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Highways, Market Access and Spatial Sorting

Stephan Fretz (Swissgrid)
Raphaël Parchet (USI)
Frédéric Robert-Nicoud (Geneva, CEPR & SERC)

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Stephan Fretz*
Raphaël Parchet**
Frédéric Robert-Nicoud***

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* Swissgrid
** Università della Svizzera Italiana
*** University of Geneva, CEPR and SERC

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Abstract
We design a spatial model featuring workers embodied with heterogeneous skills. In equilibrium, locations with improved market access become relatively more attractive to the high-skilled, high-income earners. We then empirically analyze the effects of the construction of the Swiss highway network between 1960 and 2010 on the distribution of income at the local level, as well as on employment and commuting by education level. We find that the advent of a new highway access within 10km led to a long-term 19%-increase of the share of high-income taxpayers and a 6%-decrease of the share of low-income taxpayers. Results are similar for employment data decomposed by education level, as well as for in- and out-commuters. Highways also contributed to job and residential urban sprawl.

Keywords: transportation, highway, market access, income sorting
JEL Classifications: D31; O18; H54; R11; R23

Introduction

Transportation infrastructures shape the spatial economy in fundamental ways. The advent of a new highway affects market access of firms and consumers. By facilitating commuting, highways also expand the pool of potential employees that firms may hire as well as the pool of jobs that workers have access to. Heterogeneous workers make different working and residential location choices, implying that highways affect the composition of workers and residents in the locations they connect.

In order to formalize the distributional consequences of highway expansions, the paper first develops a spatial equilibrium model featuring costly trade, costly commuting, and workers embodied with heterogeneous skills and idiosyncratic location preferences (Section 1). In equilibrium, a reduction in the cost of transporting goods and commuters increases market access and commuting possibilities for the newly connected locations, which increases their attractiveness. The multinomial logit formulation of individual location choices in our model leads to a strong complementarity between the quality of workers' skills and the attractiveness of a location. A newly connected municipality therefore attracts high-skilled workers in a disproportionate manner. The skill and earnings distributions shift to the right as a result.

We then empirically investigate the effect of improved accessibility on income distribution at the local level, exploiting variation in municipalities' accessibility over time resulting from the construction of the Swiss highway network (Section 2). Switzerland provides an ideal setting as the Swiss highway network was to a large extent defined in 1960 by the federal parliament to connect Switzerland's largest cities, but only gradually constructed over the decades that followed. From the perspective of a non-urban municipality, the opening date of a new highway section in its vicinity is close to random and exogenous to the initial path of its local economic development. Merging several distinct data sets, we exploit this variation over time to identify the effect of the opening of a new highway access point on the total number of taxpayers (resident households), the share of taxpayers in different income categories, as well as employment and commuting by education levels.

We find that the number of taxpayers and the share of top-income taxpayers both rise in non-urban municipalities located within 10km of newly opened highway access points (Section 3). While the total number of taxpayers increases by 11%, the share of low-income taxpayers decreases by 6% and the share of top-income taxpayers increases by 19%. These effects are heavily localized. For municipalities located between 10km and 15km, we still find a shift in the income distribution but no effect on the total number of taxpayers; for municipalities located beyond 15km, we find an effect only on the share of top-income taxpayers.

Our theoretical framework proposes that shifts in the income distribution of municipalities induced by highway access results from the sorting of a heterogeneous population. Other channels are possible, such as non-homothetic effects on wages and learning (De La Roca and Puga, 2017; Glaeser, 1999). Our taxpayer data do not allow us to track individuals over time and space. Instead, we provide direct evidence for sorting using census data and an alternative specification based on employment by education level. We find that the share of highly-educated residents and workers increases in municipalities that get access to the highway network, while the share of residents and workers with intermediate levels of education decreases in such municipalities.

Our model also predicts a positive effect on the number of in-commuters but an ambiguous effect on the number of out-commuters. For both in- and out-commuters, the effect should be strongest at the top of the skill distribution. Consistent with this prediction, we find no effect on the number of out-commuters, a positive effect on the number of in-commuters, and an increase in the share of in- and out-commuters with a high level of education. Finally, we include the main metropolitan areas in order to evaluate whether highway access leads to a concentration or diffusion of economic activity. We find a sub-urbanization effect on jobs and residences, a process that is especially pronounced for the high-skilled.

In the final section of the paper (Section 4), we show that our qualitative results are robust to using alternative specifications, such as adding several leads and lags to explore pre-opening trends and the impact over time, a 'difference-in-differences' specification that includes municipalities that never get treated, and a placebo test randomizing the opening time of highway access.

Understanding the spatial and economic consequences of large scale transportation infrastructures is important for several reasons. First, access to markets and proximity to workers and jobs are prominent criteria in the location decisions of firms and households. As a consequence, transportation infrastructures are an important determinant of individual welfare and regional disparities. Second, the location of airports and the design of rail, road, and highway networks influence land use patterns as much as 'first nature' geography: highways have been found to increase the size of cities (Duranton and Turner, 2012), to cause sub-urbanization (Baum-Snow, 2007; Baum-Snow, Brandt, Henderson, Turner and Zhang, 2017; Garcia-López, Pasidis and Viladecans-Marsal, 2016), to affect the product-mix of cities (Duranton, Morrow and Turner, 2014), and to increase regional disparities (Baum-Snow, Henderson, Turner, Zhang and Brandt, 2017; Faber, 2014). Third, at around five percents of GDP, the financial amounts involved in transportation infrastructure dwarf those of most other investment programs (Redding and Turner, 2015) but they may also bring large scale benefits (Allen and Arkolakis, 2014; Donaldson, forthcoming; Donaldson and Hornbeck, 2016). Furthermore, as we document below, highway access leads to worker and resident sorting along skills and incomes, which is likely to have meaningful implications for segregation, voting, and, in federal countries such as Switzerland that grant large budget autonomy to its municipalities, on tax competition (Eugster and Parchet, in press).

Our paper contributes to the literature in three ways. First, we develop a spatial general equilibrium model featuring mobile agents and costly trade in goods among heterogeneous locations as in Allen and Arkolakis (2014), Redding (2016) or Redding and Turner (2015), as well as commuting, following Monte, Redding and Rossi-Hansberg (2017). Our model innovates by featuring heterogeneous workers and by allowing for the fact that workers with different skills make different locations choices on average. We achieve the latter by assuming that idiosyncratic location preferences are distributed Gumbel instead of Fréchet, as is commonly assumed. This assumption implies that individual location choices follow a multinomial logit, a functional form that is commonly adopted in empirical work, and it leads to a strong complementarity between a worker's skill level and local attractiveness.

Second, existing studies on the heterogeneous impact of transportation infrastructure over space focus on various economic outcomes leaving distributional effects aside.[1] We complement such studies with micro-evidence on the consequences on the local composition of the workforce and of the population. We find strong evidence of sorting along skills and incomes. By linking residential location choices to highway access, we also complement works studying the sorting of workers with heterogeneous skills and incomes across local labor markets and cities.[2]

Third, our empirical identification strategy exploits variation over time within municipalities, as in Donaldson (forthcoming) and Hornung (2015), while much of the literature is cross-sectional in nature, addressing the non-randomness of highway (or railway) location using an instrumental variable approach (Mayer and Trevien, 2017; Redding and Turner, 2015). Our long panel data with heterogeneity in the timing of highway construction allow us to restrict our sample to municipalities close to a highway access and to control for municipality-specific time trends and yearly common shocks; all municipalities in our sample are eventually treated. In contrast, comparing municipalities located close to a highway with municipalities further away as in a classical difference-in-differences specification may distort results if the two groups are heterogeneous along some unobserved dimensions

[1]See Ahlfeldt and Feddersen (2017), Audretsch, Dohse and dos Santos (2017), Banerjee, Duflo and Qian (2012), Jedwab and Moradi (2016), Qin (2017), and Storeygard (2016) on regional output; Chandra and Thompson (2000) on regional earnings by industry; Atack, Bateman, Haines and Margo (2010), Baum-Snow, Henderson, Turner, Zhang and Brandt (2017), Berger and Enflo (2017), Duranton and Turner (2012), and Hornung (2015) on urban development; Donaldson (forthcoming), Donaldson and Hornbeck (2016), Duranton, Morrow and Turner (2014), Faber (2014), and Volpe Martincus and Blyde (2013) on trade; Datta (2012), Ghani, Goswami and Kerr (2015), and Gibbons, Lyytikäinen, Overman and Sanchis-Guarner (2016) on firms; or Michaels (2008) and Sanchis-Guarner (2012) on labor market outcomes.

[2]See Behrens, Duranton and Robert-Nicoud (2014), Combes, Duranton and Gobillon (2008), De La Roca (2017), De La Roca and Puga (2017), Diamond (2016), Gyourko, Mayer and Sinai (2013), Handbury (2013) or Moretti (2013). Combes, Duranton, Gobillon, Puga and Roux (2012) and Gaubert (2017) deal with the sorting of heterogeneous firms.

(Gobillon and Magnac, 2016). Indeed, even without the advent of a highway, municipalities between two major cities may experience higher degree of accessibility than regions further away in the periphery and therefore follow a different growth trajectory, though this issue is probably relatively mundane in our case.[3] Moreover, in a spatial economy in which no location is totally isolated, even municipalities that are remotely located are treated by the expansion of the highway network, possibly only little so, likely negatively, but treated nonetheless (Redding and Turner, 2015).

1. Model

We design a spatial equilibrium model featuring trade, commuting, and discrete location choices as in Monte, Redding and Rossi-Hansberg (2017) and workers endowed with heterogeneous effective units of labor. We depart from Monte, Redding, and Rossi-Hansberg's model in two respects: we allow for worker skill heterogeneity and we assume that individual location choices follow a multinomial logit.

The economy consists of a set N of locations and a measure Λ of workers. Individuals may reside and work in any location and the two are not necessarily the same. We design residential locations by subscript $n \in N$ and workplace allocations by subscript $i \in N$ (thus an individual working in i and living in n faces the wage rate w_i and the price index P_n).

1.1 Endowments and Preferences

Each location is endowed with a fixed supply of residential land H_n. Workers hold heterogeneous endowments of effective units of labor and heterogeneous preferences about each pair of locations. To save on notation we henceforth identify a worker with her endowment of effective units of labor, $\ell \in [0,1]$, with cumulative distribution function $F(\ell)$. Let $\bar{L} \equiv \int_0^1 \ell \mathrm{d}F(\ell)$ denote the average skill level in the economy. Specifically, the utility of a worker endowed with ℓ units of labor, residing in n, and working in i is equal to

$$U_{ni}(\ell) = \left(\frac{C_{ni}(\ell)}{\alpha}\right)^{\alpha} \left(\frac{H_{ni}(\ell)}{1-\alpha}\right)^{1-\alpha} B_{ni}\beta_{ni}(\ell), \qquad \alpha \in (0,1). \tag{1}$$

$C_{ni}(\ell)$ and $H_{ni}(\ell)$ denote ℓ's consumption of the final good C and housing services H, B_{ni} denotes the common component of the joint assessment of locations n and i as residential and working locations, respectively, and $\beta_{ni}(\ell)$ denotes the idiosyncratic component of the joint assessment of the pair (n,i). B_{ni} captures both n- and i-specific amenities, as well

[3] We control in all regressions that we report for municipality-specific trends, a special case of interactive fixed effects that imposes a fixed form for the common factor (Bai, 2009). Moreover, as we report in Table 1 below, the observable characteristics of treated and non-treated municipalities are similar on average.

as pair-specific amenities such as the utility cost of the bilateral commute. Therefore, a reduction in the bilateral commuting time corresponds to an increase in B_{ni}.

Let p_n and q_n respectively denote the prices of C and H pertaining in n,

$$P_n \equiv p_n^{\alpha} q_n^{1-\alpha} \tag{2}$$

denote the price index or the cost of living in n, and w_i denote the unit labor cost pertaining in i. The labor earnings of worker ℓ when working in i is then equal to ℓw_i. The indirect utility function associated with (1) is equal to

$$V_{ni}(\ell) = \beta_{ni}(\ell) V_{ni} \ell, \quad \text{where} \quad V_{ni} \equiv B_{ni} \frac{w_i}{P_n} \tag{3}$$

denotes the common component of $V_{ni}(\ell)$.

