General Equilibrium Effects of a Major Rail Investment: First Results from a Quantitative Spatial Model for Ticino, Switzerland

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1 Abstract

This paper applies a quantitative spatial model (QSM) to the Ceneri Base Tunnel in Ticino, Switzerland, producing general equilibrium predictions of how a major rail investment reshapes the spatial economy. The model adapts the Hörcher and Graham (2025) framework, which extends the standard QSM with a dual budget constraint that separates monetary and time costs of commuting, yielding an endogenous, pair-specific marginal value of time. Because spatially disaggregated floorspace price data is unavailable for the study area, we reverse the standard QSM inversion procedure: prices are recovered from observed floorspace stock using endogenous aggregates from the commuting block — an approach that, to our knowledge, has not been implemented in the QSM literature. Applied to 195 zones in the Bellinzona–Lugano corridor, the model predicts employment concentration in Lugano (+5%), residential decentralisation towards Bellinzona (+2%), and a productivity gain in Lugano (+0.3%) driven by agglomeration externalities. Wages decline across both agglomerations as effective labour supply rises. The average value of time experienced by commuters falls from 17.7 to 17.4 CHF/hr, yet the structural welfare measure registers a positive gain (+0.08%) — a divergence that connects to the theoretical literature on the value of travel time savings and has implications for how transport investments are evaluated.

Keywords: quantitative spatial models, general equilibrium, transport appraisal, value of time, rail infrastructure, spatial economics

2 Introduction

Large transport infrastructure investments do not merely redistribute passengers across routes. They change the relative attractiveness of residential and employment locations, shift land-use pressure between municipalities, and alter the economic geography of the region they serve. Evaluating such effects requires a model in which transport, location choices, and the spatial economy adjust jointly — in general equilibrium.

Quantitative spatial models (QSMs) provide this structure. QSMs jointly represent residential and workplace location choice, wages, floorspace prices, and commuting flows within a spatial general equilibrium framework Redding & Rossi-Hansberg (n.d.). The framework shares core features with the *spatial computable general equilibrium* (SCGE) tradition — discrete location choice and microeconomic welfare foundations are central to both QSMs and established SCGE models such as RELU-TRAN Anas & Liu (n.d.). The methodological advance of QSMs lies in *identification*: a smaller set of structural parameters is estimated from data using the model's own equilibrium conditions, rather than calibrated externally. Ahlfeldt et al. n.d. developed the first QSM to study the effects of the division and reunification of Berlin. Heblich, Redding, and Sturm n.d. subsequently applied the framework to the historical expansion of the London railway network, and

Allen and Arkolakis n.d. developed the welfare analysis of transportation infrastructure in a related spatial equilibrium setting. Monte, Redding, and Rossi-Hansberg n.d. extended the framework to commuting and migration with local employment elasticities. These models demonstrate the capacity of QSMs for evaluating large transport investments.
This paper presents first results from a QSM applied to the Ceneri Base Tunnel (CBT) in Ticino, Switzerland. The CBT opened in December 2020, cutting rail travel times between the canton's two main urban centres roughly in half: Bellinzona–Lugano from 27 to 14 minutes. The prototype adapts the quantitative urban model of Hörcher and Graham n.d., which extends the Ahlfeldt et al. framework with a dual budget constraint that separates monetary and time costs of commuting. The model is applied to the urban core of the Bellinzona–Lugano corridor — 195 transport analysis zones where the urban structure is well-defined and the data inputs are most reliable. A methodological contribution is the inversion procedure: because no floorspace price index with sufficient zonal coverage could be obtained, the standard QSM inversion — which takes observed prices as input and recovers location fundamentals — is reversed. Prices are instead recovered from observed floorspace stock using endogenous aggregates from the commuting block. To our knowledge, this reversal of the empirical pipeline has not been implemented in the QSM literature, where spatially disaggregated price data is treated as a prerequisite for inversion Ahlfeldt, Carozzi, et al. (n.d.). General equilibrium predictions are reported for population, wages, floorspace prices, and agglomeration-driven productivity.

3 Model

This section summarises the model structure following the notation of Hörcher and Graham n.d.; full derivations are provided there and in Ahlfeldt et al. n.d.. The economy consists of n discrete zones connected by a transport network. Three groups of agents interact: *households*, who choose where to live and work; *firms*, who produce a tradable good using labour and commercial floorspace as inputs; and a *construction sector*, which supplies floorspace subject to a capacity ceiling. For brevity, this section focuses on the household problem and location choice; the production and wage equations, floorspace supply, and the data inversion procedure are described in the Appendix.

