
6 yrs after	-0.551** (0.237)	-0.582*** (0.188)	-0.455*** (0.129)	1.257*** (0.206)	1.005*** (0.182)	0.855*** (0.164)
Detector FE (4224)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (9)	YES	YES	YES	YES	YES	YES
Observations	422241	422189	423362	422241	422189	423362
$R^2$	0.081	0.085	0.131	0.259	0.263	0.269

*Notes:* Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table F3: Cumulative elasticities, whole country, linear province-specific time trend

Dependent	Log travel time			Log travel flow		
	7:00-9:00	6:00-10:00	5:00-21:00	7:00-9:00	6:00-10:00	5:00-21:00
yr widening	-0.516*** (0.175)	-0.489*** (0.131)	-0.368*** (0.079)	0.341*** (0.103)	0.191** (0.089)	0.154** (0.076)
1 yr after	-1.118*** (0.230)	-0.948*** (0.183)	-0.643*** (0.130)	0.800*** (0.168)	0.572*** (0.142)	0.466*** (0.121)
2 yrs after	-0.955*** (0.216)	-0.842*** (0.172)	-0.582*** (0.115)	1.134*** (0.180)	0.834*** (0.153)	0.667*** (0.135)
3 yrs after	-0.724*** (0.247)	-0.669*** (0.192)	-0.411*** (0.125)	1.096*** (0.182)	0.782*** (0.152)	0.602*** (0.134)
4 yrs after	-0.658* (0.336)	-0.655** (0.254)	-0.439*** (0.163)	1.388*** (0.197)	1.082*** (0.164)	0.883*** (0.140)
5 yrs after	-0.669** (0.336)	-0.644** (0.264)	-0.444*** (0.170)	1.153*** (0.203)	0.903*** (0.166)	0.736*** (0.141)
6 yrs after	-0.590* (0.323)	-0.600** (0.266)	-0.450** (0.175)	1.088*** (0.213)	0.877*** (0.173)	0.783*** (0.148)
Detector FE (4224)	YES	YES	YES	YES	YES	YES
Month FE (12)	YES	YES	YES	YES	YES	YES
Year FE (1)	YES	YES	YES	YES	YES	YES
Observations	422241	422189	423362	422241	422189	423362
$R^2$	0.089	0.094	0.148	0.293	0.303	0.316

Notes: Standard errors (clustered at segment level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.



## G Appendix Economic effects. Yearly coefficients.

Below we report: yearly coefficients from Table 7, Table 8.

Table G1: Elasticity of employment and commercial floor space, yearly effects

Dependent	Log commercial floor			Log employment		
	0-5 km	5-10 km	0-10 km	0-5 km	5-10 km	0-10 km
3 yr before	-0.024 (0.027)	0.099 (0.073)	0.047 (0.038)	-0.015 (0.048)	0.085 (0.083)	0.047 (0.044)
2 yr before	0.006 (0.017)	-0.008 (0.032)	0.003 (0.018)	0.002 (0.036)	-0.022 (0.053)	-0.020 (0.038)
1 yr before	0.039** (0.017)	-0.047* (0.028)	0.012 (0.017)	0.003 (0.024)	0.074* (0.043)	0.057* (0.031)
yr widening	0.009 (0.019)	0.010 (0.039)	0.017 (0.031)	0.009 (0.028)	-0.015 (0.050)	-0.005 (0.033)
1 yr after	0.027 (0.023)	-0.055* (0.032)	-0.006 (0.019)	0.007 (0.029)	-0.031 (0.051)	-0.022 (0.037)
2 yrs after	0.074* (0.038)	-0.032 (0.043)	0.047 (0.032)	0.059 (0.044)	-0.082 (0.059)	-0.020 (0.052)
3 yrs after	0.034 (0.033)	-0.022 (0.039)	0.027 (0.037)	-0.013 (0.023)	-0.054 (0.035)	-0.068** (0.027)
4 yrs after	0.074*** (0.027)	-0.109*** (0.037)	-0.003 (0.020)	0.049 (0.031)	-0.077 (0.058)	0.004 (0.053)
5 yrs after	0.028 (0.018)	-0.047* (0.026)	-0.009 (0.016)	0.076*** (0.027)	0.043 (0.048)	0.128*** (0.047)
6 yrs after	0.026 (0.052)	0.040 (0.046)	0.064 (0.049)	0.049 (0.048)	0.008 (0.064)	0.048 (0.046)
Zip code FE		559	559		559	559
Year FE		12	12		12	12
Observations		6707	6707		6707	6707
$R^2$ within		0.36	0.36		0.24	0.24

*Notes:* Standard errors (clustered at the region level) are in parentheses. \*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.

Table G2: Elasticity of population and residential floor space, yearly effects

Dependent	Log residential floor			Log population		
	0-5 km	5-10 km	0-10 km	0-5 km	5-10 km	0-10 km
3 yr before	0.045 (0.032)	-0.045 (0.050)	0.026 (0.021)	0.069 (0.050)	-0.067 (0.074)	0.046 (0.039)
2 yr before	0.019 (0.016)	-0.022 (0.023)	0.001 (0.015)	-0.023 (0.031)	0.005 (0.040)	-0.031 (0.022)
1 yr before	0.012 (0.010)	-0.011 (0.018)	0.009 (0.013)	0.010 (0.017)	-0.015 (0.027)	0.007 (0.019)
yr widening	0.001 (0.015)	0.013 (0.028)	0.013 (0.017)	0.029 (0.018)	-0.047 (0.036)	-0.003 (0.021)
1 yr after	-0.002 (0.013)	-0.002 (0.024)	-0.003 (0.010)	0.011 (0.025)	-0.024 (0.034)	-0.002 (0.022)
2 yrs after	-0.002 (0.019)	0.015 (0.025)	0.016 (0.014)	-0.007 (0.027)	0.026 (0.038)	0.011 (0.024)
3 yrs after	0.010 (0.012)	0.003 (0.025)	0.015 (0.016)	0.027 (0.025)	-0.021 (0.038)	0.013 (0.017)
4 yrs after	-0.012 (0.013)	0.024 (0.028)	0.002 (0.018)	-0.010 (0.029)	0.024 (0.053)	-0.000 (0.024)
5 yrs after	0.002 (0.010)	-0.021 (0.027)	-0.014 (0.020)	0.042 (0.100)	-0.050 (0.087)	0.014 (0.063)
6 yrs after	-0.020 (0.022)	0.084** (0.040)	0.053* (0.031)	-0.020 (0.044)	0.084 (0.070)	0.059 (0.053)
Zip code FE	596		596	596		596
Year FE	12		12	12		12
Observations	7130		7130	7130		7130
$R^2$ within	0.31		0.31	0.18		0.18

*Notes:* Standard errors (clustered at the region level) and are in parentheses.

\*, \*\*, \*\*\*, 10%, 5%, 1% significance, respectively.