1.2 *Worker Location and Commuting*

We assume that the $\beta_{ni}(\ell)$'s are independently and identically drawn from a Gumbel distribution with mean zero and standard deviation $\epsilon\pi/\sqrt{6}$ so that the probability that worker ℓ chooses to live in n and work in i, denoted as $\lambda_{ni}(\ell)$, obeys the multinomial logit with shape parameter $\epsilon > 0$:

$$\lambda_{ni}(\ell) = \frac{\exp\left(\ell V_{ni}/\epsilon\right)}{\sum_{r \in N} \sum_{s \in N} \exp\left(\ell V_{rs}/\epsilon\right)}. \tag{4}$$

Note that $\lambda_{ni}(\ell)$ is log-supermodular in V_{ni} and ℓ: this strong complementarity between a worker's skills and (endogenous) amenities implies that the high-ℓ workers disproportionately pick high-V_{ni} residential-working pairs of locations.[4] High-skilled workers are also more sensitive to changes in V. To see this property of the model, let us compute the semi-elasticity of the odds of living in n and working in i with respect to V_{ni},

$$\frac{\partial}{\partial V_{ni}} \ln\left(\frac{\lambda_{ni}}{1-\lambda_{ni}}\right) = \frac{\ell}{\epsilon}. \tag{5}$$

It is increasing in ℓ by inspection.

The population of workers who reside in n is equal to

$$R_n = \Lambda \int_0^1 \sum_{i \in N} \lambda_{ni}(\ell) \mathrm{d}F(\ell). \tag{6}$$

[4]To see this result, let ℓ and ℓ' be two arbitrary workers such that $\ell' > \ell$ and V_{ni} and V_{rs} be two arbitrary pairs of locations such that $V_{rs} > V_{ni}$; then the following equality holds by inspection:

$$\frac{\lambda_{ni}(\ell)}{\lambda_{rs}(\ell)} \left(\frac{\lambda_{ni}(\ell')}{\lambda_{rs}(\ell')}\right)^{-1} = \exp\left(\frac{(\ell'-\ell)\left(V_{rs}-V_{ni}\right)}{\epsilon}\right) > 1,$$

namely, the higher skill worker ℓ' is the most likely of the two workers to pick the relatively high amenity location pair (r,s).

By the same token, employment in i and the effective labor force in i are respectively equal to

$$E_i = \Lambda \int_0^1 \sum_{n \in N} \lambda_{ni}(\ell) \mathrm{d}F(\ell) \quad \text{and} \quad L_i = \Lambda \int_0^1 \sum_{n \in N} \lambda_{ni}(\ell) \ell \mathrm{d}F(\ell). \tag{7}$$

Location pairs (n,i) that command a relatively high utility V_{ni} end up attracting a large number of residents by (6) and a high labor force by (7). Wages and prices are two key components of V_{ni}. We next turn to the determination of w_i and P_n.

1.3 Production

We follow Monte, Redding and Rossi-Hansberg (2017) and Redding and Turner (2015) by modeling the consumption good C as a monopolistically competitive industry à la Dixit and Stiglitz (1977). Firms produce differentiated products (and hence enjoy market power) under increasing returns to scale and entry and exit are free so that profits are zero in equilibrium. Labor is the only input.

The cost function of the representative firm is $C_i(x) = (F + x/A_i)w_i$, where F is the fixed component of labor, A_i is local TFP, and x denotes output. Profit maximizing firms break even if and only if the scale of the representative firm and the wage rate respectively obey

$$x_i = A_i F(\sigma - 1) \tag{8}$$

and

$$w_i = \frac{1}{\zeta} A_i^{1-1/\sigma} fma_i^{1/\sigma}, \qquad \zeta \equiv \frac{\sigma}{\sigma - 1} \left[F(\sigma - 1)\right]^{1/\sigma}. \tag{9}$$

Above, σ is the perceived elasticity of demand and fma denotes 'firm market access' and is defined in (15) below. This expression implies that nominal labor productivity is higher in locations endowed with a high TFP and a good access to markets; wages are also decreasing in the firm markup (the first term in the right-hand side of the definition of ζ) and in the fixed cost of production.

Let M_i denote the mass of firms that enter the labor market in i. Labor market clearing requires $L_i = M_i(F + x_i/A_i)$; using (8), this expression implies that the equilibrium mass of firms is proportional to the labor force in effective units and equal to

$$M_i = \frac{L_i}{F\sigma}. \tag{10}$$

1.4 Consumption

We assume that the consumption good C is a CES aggregate of differentiated varieties that are tradable among locations, with pairwise elasticity of substitution $\sigma > 1$; the cost of purchasing one unit of the basket C at location n is equal to

$$p_n = \left(\frac{1}{cma_n}\right)^{1/(\sigma-1)},$$

where cma denotes 'consumer market access' and is defined in (14) below. This expression implies that the tradable goods are more affordable in locations that are cheap to source to.

In equilibrium workers spend a fraction $1-\alpha$ of their income on land. We assume for simplicity that landowners are immobile and spend all of their earnings on the consumption good C. This assumption implies that total expenditure on C is equal to

$$p_n C_n = v_n R_n, \quad \text{where} \quad v_n \equiv \frac{\Lambda \int_0^1 \sum_{i \in N} \lambda_{ni}(\ell) w_i \ell \mathrm{d}F(\ell)}{R_n} \tag{11}$$

is the average earnings of the workers residing in n. The market clearing price in the local residential land market, q_n, obeys

$$q_n H_n = (1-\alpha) v_n R_n. \tag{12}$$

1.5 Trade

Bilateral trade of the differentiated good C is costly. We assume that $T_{ni} \geq 1$ units of the good must be shipped from i to arrive in n. Mill pricing is optimal under Dixit-Stiglitz monopolistic competition so that $p_{ni} = T_{ni} \frac{\sigma}{\sigma-1} \frac{w_i}{A_i}$. It then follows that the combined market shares of firms producing in i and selling in n is equal to

$$\pi_{ni} = \frac{L_i \left(T_{ni} w_i / A_i\right)^{1-\sigma}}{\sum_{j \in N} L_j \left(T_{nj} w_j / A_j\right)^{1-\sigma}} \tag{13}$$

and that consumer market access is equal to

$$cma_n = p_n^{1-\sigma} = \sum_{i \in N} T_{ni}^{1-\sigma} M_i \left(\frac{\sigma}{\sigma-1} \frac{w_i}{A_i}\right)^{1-\sigma} = \frac{L_n}{\sigma F \pi_{nn}} \left(\frac{\sigma}{\sigma-1} \frac{T_{nn} w_n}{A_n}\right)^{1-\sigma}, \tag{14}$$

where the last equality follows from (10) and from applying (13) to π_{nn}, the so-called 'autarkyness' of municipality n (Arkolakis, Costinot and Rodríguez-Clare, 2012). Consumers located in n enjoy a good market access if their municipality has a low degree of 'autarkyness' and its firms charge low prices. Municipality n is open to trade if bilateral trade costs between n and locations offering any combination of many firms (and hence many differentiated varieties), high TFP, and low wages, are low; its firms charge low prices if wages and own trade costs are low relative to local TFP.

Firms located in i enjoy a good market access if bilateral costs between i and locations offering a combination of high expenditure and low competition are low:

$$fma_i = \sum_{n \in N} T_{ni}^{1-\sigma} v_n R_n p_n^{1-\sigma}. \tag{15}$$

Plugging (14) and (15) into (3) and using (2) and (9) yields the following relationship between the common component of utility V_{ni} on the one hand and bilateral amenities as well as our two measures of market access on the other:

$$V_{ni} = \frac{1}{\zeta(1-\alpha)^{1-\alpha}} A_i^{1-1/\sigma} fma_i^{1/\sigma} B_{ni} cma_n^{\alpha/(\sigma-1)} \left[\frac{v_n R_n}{H_n}\right]^{-(1-\alpha)}. \tag{16}$$

Residential-working pairs that command good firm and consumer market access are desirable because they command high wages and low consumer prices. Desirable bilateral amenities such as short commutes also act as pull factors; in turn, desirable residential locations attract a large number of residents by (4), and disproportionately the high earners among them, both leading to high housing prices, which then act as a stabilizing push factor.

1.6 Equilibrium

Building on Allen and Arkolakis (2014), Monte, Redding and Rossi-Hansberg (2017) and Redding and Turner (2015), we can describe the equilibrium as the vector of the variables $\Theta_n \equiv \{w_n, v_n, q_n, p_n, L_n, R_n\}$ and the function $U(\ell)$, where

$$U(\ell) \equiv \mathbb{E}[U_{ni}(\ell)] = \epsilon \ln \left(\sum_{n \in N} \sum_{i \in N} \exp\left(\frac{\ell V_{ni}}{\epsilon}\right)\right),$$

as shown by Small and Rosen (1981). Note that this expression yields an economic interpretation of the denominator of the λ_{in}'s of (4) as the exponential of the expected utility $U(\ell)/\epsilon$. We can express all other endogenous variables of the model as functions of the vector Θ_n and of the function $U(\ell)$. The novelty of our framework is that agents are heterogeneously skilled and $U(\ell)$ is a function, not a scalar.

The equilibrium vector Θ_n solves the following set of equations: income equals expenditure,

$$w_i L_i = \sum_{n \in N} \pi_{ni} v_n R_n;$$

the labor force, (7); the residential population, (6); the average residential income, (11); the market clearing condition for land, (12); and the price index of the differentiated good, (14).

Finally, the full employment conditions

$$\Lambda = \sum_{n \in N} R_n = \sum_{i \in N} E_i = \frac{1}{\bar{L}} \sum_{i \in N} L_i$$

pin down the function $U(\ell)$.

1.7 From Theory to Estimation

Consider an arbitrary municipality m before and after it gets connected to the highway network. In the model, its residential population varies according to (6):

$$\mathrm{d}R_m = \int_0^L \sum_{i \in N} \mathrm{d}\lambda_{mi}(\ell)\mathrm{d}F(\ell). \tag{17}$$

Likewise, employment and the effective labor force of such a municipality vary according to (7):

$$\mathrm{d}E_m = \int_0^L \sum_{n \in N} \mathrm{d}\lambda_{nm}(\ell)\mathrm{d}F(\ell) \quad \text{and} \quad \mathrm{d}L_m = \int_0^L \sum_{n \in N} \mathrm{d}\lambda_{nm}(\ell)\ell\mathrm{d}F(\ell). \tag{18}$$

In order to get an expression for the variation in shares $\mathrm{d}\lambda$ in equations (17) and (18), we can use (5) to recall that the semi-elasticities of the odds ratio of living in n and commuting to i with respect to the common component of utility V_{ni} are (**i**) positive and (**ii**) increasing in ℓ. Property (**i**) implies that municipalities that get a positive shock ($\mathrm{d}V_{mi} > 0$ and $\mathrm{d}V_{nm} > 0$) attract more residents from all income types and more workers from all skill types. Property (**ii**) implies that such municipalities also experience a right shift of the distribution of residential incomes and a right shift of the distribution of worker skills.

In our reduced form regressions below, we treat a connection to the highway system as a positive shock to market access (an increase in both fma_m and cma_m) and to commuter access (an increase in both B_{mi} and B_{nm}). In logarithmic differences:

$$\widehat{V}_{mi} = \widehat{B}_{mi} + \frac{\alpha}{\sigma - 1}\widehat{cma}_m - (1-\alpha)\widehat{v_m R_m} > 0 \tag{19}$$

and

$$\widehat{V}_{nm} = \widehat{B}_{nm} + \frac{1}{\sigma}\widehat{fma}_m > 0. \tag{20}$$

Both are positive under the assumption that a highway connection increases producer and consumer market access, and reduces the bilateral commuting dis-utility. As a result, highway access to municipality m makes it more attractive to both workers and residents.

The effect of highway access on the number of commuters is ambiguous, however: a better access from and to municipality m makes it at once a more desirable place to live (and possibly commute from) and a more attractive workplace (and possibly commute to). To see this result, consider V_{mi}/V_{mm} for an arbitrary municipality $i \neq m$. If high, this ratio suggests that m is especially attractive as a residential location and should thus attract many out-commuters. This ratio is increasing in B_{mi}/B_{mm} and in fma_i/fma_m by (16):

$$\frac{V_{mi}}{V_{mm}} \propto \left(\frac{fma_i}{fma_m}\right)^{1/\sigma} \frac{B_{mi}}{B_{mm}}. \tag{21}$$

Highway access of municipality m, conditional on the situation of municipality i, increases B_{mi}/B_{mm} (because highways reduce inter-municipality commuting costs but do not affect local traffic directly) and reduces fma_i/fma_m (because m benefits from an improvement in firm market access relative to i). The two effects work in opposite directions, with an ambiguous effect on the number of out-commuters.

Using similar reasoning, the number of in-commuters should rise since highway access has an unambiguous effect on the ratio

$$\frac{V_{nm}}{V_{nn}} \propto \left(\frac{fma_m}{fma_n}\right)^{1/\sigma} \frac{B_{nm}}{B_{nn}} \tag{22}$$

which, if high, suggests that municipality m is especially attractive as a production location.

1.8 Qualitative Predictions

Summing up the analysis of the subsection above, the qualitative predictions of the model that we take to the data are as follows:[5]

1. **Size**: A municipality that gets a connection to the highway network experiences an increase in both employment and population by (6)-(7) and (19)-(20).

2. **Composition:** A municipality that gets a connection to the highway network experiences a shift to the right of its wage and skill distributions by (5)-(7) and (19)-(20).

3. **Commuting:** The effect of a highway connection on the number of out-commuters in a municipality is ambiguous a priori by (21), while the effect on the number of in-commuters is unambiguously positive by (22). For both out- and in-commuters, the effect is strongest in absolute value for workers at the top of the skill distribution by (5)-(7).

2. Empirical Strategy

We assemble several data sets and test the predictions of the model using evidence from the Swiss highway network. As laid out in more detail in Appendix A, the Swiss highway network provides an ideal setting for our analysis. The Swiss highway network was to a large extent defined in 1960 by the federal parliament to connect Switzerland's largest cities, but only gradually constructed over the decades that followed. Figure 1 displays the distribution of municipalities receiving a highway access within 10km reach, by opening year. We exploit this variation over time to identify the effect of the opening of a new highway access point on the total number of taxpayers (households), the share of taxpayers in different income categories, as well as employment and commuting by education levels.

[5]To get Predictions 1 and 3, plug (5) into (17) and (18), using (19) and (20) for Prediction 1, or (21) and (22) for Prediction 3. Prediction 2 arises from the magnification of the utility effect into location decisions by skill level, as explicit in (5).

2.1 *Data*

We rely on two sets of household data: tax data from the federal income statistics for the period 1947-2010 and data on employment from the national censuses from 1950 to 2010.

We construct data on the income distribution using the Swiss federal income tax statistics with information at the municipality level from 1947 to 2010. These statistics encompass all regular taxpaying units subject to the federal income tax. These taxpaying units are individuals or households (depending on the marital status) who reside in Switzerland and earn no income in foreign countries. This definition excludes foreign taxpayers, taxpayers with special tax treatment, and taxpayers with annual income below a certain threshold (CHF 16,000 for singles and CHF 27,000 for couples in 2010).[6] Data are available on a two-year basis from 1947 to 2000 and on a yearly basis thereafter. We aggregate all data into two-year averages.[7]

Our two main measures of the distribution of income at the municipality level are the number of taxpayers and the share of taxpayers with income above some income percentiles (median, 75th and 90th percentile). Percentiles are calculated on the basis of the nation-wide population of taxpayers for each tax period. To fix ideas, in year 2010 these percentiles corresponded to pre-tax incomes of CHF 54,200, CHF 78,300, CHF 115,000 for the 50th, 75th and 90th percentile, respectively.[8] We compute percentiles using individual-level data for the period 1973-2010. For the period 1947-1972 we use statistics at the national level aggregated by income classes.[9]

We complement these statistics with census data on employment by education level for decennial years for the period 1950-2010. We compute residence-based and workplace number of employees as well as the number of out- and in-commuters for three different levels of education: compulsory school ("low education"), maturity and professional vocation ("middle education"), university-level ("high education") using individual-level census data available for the years 1970-2010.[10] We complement information on workplace-, residence-

[6]In 2010, the share of taxpayers not paying the federal income tax was 20% and, among those paying the federal income tax, 90% were regular taxpayers whose earnings accounted for 86% of the taxable income.

[7]The tax collection changed from a bi-annual praenumerando system to an annual postnumerando system during the early 2000s (the exact timing varies by canton).

[8]The average exchange rate between 1970 and 2010 is 1.80 US Dollar to the Swiss Francs (CHF).

[9]The federal income tax statistics for the years 1947-1972 report, at the national level, the number of regular taxpayers paying a federal income tax and their income by income classes. We approximate percentiles using a Pareto interpolation. Statistics at the municipality level report the count of taxpayers for 5 to 8 income classes (depending on the years) with the upper class counting taxpayers with income higher than CHF 100,000 (CHF 50,000 before 1951). We approximate the share of taxpayers using a linear interpolation between the logarithms of taxpayer shares and incomes as implied by a Pareto distribution.

[10]For year 2010, we use the new census that covers a sample of 300,000 individuals each year over the period 2010-2014. Census data contain only information on the residents in Switzerland. The number of workers does not include cross-border workers living in another country.

based employment and commuting with census data aggregated at the municipality level for 1950 and 1960.

Table 1 displays the mean values for different sub-samples. Column (1) refers to all municipalities, Column (2) to municipalities that are not part of a metropolitan area, and Column (3) to non-urban municipalities that got a highway access within 10km reach during the sample period.[11] Column (4) presents the mean values for the 27 major 'urban centers'.[12] Non-urban municipalities have on average fewer inhabitants, taxpayers, and workers than urban municipalities. Treatment of municipalities that are not part of a metropolitan area is close to random because highways were built with the purpose of connecting Switzerland's main cities. Column (3) municipalities form our sample group for this reason. Observe that the average non-urban municipality that got a 10km highway access during the sample period is very similar to the average non-urban municipality that did not get such access (figures in Columns (2) and (3) are very similar).

2.2 *Identification*

Our identification strategy exploits the spatial variation and the long panel dimension of the data in three ways. First, we rely on a long panel data set in which the timing of the treatment (i.e. opening of the highway access point) differs across the various sections of the highway network. We restrict our sample to municipalities that get a highway access over our observation period and exploit the heterogeneity in the opening time of the access as in Donaldson (forthcoming) and Hornung (2015). Thus, all municipalities in our sample are eventually treated. Restricting the sample to municipalities that are all located within the same distance to the next highway increases the homogeneity of our sample and minimizes a potential source of bias, which arises if heterogeneous municipalities follow heterogeneous growth paths.

Second, we include municipality fixed effects as well as municipality-specific time trends to control for unobservable differences in the growth rate. Note that identification of the municipality time trends are in large part identified over a large number of pre-treatment years. We also include year dummies, which account for any macroeconomic shock that affects all municipalities in the sample. The highway access effects that we estimate are thus deviations from individual growth trajectories and countrywide shocks.

Third, we exclude urban municipalities from our sample in order to eliminate a major source of selection bias following Chandra and Thompson (2000) for the US and Faber (2014) for China. Indeed, in Switzerland as in these large countries, highways were designed to

[11] We also experiment with other buffers (5km, 15km, and 20km). See footnote 17 below.

[12] We qualify as 'centers' cities of categories 1 and 2 according to the nomenclature of the municipalities developed by the Swiss Federal Statistical Office (2000).

connect the major urban centers so that getting an access to the highways network is as close to a random event as it gets to non-urban municipalities. These municipalities are small (see Table 1) and our identifying assumption is that they are unlikely to have systematically influenced the opening time of the highway access. As we develop in Appendix A, the design of the Swiss highway network was to a large extent sealed in 1960. The network was then only gradually constructed over time. Considerations based on inter-city transportation defined priorities. To the best of our knowledge, the connection of certain municipalities outside of agglomerations to the highway network did not feature in such considerations. The opening of certain highway sections was also subject to substantial delays, due to opposition by environmental groups among other reasons, creating additional randomness in the timing.

Our long panel data enable us to improve on identification strategies that can rely on variations across space only. Indeed, peripheral regions that are located along a direct route between two cities may follow different growth and development paths from those located further away, irrespective of the opening of a highway or not. We circumvent this issue by focusing our analysis on non-urban municipalities that eventually get access to a highway and by including municipality-specific time trends and levels (the implicit common trend assumption of cross-sectional studies is un-testable by construction, see e.g., Datta, 2012, p. 55). Since all municipalities in our sample eventually get treated, but only gradually over time, there are treated and control municipalities at any point in time. Furthermore, the treatment and the control groups are similar. This being said, non-urban municipalities in our sample are very similar to non-urban municipalities that are excluded form it along observable dimensions (see columns (2) and (3) of Table 1). It turns out that our results are largely unaffected if we include non-treated municipalities as a control group in our regression analysis (see Section 4.3).

Proper identification of our coefficients also requires that municipalities that are treated early be similar to municipalities that are treated later on. Table 2 reports summary statistics pertaining to the planning phase (1947-1955), namely, before the opening of the first highway section. Column (1) displays the mean values for our sample of non-urban municipalities that eventually get a 10km-highway access. Columns (2) to (4) decompose the sample according to different stages of the construction of the network. The fifth column reports the p-values of testing the hypothesis that the figures reported in columns (2)-(4) are identical. Results display no statistically meaningful differences in the mean population, number of taxpayers, workplace- and residence-based employment, nor in the growth rate or the income distribution of taxpayers between municipalities getting a 10km-highway access before 1970, between 1970 and 1990, or after 1990. We conclude that there is no observable difference among such municipalities in terms of overall economic activity or residential composition.[13]

In this paper we estimate the effects of highways on location decisions. The Swiss railway network is also famously developed and its expansion would be a confounding factor undermining our identification strategy if its developments were systematically correlated in time and space with the opening of highways. There is no evidence that is the case over our period of observation. The Swiss railway network was to a very large degree constructed in the second half of the 19th century and in the first decade of the 20th century. Switzerland had one of the densest railway networks across the world already back in 1900. By that time, 70% of Switzerland's population lived in a municipality crossed by a railway track (Büchel and Kyburz, 2016). Further expansion of the railway network after the first decade of the 20th century was limited. The next major upgrade of the network took place in 2004 only, with the so-called "Bahn 2000" (or "Rail 2000") initiative. The network expanded with the opening of 51km of lines, which amounts to the cumulative expansions of the ninety preceding years (Wägli, 2010).

The main enhancement of rail services in the 20th century came from the development of commuter lines within major urban areas towards the end of the century.[14] These urban areas are excluded from our sample. Another major improvement in the quality of the public transportation offering was the introduction of the hourly timetable in May 1982.[15] Its effect is accounted for by our year dummies as it affected all train connections simultaneously.

2.3 *Specification*

We identify the effect of highway access by exploiting the heterogeneity in the opening times of highway accesses across municipalities using the panel dimension.

We use a distributed lag model and focus on the long-term effect of highway access because we expect the effect of highways to materialize over time. Our baseline specification includes 10 two-year lags of the highway access variable (i.e. 20 years), yielding the following regression equation:

$$\ln n_{i,t} = \sum_{\tau=0}^{10} \beta_\tau \, Access_{i,t-\tau} + \alpha_i + \lambda_t + \rho_i \, t + \varepsilon_{i,t} \,, \qquad i = 1,...,782, \quad t = 1947,...,2010, \quad (23)$$

where subscripts i and t denote municipality and a two-year periods, respectively; $n_{i,t}$ is the number of taxpayers or the share of taxpayers in different income percentiles; $Access_{i,t}$ is a

[13] There is a borderline statistically significant (at 10%) difference in the share of bottom-50% income taxpayers. Differences in mean values are however very small and thus unlikely to have affected the highway opening year in a substantial way. Note that the negative growth rate of the number of taxpayers is due to changes in deductions of the federal income tax for the fiscal periods 1949/50 and 1951/52.

[14] For instance, Zurich's S-Bahn commuter train was launched in 1990, Basel's Regio-S-Bahn in 1997 (see Berger, Güller, Mauch and Oetterli, 2009).

[15] The hourly timetable ensures that the same train connections are offered at the same time every hour.

dummy variable that takes the value 1 for municipalities with access to a highway within a road distance of a certain number of kilometers, and zero otherwise; α_i is a municipality fixed effect, $\rho_i\, t$ is a linear municipality time trend, λ_t is a year fixed effect, and $\varepsilon_{i,t}$ is a municipality-year error term, clustered at the municipality level.

We are interested in the long-term impact of highway access, $\gamma \equiv \sum_{\tau=0}^{10} \beta_\tau$. Following Davidson and MacKinnon (2004, p. 575), we therefore reparametrize equation (23) by adding and subtracting $\sum_{\tau=1}^{10} \beta_\tau\, Access_{i,t}$, so that we can estimate γ directly:

$$\ln n_{i,t} = \gamma\, Access_{i,t} + \sum_{\tau=1}^{10} \beta_\tau \left(Access_{i,t-\tau} - Access_{i,t}\right) + \alpha_i + \rho_i\, t + \lambda_t + \varepsilon_{i,t}\,. \qquad (24)$$

Above, γ quantifies the effect on the variable of interest at the municipality level of getting a highway access at time t relative to getting it at a later stage. As such, it is thus a lower bound to the effect of getting a highway access relative to not getting it. The latter effect can be estimated using a difference-in-difference estimator, which we perform in Section 4.3.[16]

In the baseline specification, we only include one specific $Access_{i,t}$ variable, relating to all municipalities that eventually get an access to the highway within 10km.[17] In additional specifications, we include a vector of $Access_{i,t}$ variables (e.g., for 0-5, 5-10, 10-15, 15-20km) in order to identify the long-term effect for different distance bandwidths at the same time.

3. Results

In this section we report regression results of various estimations of equation (24).

3.1 *Size and Composition of Taxpayer Populations*

We start by estimating the long-term effects of highway access on the number of taxpayers (Qualitative Prediction no. 1 of Subsection 1.8) and on the income distribution (Qualitative Prediction no. 2) for our baseline sample of municipalities. Table 3 contains the results.

[16] Insofar as results are similar in magnitude, we conclude that treated and non-treated municipalities are similar conditional on municipality fixed effects and time trends.

[17] The 10km-buffer appears to be a reasonable threshold for our baseline specification for several reasons. First, like Faber (2014) for the Chinese National Trunk Highway System, we find that the effect vanishes quickly beyond 10km. Second, the typical distance between two highway stops in Switzerland equals 5-10km. A distance band of 10km around each access point implies that our sample of municipalities encompasses municipalities located in a corridor of roughly 10km on both sides of the highway. Third, as explained in Appendix B, the actual individual travel distances are likely distributed around our proxy by up to a few kilometers, due to the geographical spread of people within municipalities. Therefore, a more narrow definition (e.g., 5km) might exclude municipalities with individuals that are actually in close reach of the highway. Finally, close proximity to a highway also brings negative externalities to residents. For this reason, people are likely to desire living in municipalities close to, but not directly located along, a highway. Allowing for a distance of up to 10km takes such preferences into account.

All specifications include ten two-year lags, municipality fixed effects, and year dummies. Columns (2)-(6) also control for municipality-specific linear time trends.

Qualitative Prediction no. 1 (Municipality Size)

The long-term effect of getting a highway access within 10km on the number of taxpayers in the municipality is positive and statistically significant. Controlling for a municipality-specific time trend, in column (2), leads to a smaller estimated effect (the difference between the two being statistically insignificant). The effect of highway access is also economically significant: on average, the number of taxpayers twenty years (ten periods) after the opening of an access point within 10km is approximately 11.1% higher ($e^{0.105} - 1 = 0.1107$) than what it would be in the absence of such an access, had the taxpayer population of the municipality continued to grow along its trend.

Qualitative Prediction no. 2 (Municipality Composition)

Columns (3) to (6) investigate the effects of a highway access on the distribution of taxpayers within municipalities. The dependent variable is the natural logarithm of the share of various groups of taxpayers classified according to the percentiles of the nation-wide income distribution. Column (3) reports that the opening of a nearby highway access within 10km led to a decrease of the share of taxpayers with a below-median income by about 6.2%. Columns (4) to (6) indicate that the shares of taxpayers between the median and the third quartile, between the top quartile and the top decile, and of the top decile increased by 5%, 17.2%, and 18.8%, respectively. The difference between the effects reported in Column (4) and Column (5) is statistically significant, while results from Column (5) cannot be distinguished statistically from Column (6).

To sum up, we find that highway access has a positive effect on the size of local jurisdictions and shifts the income distribution towards higher incomes.

3.2 Employment Size and Composition

The results on the distribution of income reported in the previous subsection cannot fully distinguish between a heterogeneous increase in earnings and income sorting. For this reason, we complement these results with an analysis of the effects of highway access on employment by education level (Qualitative Prediction no. 2). For the sake of comparison with Table 3, we also report the effects of highway access on total employment (Qualitative Prediction no. 1).

Table 4 presents the results using decennial census data on the working population. The data cover the period 1950 to 2010. Because census data collect information only every ten years (seven decades), we have far fewer observations than in Subsection 3.1. We estimate our baseline equation (24) using two lags of our access dummy variable. We report results for employees residing in the treated municipality in Panel A and for employees working in the municipality in Panel B. All regressions include municipality fixed effects, year fixed effects, and municipality time trends. Thus, the coefficients of Table 4, Column (1) should be compared to those of Table 3, Column (2).

Qualitative Prediction no. 1 (Municipality Size)

The coefficient of the long term effect for the number of residents (Table 4, Panel A, Col. 1) is positive (+7,4%) and statistically significant while the long term effect for the number of workers (Table 4, Panel B, Col. 1) is also positive (+4,7%) but not statistically significant.

Qualitative Prediction no. 2 (Municipality Composition)

Columns (2) to (5) of Table 4 restrict the sample to years 1970-2010 for which employment by education level is available. The size of the sample drops further by more than a fourth and coefficients are less precisely estimated as a result. Column (2) replicates the specification of Column (1) and the estimated long-term effect effect loses statistical significance. Results on the composition effect show that highway access attracts high-skilled residents (Panel A, Col. 5) and workers (Panel B, Col. 5) disproportionally more than residents and workers with intermediate level of education (Col. 4). These results are consistent with the result of Table 3 on the share of top-income taxpayers.

3.3 Commuting

In this subsection we investigate the evidence for Qualitative Prediction no. 3. We expect that a highway access increases the numbers of in-commuters, while the effect on the number of out-commuters is ambiguous a priori. In both cases, the effect on commuters is predicted to be strongest at the top of the skill distribution.

We report the results in Table 4, Panels C and D. We find evidence that the number of in-commuters indeed increases by 19.5% as a result of highway access (Panel D, Col. 1). The effect is less precisely estimated for the census sub-sample of years 1970-2010 (Panel D, Col. 2). The composition of in-commuters also changes with an increase in the share of in-commuters with high education and a decrease in the share of in-commuters with intermediate level of education (Panel D, Col. 4 and 5). In contrast to in-commuters, we find no effect on the number of out-commuters (Panel C, Col. 1 and 2). However, consistent with our theoretical prediction, we do find a positive effect on the share of high-skilled out-commuters (Panel C, Col. 5).

It is instructive to cross these results with the 2015 survey results of the Federal Statistical Office's (2017) 'Microcensus Mobility and Transport', which reports an increase in the average commuting distance over time and a less-than proportional increase in the average commuting time, as well as a positive correlation between the daily distance traveled by a household and its income. Together, these results and our findings suggest that highways may ease the dual location choice of households and individuals as residents and workers and that this effect especially benefits those at the top of the skill distribution.

3.4 Sprawl

In this subsection we are interested in the relationship between urban sprawl and highway access. For this purpose, we include all urban municipalities to our sample. These are the 27 largest Swiss cities and towns, ranging from Zurich (382,623 inhabitants) to Locarno (15,637 inhabitants). Table 1, column (4), reports the summary statistics for this sample.

Table 5 reports the regression results. We find that highways contribute to the spatial decentralization of jobs and residences and that this process is especially pronounced for the high-skilled. Specifically, the coefficients in column (2) imply that highway access leads to substantial long term reductions in the numbers of residents and jobs in central municipalities: about a third for the former (-33%, Panel A) and about a quarter for the latter (-22%, Panel B). The reductions of the numbers of in- and out-commuters (Panels C and D) depict a similar picture.

Where do these residents and jobs move to? The coefficients of column (2) seem to be answering 'all over the place': the coefficients of the long-term effects on non-central municipalities are positive but imprecisely estimated. The coefficients of column (1), which we estimate using the longer panel, suggest that residents and jobs moved within 40km of the central municipality.

Columns (3) to (5) reveal a increase in the share of low-skilled residents and workers (Panel A) and workers (Panel B) in central municipalities, especially at the expense of the share of high-skilled residents and workers. The pattern for out-commuters is similar (Panel C). Interestingly, highway access leads to an increase in the share of high-skilled in-commuters in central cities, which implies that high-skilled residents flee central municipalities in highest number than high-skilled jobs.

Rossi-Hansberg, Sarte and Owens (2009) report that the sub-urbanization for both jobs and residences was at work in 1980-90 in the US. Our results suggest that the same pattern may be at work in Switzerland, especially at the top of the skill distribution, and that highways are contributing to it.

4. Further Results and Robustness Checks

4.1 Impact over Time

The baseline results for taxpayers presented in Table 3 examine the long-term effect of a highway access after 10 two-year periods, namely, 20 years. However, the opening of a nearby highway access likely already leads to effects that materialize over shorter time lags, as acknowledged by the vector of β_τ's in our baseline specification in (23) or (24). Here we investigate the shape of the impact over time, designing a strategy similar to Chandra and Thompson (2000); specifically, we include eight forward lags ($\tau \in \{-8,...,10\}$ in the terminology of subsection 2.3) and estimate the values of $\tilde{\beta}_\tau = \sum_{s=0}^{\tau} \beta_s$ for $\tau \geq 0$ and $\tilde{\beta}_\tau = \sum_{s=-8}^{\tau} \beta_s$ for $\tau < 0$. That is to say, $\tilde{\beta}_\tau$ estimates the effect of highway access τ periods after getting the access if τ is positive (and τ periods before it if τ is negative). We lump together years 20 and more in a single dummy variable. We include the same full set of municipality fixed effects, linear time trends, and year dummies as in our baseline specification, equation (24) and regression results in Table 3, Col. (2).

Figure 2 displays the results for the number of taxpayers as dependent variable. In line with expectations, the positive effect of the highway opening gradually increases over time as relocation and moving is costly and construction of new housing takes time. There is no effect for the years prior to the opening until 4 years before, indicating that pre-opening dynamics are correctly captured by the set of fixed effects. The positive impact of highway access observed after year -4 is likely driven by the construction of the highway itself, similar as for other major transportation infrastructures (Ahlfeldt and Feddersen, 2017). Remember that the number of taxpayers consists of households that do pay the federal income tax, i.e. are above exemption levels. An increase in the number of taxpayers reflects therefore both positive net in-migration (of non-poor taxpayers) as well as an increase in income of residents driven by more economic activity (due to, e.g., the construction of the highway). This explanation is supported by Figure 3, which displays the results for the number of taxpayers in the top-25% of the nation-wide income distribution. Highway access has no discernible impact on the number of top-income taxpayers before the highway opening.

4.2 Placebo Test for Opening Years

To further validate our baseline results we run a placebo experiment by randomizing 1,000 times the opening access date among the municipalities included in our sample (i.e. non-urban municipalities within 10km of a highway access). Figure 4 plots the distribution of the long-term coefficients obtained by estimating the baseline model for the number of taxpayers. Dashed lines show the implied estimate for which an effect is statistically significant at a 5% significance level. The red line is the coefficient from the baseline regression of Table 3, column (2). Figure 4 reports that our baseline estimate is three times as large as one obtained only by chance. It therefore confirms the positive effect of highway access on the number of taxpayers.

4.3 Difference-in-Differences Estimates

In our central specifications γ quantifies the long run effect of getting a highway access on the variables of interest at time t relative to getting it at an earlier time. Here, we report estimates of the effect of getting a highway access relative to not getting it, which we estimate using a difference-in-differences estimator, on the size and composition of municipalities. The number of municipalities in the extended sample almost doubles: about half of municipalities are never directly treated and thus form the 'control' group. With the exception of the average distance to the closest urban center, these municipalities are observationally similar to 'treated' municipalities in the senses that the averages and standard deviations of the variables of interest of the two groups are statistically indistinguishable at the usual confidence levels (see columns (2) and (3) of Table 1).[18]

Table 6 reports the results. The coefficients of this difference-in-differences specification are quantitatively close to those of our central within specification reported in Table 3. This result suggests that treated and untreated municipalities are similar, conditional on their time invariant characteristics and their specific time trend.

4.4 Heterogeneous Effects

Results in Table 3 are calculated for a single distance band of 0-10km around the highway access point. In Table 7, we differentiate the effect for distance bands of 5km width up to a distance of 20km. Here, the sample is the population of non-urban municipalities that gained access to the highway network within 20km during our observation period (the number of such municipalities is 1263, to be compared with 782 municipalities in our baseline sample).

Column (1) explores the effect of highway access on the number of taxpayers. Results show that the positive effect is restricted to municipalities within 10km from the highway access, with municipalities located further away experiencing no effect statistically significantly different from zero.

Columns (2) to (5) explore the effect on the distribution of taxpayers within municipalities for different distance bands. Change in income distribution are concentrated mainly among municipalities located between 5 and 15km. Interestingly, municipalities located between 10 and 15km experienced a shift to the right of their income distribution but no change in the

[18]The average distance to the closest urban center of the connected municipalities is 14% lower than that of the non-connected ones. This qualitative result is to be expected, since the purpose of the Swiss highway network is to connect its urban centers.

total number of taxpayers. Highway access has no effect on municipalities located beyond 15km, except for the top-10% income taxpayers.

Summary and Conclusion

In this paper we analyze the impact of a reduction in transportation costs on employment and the residential location decisions of a heterogeneous population. To this aim, we first develop a multi-region model with trade and commuting costs, and where workers are endowed with heterogeneous location preferences and labor productivity. Location choices are modeled as a multinomial logit. In this environment, high-skilled (high-income) workers are more sensitive to income and cost changes and, therefore, benefit more from an improvement in accessibility than lower skilled workers. The model leads to three predictions: (1) municipalities that get a highway connection attract more workers and more residents; (2) these municipalities also become relatively high-type abundant; and (3) the number of in-commuters increases while the effect on the number of out-commuters is ambiguous a priori. The effect is however strongest for both in- and out-commuters at the top of the skill distribution. A corollary of this mechanism is that highways contribute to skill-biased urban sprawl.

We provide empirical evidence for these theoretical predictions by analyzing the impact of the Swiss highway network on the number and distribution of taxpayers as well as on employment and commuting at the local level. For identification purposes, we primarily rely on time variation based on a long panel data set covering the period 1947-2010. Specifically, our sample consists of non-urban municipalities that eventually get access to a highway entry and exit point within 10km. We exploit the fact that the sections of the highway network, which had been defined to a large extent in 1960 by the federal parliament, were opened at different points in time spanning several decades. Using this 'within' variation mitigates potential issues resulting from differences in growth trends across municipalities that are unrelated to the transport infrastructure of interest, but might be systematically correlated with accessibility measures and thus undermine the common trend assumption.

Our results show that access to a new highway leads to an increase both in the total number of taxpayers and in the share of high-income taxpayers in our sample of Swiss municipalities. Highway access also has a causal effect on employment and on the number of in-commuters in the connected municipalities; the latter effect is driven by a rise in the number of highly educated workers. We also find an effect on the number of out-commuters at the top of the skill distribution. The empirical findings thus provide support for the theoretical predictions of the model. The data are also consistent with the hypothesis that Swiss highways contributed to urban sprawl in the country.

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Tables

Table 1: Summary statistics

	All municipalities	Non-agglomeration municipalities	Non-agglomeration municipalities, access within 10 km	Urban centers
	(1)	(2)	(3)	(4)
Population (in 1,000)	2.73	1.14	1.18	64.10
	(10.72)	(1.42)	(1.47)	(75.48)
#Taxpayers (in 1,000)	0.83	0.31	0.33	25.41
	(4.04)	(0.47)	(0.49)	(31.99)
Share in bottom-50% income	0.57	0.61	0.59	0.50
	(0.12)	(0.11)	(0.10)	(0.06)
Share in 50-25% quartile	0.23	0.23	0.23	0.25
	(0.05)	(0.06)	(0.05)	(0.02)
Share in top-25-10%	0.12	0.11	0.11	0.15
	(0.05)	(0.05)	(0.05)	(0.02)
Share in top-10% decile	0.08	0.06	0.06	0.10
	(0.06)	(0.04)	(0.04)	(0.03)
#Workers (in 1,000)	1.25	0.43	0.43	48.83
	(8.15)	(0.69)	(0.72)	(65.60)
Share with low education	0.34	0.37	0.36	0.24
	(0.17)	(0.18)	(0.17)	(0.09)
Share with middle education	0.53	0.52	0.53	0.54
	(0.12)	(0.13)	(0.13)	(0.06)
Share with high education	0.13	0.11	0.12	0.22
	(0.09)	(0.09)	(0.09)	(0.11)
#Residents (in 1,000)	1.24	0.51	0.53	31.18
	(5.47)	(0.66)	(0.68)	(38.79)
Share with low education	0.30	0.33	0.32	0.27
	(0.17)	(0.18)	(0.17)	(0.08)
Share with middle education	0.54	0.54	0.54	0.51
	(0.11)	(0.12)	(0.11)	(0.07)
Share with high education	0.16	0.13	0.14	0.22
	(0.11)	(0.10)	(0.10)	(0.12)

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	(1)	(2)	(3)	(4)
#Out-commuters (in 1,000)	0.56	0.23	0.26	7.56
	(1.37)	(0.33)	(0.36)	(8.39)
Share with low education	0.26	0.28	0.27	0.24
	(0.16)	(0.17)	(0.17)	(0.08)
Share with middle education	0.57	0.57	0.57	0.51
	(0.12)	(0.13)	(0.12)	(0.08)
Share with high education	0.17	0.15	0.16	0.24
	(0.12)	(0.11)	(0.11)	(0.12)
#In-commuters (in 1,000)	0.57	0.13	0.15	25.21
	(4.11)	(0.33)	(0.37)	(36.10)
Share with low education	0.30	0.31	0.31	0.20
	(0.18)	(0.21)	(0.20)	(0.09)
Share with middle education	0.57	0.58	0.58	0.56
	(0.17)	(0.20)	(0.19)	(0.07)
Share with high education	0.12	0.11	0.11	0.23
	(0.12)	(0.12)	(0.11)	(0.11)
Distance to closest urban center	22.80	27.12	23.36	-
	(16.14)	(16.54)	(13.03)	
No. of municipalities	2479	1571	782	27

Note: Standard deviation in parentheses. Population is based on yearly data for 1981-2010 and decennial census data for 1950-1980. Number of workers (residents) is the number of employees working (residing) in a municipality. The number of out-commuters (in-commuters) consists of the number of residents (workers) working (living) in another municipality. Source: Decennial population census data 1950-2010 (1970-2010 for decomposition by education level). Distance to the closest urban center is computed using the road network as of 2012 (including highways). An 'urban center' is a city of category 1 or 2 according to the nomenclature of the municipalities developed by the Swiss Federal Statistical Office (2000).

Table 2: Characteristics of municipalities getting a 10km-access to highway by time period

	Mean values for period 1947-1955 for restricted sample of municipalities				
	All opening years (1)	Access opened before 1970 (2)	Access opened 1970-1990 (3)	Access opened after 1990 (4)	Test equality p-value
Population (in 1,000)	0.94	0.90	1.00	0.82	0.26
	(1.13)	(0.99)	(1.27)	(0.87)	
#Taxpayers (in 1,000)	0.16	0.16	0.17	0.15	0.72
	(0.25)	(0.19)	(0.29)	(0.20)	
Share in bottom-50% income	0.62	0.62	0.63	0.62	0.09
	(0.10)	(0.10)	(0.10)	(0.10)	
Share in 50-25% quartile	0.21	0.21	0.21	0.21	0.15
	(0.06)	(0.06)	(0.06)	(0.06)	
Share in top-25-10%	0.11	0.11	0.10	0.11	0.11
	(0.06)	(0.06)	(0.06)	(0.06)	
Share in top-10% decile	0.06	0.07	0.06	0.06	0.16
	(0.04)	(0.05)	(0.04)	(0.04)	
#Taxpayers yearly growth rate	-7.27	-6.96	-7.72	-6.34	0.15
	(30.29)	(29.08)	(31.37)	(29.42)	
#Workers (in 1,000)	0.37	0.34	0.40	0.31	0.11
	(0.51)	(0.44)	(0.58)	(0.37)	
#Residents (in 1,000)	0.40	0.39	0.43	0.35	0.23
	(0.49)	(0.42)	(0.56)	(0.36)	
No. of municipalities	782	302	391	89	-

Note: Standard errors clustered at municipality level in parentheses. Taxpayer data are based on the Federal Income Tax statistics for the period 1947-1955. Population, workplace and residence-based employment are from the population census 1950.

Table 3: Impact of highway access on number and composition of taxpayers

	No taxpayers		Share of taxpayers			
			below 50%	top 50%-25%	top 25%-10%	top 10%
	(1)	(2)	(3)	(4)	(5)	(6)
Long-term effect ($\hat{\gamma}$)	0.117***	0.105***	-0.060***	0.049***	0.159***	0.172***
	(0.028)	(0.019)	(0.011)	(0.019)	(0.029)	(0.046)
10 periods lag included	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality time trends	No	Yes	Yes	Yes	Yes	Yes
No. of observations	24885	24885	24778	24722	24487	23386
No. of municipalities	782	782	782	782	782	782
R2-adjusted	0.968	0.985	0.713	0.424	0.562	0.479

Notes. *** p<0.01, ** p<0.05, * p<0.10. Standard errors (in parentheses) are clustered by municipality. The sample includes all municipalities within 10km from a highway access that are not part of a metropolitan area. Two-year panel covering the period 1947-2010. The dependent variable is the log of the number of taxpayers in columns (1) and (2) and the log of the share of taxpayers in different income percentiles in columns (3) to (6).

Table 4: Impact of highway access on employment size and composition

	No employees		Share of employees by education level:		
			low	middle	high
	(1)	(2)	(3)	(4)	(5)
Panel A: Residents					
Long-term effect ($\hat{\gamma}$)	0.071***	-0.013	-0.058	-0.059*	0.146*
	(0.021)	(0.036)	(0.046)	(0.030)	(0.075)
No. of observations	5201	3839	3823	3838	3765
No. of municipalities	782	782	782	782	781
R2-adjusted	0.986	0.988	0.887	0.777	0.887
Panel B: Workers					
Long-term effect ($\hat{\gamma}$)	0.046	0.045	0.030	-0.086**	0.212**
	(0.034)	(0.050)	(0.056)	(0.038)	(0.083)
No. of observations	5114	3749	3717	3747	3599
No. of municipalities	782	778	778	778	773
R2-adjusted	0.977	0.979	0.817	0.734	0.829
Panel C: Out-commuters					
Long-term effect ($\hat{\gamma}$)	0.022	-0.016	-0.071	-0.042	0.218***
	(0.034)	(0.045)	(0.057)	(0.035)	(0.080)
No. of observations	5197	3854	3799	3845	3640
No. of municipalities	782	782	780	782	774
R2-adjusted	0.971	0.978	0.808	0.663	0.851
Panel D: In-commuters					
Long-term effect ($\hat{\gamma}$)	0.178**	0.145	0.017	-0.124**	0.269*
	(0.080)	(0.092)	(0.090)	(0.056)	(0.150)
No. of observations	4901	3761	3467	3667	2832
No. of municipalities	779	779	760	776	685
R2-adjusted	0.935	0.951	0.592	0.486	0.639

Notes. *** p<0.01, ** p<0.05, * p<0.10. Standard errors (in parentheses) are clustered by municipality. The sample includes municipalities within 10km from a highway access that are not part of a metropolitan area. Column (1) presents results using 10-year census data from 1950-2010. Columns (2)-(4) restrict the sample to the period 1970-2010 and use only employees for which information on education level is available. The number of workers (residents) consists of the number of employees working (residing) in a given municipality. The number of out-commuters (in-commuters) consists of the number of residents (workers) working (living) in another municipality. All regressions include municipality fixed effects, time fixed effects, and municipality-specific time trends.

Table 5: Impact of highway access on urban sprawl (27 cities)

	No employees		Share of employees by education level:		
			low	middle	high
	(1)	(2)	(3)	(4)	(5)
Panel A: Residents					
Long-term effect (center)	-0.279***	-0.396***	0.966***	-0.223***	-1.214***
	(0.087)	(0.058)	(0.130)	(0.062)	(0.122)
Long-term effect (1-20 km)	0.104***	0.032	0.012	-0.095***	-0.005
	(0.027)	(0.036)	(0.044)	(0.022)	(0.056)
Long-term effect (21-40 km)	0.231***	0.016	-0.055	-0.034	0.138*
	(0.029)	(0.038)	(0.052)	(0.034)	(0.082)
Long-term effect (>40 km)	0.112	-0.017	0.145	-0.150*	-0.105
	(0.074)	(0.089)	(0.133)	(0.079)	(0.182)
No. of observations	10261	7553	7537	7552	7477
No. of municipalities	1528	1528	1528	1528	1527
R2-adjusted	0.986	0.992	0.891	0.794	0.905
Panel B: Workers					
Long-term effect (center)	-0.163**	-0.254***	0.216*	-0.135***	-0.575***
	(0.077)	(0.067)	(0.114)	(0.051)	(0.100)
Long-term effect (1-20 km)	0.138***	0.077*	0.050	-0.133***	0.129**
	(0.030)	(0.042)	(0.046)	(0.026)	(0.063)
Long-term effect (21-40 km)	0.102**	0.006	0.067	-0.056	0.308***
	(0.044)	(0.057)	(0.060)	(0.042)	(0.093)
Long-term effect (>40 km)	-0.079	-0.094	0.193	-0.164*	-0.127
	(0.089)	(0.144)	(0.139)	(0.092)	(0.215)
No. of observations	10169	7458	7423	7454	7288
No. of municipalities	1528	1524	1524	1524	1518
R2-adjusted	0.982	0.987	0.829	0.746	0.853

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	(1)	(2)	(3)	(4)	(5)
Panel C: Out-commuters					
Long-term effect (center)	-0.263***	-0.382***	1.325***	-0.263***	-0.994***
	(0.086)	(0.101)	(0.147)	(0.066)	(0.125)
Long-term effect (1-20 km)	0.018	-0.036	0.051	-0.067***	0.030
	(0.034)	(0.040)	(0.051)	(0.026)	(0.059)
Long-term effect (21-40 km)	0.197***	0.065	-0.082	-0.034	0.084
	(0.042)	(0.051)	(0.069)	(0.038)	(0.085)
Long-term effect (>40 km)	0.338***	0.066	0.029	-0.081	0.153
	(0.108)	(0.149)	(0.156)	(0.096)	(0.207)
No. of observations	10257	7569	7513	7560	7346
No. of municipalities	1528	1528	1526	1528	1520
R2-adjusted	0.979	0.987	0.832	0.717	0.880
Panel D: In-commuters					
Long-term effect (center)	-0.263***	-0.470***	-0.252*	-0.003	0.352***
	(0.087)	(0.101)	(0.131)	(0.056)	(0.132)
Long-term effect (1-20 km)	0.107	0.077	0.069	-0.067*	0.295***
	(0.069)	(0.072)	(0.070)	(0.037)	(0.104)
Long-term effect (21-40 km)	0.223**	0.119	0.028	-0.088	0.336**
	(0.092)	(0.102)	(0.088)	(0.058)	(0.144)
Long-term effect (>40 km)	0.330	-0.076	0.087	-0.096	0.380
	(0.242)	(0.286)	(0.221)	(0.147)	(0.318)
No. of observations	9890	7470	7126	7357	6305
No. of municipalities	1525	1525	1504	1521	1417
R2-adjusted	0.956	0.971	0.650	0.535	0.722

Notes. *** p<0.01, ** p<0.05, * p<0.10. Standard errors (in parentheses) are clustered by municipality. The sample includes all municipalities within 10 km from a highway access (including metropolitan areas). A 'center' is defined as a city of category 1 or 2 by the Swiss Statistical Office (27 cities). Column (1) presents results using 10-year census data from 1950-2010. Columns (2)-(4) restrict the sample to the period 1970-2010 and use only employees for which information on education level is available. The number of workers (residents) consists of the number of employees working (residing) in a given municipality. The number of out-commuters (in-commuters) consists of the number of residents (workers) working (living) in another municipality. All regressions include municipality fixed effects, time fixed effects, and municipality-specific time trends.

Table 6: Impact of highway access on number and composition of taxpayers – Difference-in-differences

	No taxpayers		Share of taxpayers			
			below 50%	top 50%-25%	top 25%-10%	top 10%
	(1)	(2)	(3)	(4)	(5)	(6)
Long-term effect ($\hat{\gamma}$)	0.065***	0.114***	-0.064***	0.037**	0.182***	0.241***
	(0.022)	(0.019)	(0.010)	(0.018)	(0.027)	(0.047)
10 periods lag included	Yes	Yes	Yes	Yes	Yes	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Municipality time trends	No	Yes	Yes	Yes	Yes	Yes
No. of observations	50083	50083	49847	49616	48874	45643
No. of municipalities	1571	1571	1571	1571	1570	1566
R2-adjusted	0.959	0.981	0.717	0.442	0.558	0.463

Notes. *** p<0.01, ** p<0.05, * p<0.10. Standard errors (in parentheses) are clustered by municipality. The sample includes all municipalities that are not part of a metropolitan area. Two-year panel covering the period 1947-2010. The dependent variable is the log of the number of taxpayers in columns (1) and (2) and the log of the share of taxpayers in different income percentiles in columns (3) to (6).

Table 7: Impact of highway access on number and composition of taxpayers - Distance bands

	No taxpayers	Share of taxpayers			
		below 50%	top 50%-25%	top 25%-10%	top 10%
	(1)	(2)	(3)	(4)	(5)
Long-term effect (0-5 km)	0.051*	-0.030*	-0.032	0.069*	0.181***
	(0.029)	(0.016)	(0.028)	(0.041)	(0.069)
Long-term effect (5-10 km)	0.106***	-0.077***	0.087***	0.236***	0.271***
	(0.024)	(0.013)	(0.023)	(0.038)	(0.063)
Long-term effect (10-15 km)	-0.018	-0.036***	0.054**	0.105***	0.181***
	(0.025)	(0.013)	(0.022)	(0.035)	(0.057)
Long-term effect (15-20 km)	-0.024	-0.006	-0.007	-0.000	0.115*
	(0.024)	(0.012)	(0.022)	(0.036)	(0.059)
No. of observations	40239	40059	39935	39483	37262
No. of municipalities	1263	1263	1263	1262	1262
R2-adjusted	0.984	0.712	0.436	0.565	0.462

Notes. *** $p<0.01$, ** $p<0.05$, * $p<0.10$. Standard errors (in parentheses) are clustered by municipality. The sample includes all municipalities within 20km from a highway access that are not part of a metropolitan area. Two-year panel covering the period 1947-2010. The dependent variable is the log of the number of taxpayers in column (1) and the log of the share of taxpayers in different nation-wide income percentiles in columns (2) to (5). All regressions include municipality fixed effects, time fixed effects and municipality-specific linear time trends.

Figures

Figure 1: Number of municipalities receiving a highway access within 10km, by opening year (frequency, left axis; and cumulative, right axis).

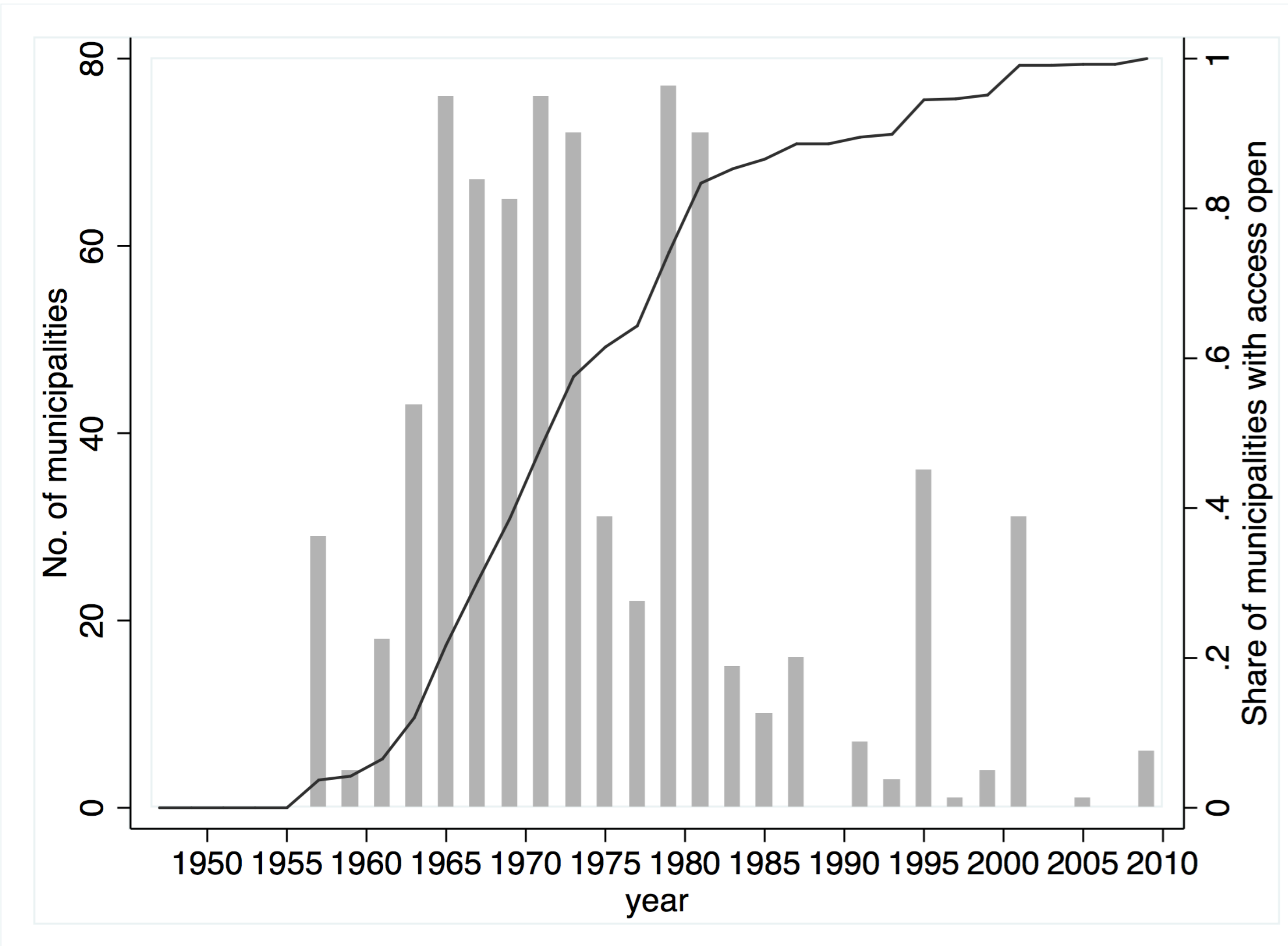
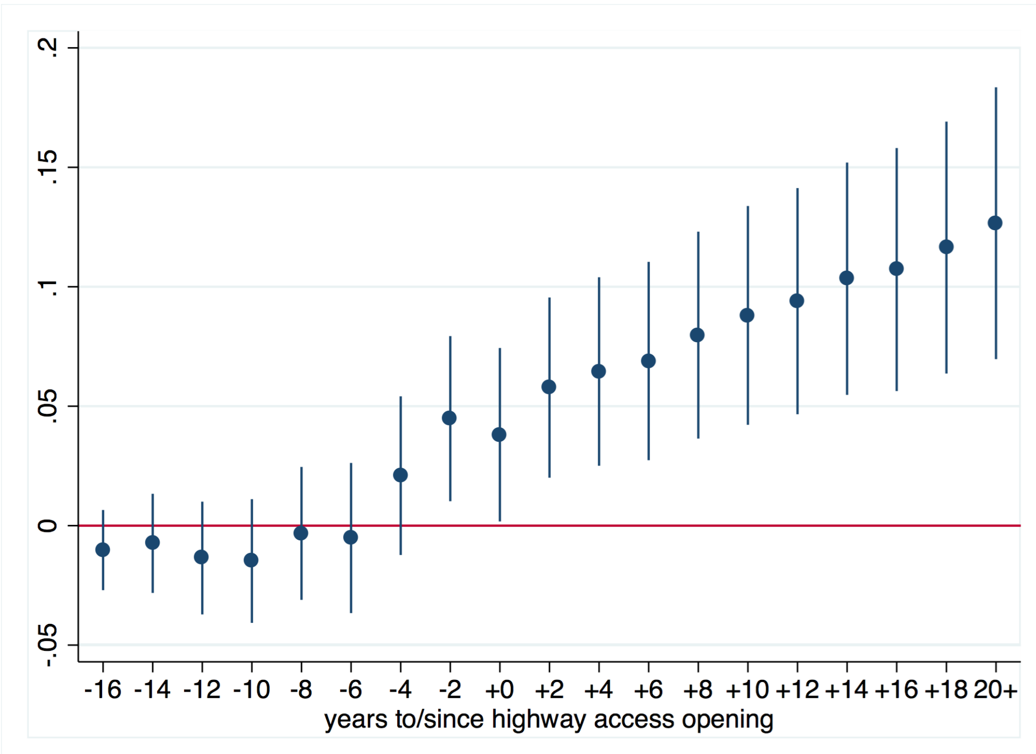
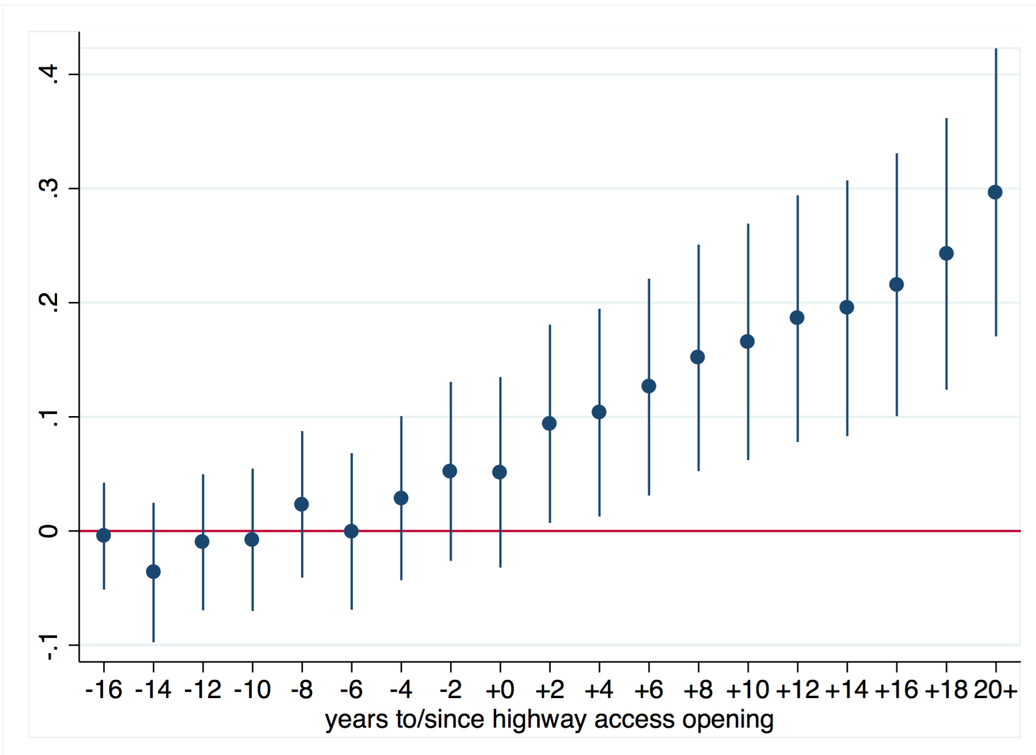


Figure 2: Effect on number of taxpayers over time



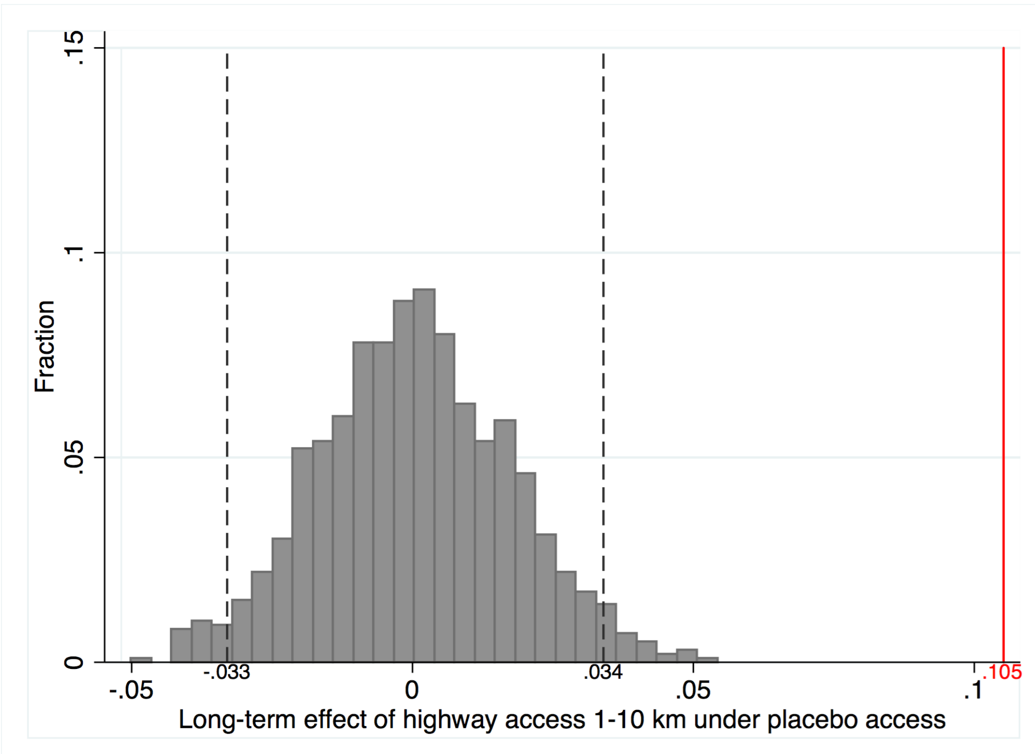
Note: The figure shows the point estimates of dummy variables for 16 years before and up to 20 years after the opening of the highway access. The last dummy variables takes the value 1 after 20 years and during all years thereafter. Vertical bars denote the 95% confidence interval of the estimates. The dependent variable is the log of the number of taxpayers. The sample includes all municipalities within 10km from a highway access that are not part of a metropolitan area. The regression includes municipality fixed effects, time fixed effects and municipality-specific linear time trends. Two-year panel covering the period 1947-2010.

Figure 3: Effect on number of top-25% income taxpayers over time



Note: The figure shows the point estimates of dummy variables for 16 years before and up to 20 years after the opening of the highway access. The last dummy variables takes the value 1 after 20 years and during all years thereafter. Lines denote the 95% confidence interval of the estimates. The dependent variable is the log of the number of taxpayers in the top quartile of the nation-wide income distribution. The sample includes all municipalities within 10km from a highway access that are not part of a metropolitan area. The regression includes municipality fixed effects, time fixed effects and municipality-specific linear time trends. Two-year panel covering the period 1947-2010.

Figure 4: Effect on the number of taxpayers - placebo test



Note: Highway access opening date randomized 1,000 times. The dependent variable in the log of the number of taxpayers. The sample includes all municipalities within 10km from a highway access that are not part of a metropolitan area. The regression includes municipality fixed effects, time fixed effects and municipality-specific linear time trends. Two-year panel covering the period 1947-2010. Dashed lines show the implied estimate for which an effect is statistically significant at a 5% significance level. Red line is the coefficient from the baseline regression.

Appendix A. Background on the Swiss Highway Network

Compared to some of its neighboring countries such as Germany and Italy, Switzerland began relatively late to construct its own national highway network. After World War II, the number of cars in Switzerland experienced a strong increase: from 18,000 personal cars in 1945 to 150,000 in 1950 and 500,000 in 1960 (Grotrian, 2007, p. 44). As a result, motorized traffic rose strongly and in the late 1950s, the federal government created a planning commission for a national road network. Before 1950, several ideas for highway projects in specific regions (e.g., between Berne and Thun) had been put forward, but none had been realized (see Blum, 1951, pp. 137-144).

The commission analyzed different options for the scope of the future road network, based on the guiding principle that the national road network should only serve the most important transport needs, i.e. primarily long-distance travel (Planungskommission, 1959, Band 2, p. 1). The proposal for the national road network not only consisted of highways, but of three different types of roads, including some class III roads that were opened to non-motorized traffic as well. In contrast, class I and class II roads were restricted to motorized travel, with class I roads always requiring a complete separation of the directions of travel and at least four lanes, two in each direction (Planungskommission, 1959, Band 1, pp. 65-66). In 1960, the Swiss parliament passed the national roads law and thus also defined the future location of highways in Switzerland to a large extent.

The subsequent construction of the network spanned over several decades, with cantons being responsible for detailed planning and actual construction work. As one of the first sections, the highway between Geneva and Lausanne was opened to public in 1963/1964, on time for the 1964 national exhibition in Lausanne. A substantial portion of the highway A1 connecting Geneva in the west with St. Gallen in the east was completed in the late 1960s. Other highways constructed during this early phase included a large portion of the A3 linking Zurich with the canton of Grisons, and first highway sections in the canton of Ticino. Other parts of the network, including the construction of the A2 crossing Switzerland from north (Basel) to south (Chiasso), followed a few years later.

Figure Appendix A.1 contains a map of Switzerland's municipalities and its national motorway network as of 2012[1]. The map on the top shows, in light grey, municipalities with an access point located within 10km reach that was open in 1960, while the map at the bottom shows municipalities with an access point within 10km open in 2010, the end of our observation period. Note that municipalities close to the A16 'Transjurane' (North/North-West) are not included in our sample as this highway was not part of the original planned network but added in 1984 after the creation of the canton of Jura. Shaded

[1]See Section Appendix B for a definition of motorways and other types of highways.

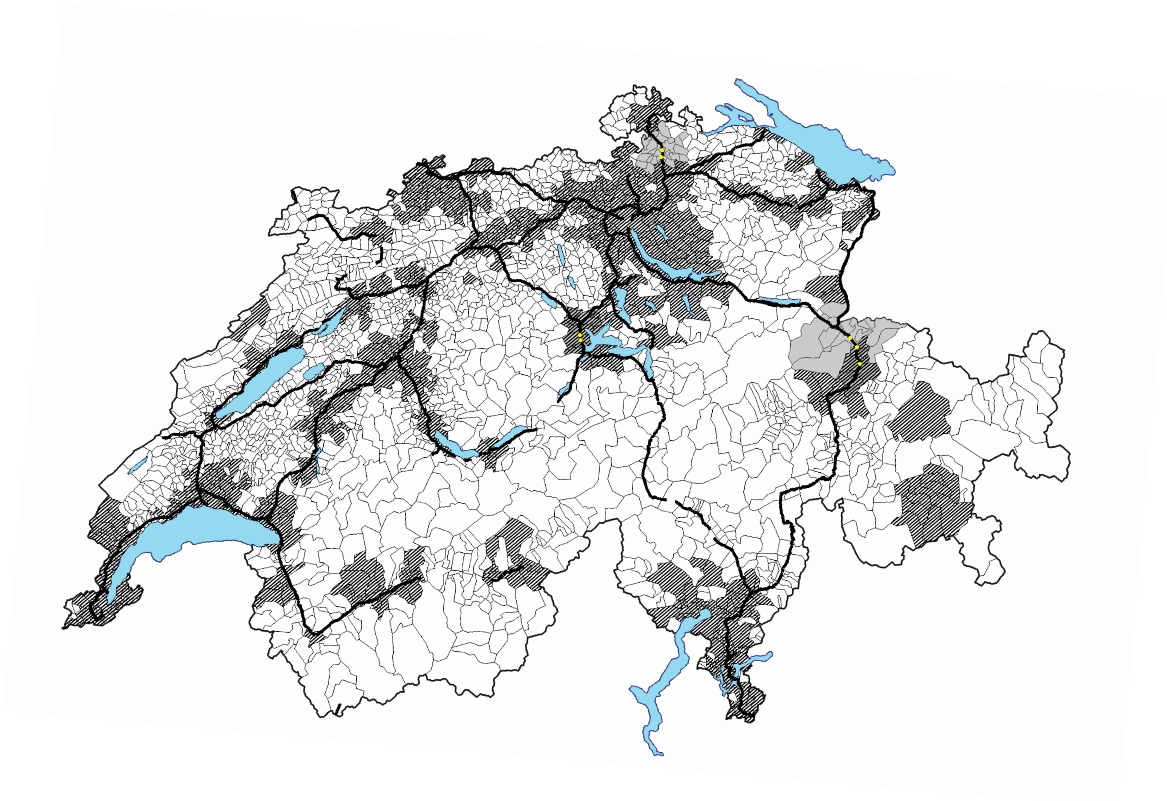
areas are municipalities that are part of a metropolitan area, as defined by the Federal Statistical Office in 2000.

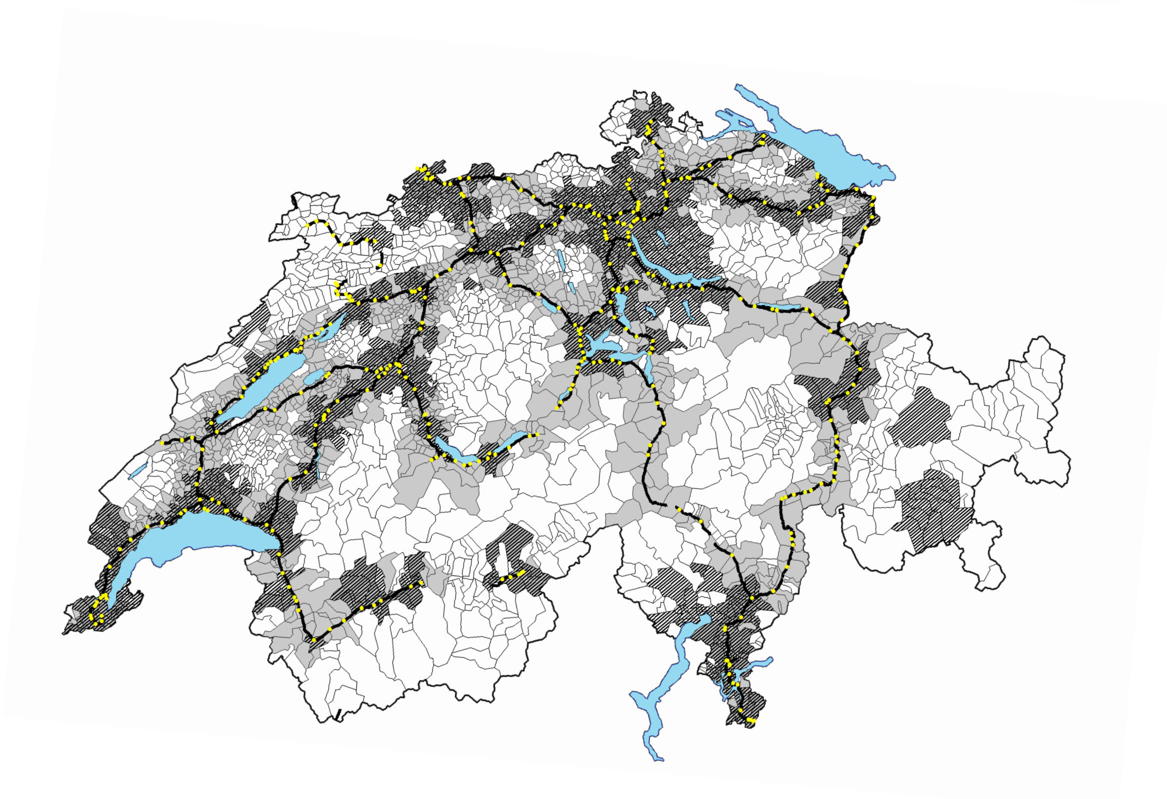
Besides the cantons, also municipalities and the general public (e.g., land owners) were granted a say in the planning process of the highway network. As a result, the construction of the Swiss highway network was characterized by a 'certain inertia' not present in other countries (Ruckli, 1966, p. 7). Moreover, starting in the 1970s, there was growing opposition against new highway construction by environmental groups, which further slowed down the process (Schärer, 1999). In 1978, the Federal Council established a commission to reevaluate the expected benefits of six highway sections that were planned, but not yet constructed. The recommendation by the commission was to keep all investigated sections in the network, with the exception of one (see Kommission zur Überprüfung von Nationalstrassenstrecken, 1981). In 1986, the national parliament decided differently, removing two other sections from the network (Fischer & Volk, 1999).

Today, the Swiss national road network has a defined length of 1,892.5km, only slightly more than the originally planned network of 1,840km. Of these national roads, roughly 69km still have to be built (Bundesamt für Strassen, 2017). In addition, some cantons have also established cantonal highways that are not part of the national road network. These highways represent only a small fraction of all highways, however.

Until 2007, construction and maintenance of the national roads was the responsibility of the cantons, under supervision of the federal government. However, the cantons received substantial financial contributions from the federal government (Ruckli, 1966). These federal funds came from taxes on gasoline, payments from the general budget, and since 1985 from a yearly lump-sum user fee to use the national highways (the so-called 'vignette'). In the initial years between 1959 and 1965, the average funding share of the federal government equaled 86 percent (Ruckli, 1966, p. 9). Cost of highway construction rose substantially over time, soon reaching a multiple of the originally projected cost. By 1996, the estimated cost of the network had increased tenfold (Heller & Volk, 1999). As of January 1, 2008, the national roads and all responsibilities were transfered to the federal government (Galliker, 2009). The national road network plays a crucial role for both traffic within Switzerland and transit across Europe. The national roads account for only 2.5 percent of all roads in Switzerland, but carry more than 40 percent of all motorized traffic (Bundesamt für Strassen, 2014).

Figure Appendix A.1: Municipalities with highway access in 1960 and 2010





Note: Shaded areas denote municipalities that are part of a metropolitan area as defined by the Federal Statistical Office in 2000. Municipalities with highway access within 10km road distance are in light gray. Access points open at a given year are in yellow.

Appendix B. Data on Highway Access Points

Our database of highway access points is based on all access points contained in the VECTOR200 database from the Swiss Federal Office of Topography, swisstopo (version as of 2013). For each access point, we identified the opening date based on a list with highway section opening dates provided by the Swiss Federal Roads Office (ASTRA). For access points for which the list from ASTRA did not contain an opening date, we relied on information presented in Fischer and Volk (1999), historical maps from swisstopo accessed via their website, and on other public information sources (press releases, newspaper articles, etc.). For access points that were subject to capacity enhancements, we used the year when a new section was originally opened to public, rather than when it was upgraded later. One limitation of this definition is that some important upgrades of the network (such as the Kerenzerberg Tunnel along Walensee) are not captured in our database.

We limit our analysis to highways that have the status of national motorways ('Autobahnen') or dual-carriageways ('Autostrassen'), i.e. we exclude from the analysis cantonal highways. According to the swisstopo classification, national motorways encompass all fast-traffic controlled-access national roads with at least two lanes in each direction and a dividing strip while national dual-carriageways are defined as a national motorways without a dividing strip (with a lower speed limit). Cantonal highways (motorways and dual carriageways) were not necessarily built in order to connect Switzerland's large cities, but to improve accessibility of specific cities or regions[2]. Therefore, their construction is prone to be endogenous to local economic development.

For each town and year, we use the ArcGIS software to calculate the minimum road distance to the next highway access point based on the non-highway road network listed in the VECTOR200 database. These distances serve as proxy for the actual road distance between the place of residency in a municipality and the next highway access point. The actual road distance may slightly deviate from this measure for two main reasons: First, a municipality may contain more than one town and not all residents live at the town center. Second, certain local roads which are part of our road network database (consisting of all roads opened at the end of 2012) may have only been constructed during the course of the observation period. However, the average area of a municipality only equals approximately 16km^2. Therefore, these deviations should be fairly small and not systematically bias the results, as distances would be overestimated for some residents and underestimated for others. For municipalities consisting of more than one town, we use the minimum distance. The same procedure was used for municipalities that merged over the observation period.

[2]We distinguish between national and cantonal motorways by the requirement of national motorways to display the national motorway tax vignette on the car.

Based on the estimated travel distance to the next highway access point, we clustered municipalities into different distance bands: 1-5km, 5-10km, 10-15km and 15-20km. Distance band 1-5km includes all municipalities with a calculated road distance of up to 5.0km, band 5-10km all municipalities with a distance larger than 5.0km and up to 10.0km, band 10-15km all municipalities with a distance larger than 10.0km and up to 15.0km, and band 15-20km all municipalities with a distance larger that 15.0km and up to 20.0km. We exclude all 908 municipalities that are part of a metropolitan area based on the definition by the Swiss Federal Statistical Office in 2000, to further reduce potential endogeneity concerns (see Section 2.2 for details). We also do not look at municipalities located 20km and further away from highway access points as these municipalities are to a large extent concentrated in mountainous regions in the cantons of Valais and Berne.

According to the report by the national planning commission, 5, 10 and 15km represent relevant thresholds for the impact reach of highways. Based on an analysis of personal, labor, business, cultural and touristic relations, the planning commission estimated that the density of relations decreases according to the following pattern (see Planungskommission,1959, Band 2, p. 44): 100% in 0-5km, 75% in 5.1-7.5km, 50% in 7.6-10.0km, 25% in 10.1-12.5km, and 10% in 12.6-15.0km.

Spatial Economics Research Centre (SERC)
London School of Economics
Houghton Street
London WC2A 2AE

Web: www.spatialeconomics.ac.uk