Household problem

A worker residing in zone i and commuting to workplace j derives utility from leisure L_{ij}, consumption C_{ij}, and residential floorspace H^R_{ij}:

$$U_{ij} = \left(\frac{L_{ij}}{1-\gamma}\right)^{1-\gamma} \left(\frac{K_{ij}}{\gamma}\right)^{\gamma} z_{ij}, \qquad K_{ij} = \left(\frac{C_{ij}}{\beta}\right)^{\beta} \left(\frac{H^R_{ij}}{1-\beta}\right)^{1-\beta}, \tag{1}$$

where z_{ij} is an idiosyncratic taste shock drawn from a Fréchet distribution. The household faces two separate budget constraints. The pecuniary budget links labour income net of monetary commuting cost τ_{ij} to expenditure on consumption and floorspace:

$$x_{ij}(w_j - \tau_{ij}) = p_i C_{ij} + q_i H^R_{ij}, \tag{2}$$

where x_{ij} is individual labour supply, w_j the wage at workplace j, and q_i the floorspace price at residence i. The time budget allocates the daily endowment $\bar{L}$ between leisure, work, and commuting:

$$\bar{L} = L_{ij} + x_{ij}(T + t_{ij}), \tag{3}$$

where T is the length of a working day and t_{ij} is commuting time. This double-constraint

structure replaces the standard iceberg treatment of transport costs.[1] Here, both travel time and monetary cost affect utility directly through their respective constraints, producing an endogenous, pair-specific marginal value of time:

$$v_{ij} = \frac{w_j - \tau_{ij}}{T + t_{ij}}. \tag{4}$$

This can be interpreted as an hourly net wage that varies across all residence-workplace pairs. Individual labour supply is

$$x_{ij} = \frac{\gamma \bar{L}}{T + t_{ij}}, \tag{5}$$

so that longer commutes reduce work participation — a channel through which transport supply affects labour markets directly. This is the mechanism behind the wage results reported in Section 3: when the tunnel reduces commuting times, labour supply increases, raising the effective workforce at destination zones and putting downward pressure on wages through the production function (Appendix A).

Location choice and commuting gravity

Idiosyncratic taste shocks — reflecting unobserved individual preferences such as proximity to family — are drawn from a Fréchet distribution with shape parameter ϵ and location-specific scales X_i and E_j, representing residential and workplace amenity fundamentals.[2] The share of workers living in i and working in j takes the form of a commuting gravity equation:

$$\lambda_{ij} = \frac{X_i E_j \left[\frac{v_{ij}}{p_i^{\beta} q_i^{1-\beta}}\right]^{\gamma\epsilon}}{\sum_{r,s} X_r E_s \left[\frac{v_{rs}}{p_r^{\beta} q_r^{1-\beta}}\right]^{\gamma\epsilon}}. \tag{6}$$

The composite exponent $\nu = \gamma\epsilon$ governs the sensitivity of commuting flows to transport costs and is a key elasticity for counterfactual analysis. Residence and workplace populations follow as $N_i^R = N \sum_j \lambda_{ij}$ and $N_j^W = N \sum_i \lambda_{ij}$, where N is the total population of commuters.

The model is *invertible*: given observed data in a baseline year, location fundamentals — amenities, productivities, and floorspace capacity ceilings — are recovered as structural residuals of the equilibrium conditions (Hörcher & Graham, n.d., sec. 4). Counterfactual analysis then perturbs one or more inputs — here, the bilateral travel time matrix — holding fundamentals fixed, and solves for the new equilibrium. Structural parameters are adopted from Hörcher and Graham n.d.; the floorspace supply specification and data inversion procedure are detailed in the Appendix.

4 Application: the Ceneri Base Tunnel

Study area

The CBT connects Bellinzona and Lugano through the Ceneri mountain, halving rail travel times between the two agglomerations. This is a large and spatially concentrated accessibility shock, well suited to the quasi-experimental identification strategies common

[1] In iceberg transport costs, costs are proportional to the value shipped rather than additive. This convention, originating in trade theory, means that travel time and monetary cost cannot enter the utility specification separately.

[2] In the discrete choice literature, the location-specific scales X_i and E_j play the same role as alternative-specific constants in logit models. The Fréchet distribution belongs to the Type II extreme value family and produces choice probabilities consistent with the McFadden random utility framework McFadden (n.d.).

in the QSM literature Ahlfeldt, Redding, et al. (n.d.); Heblich, Redding, et al. (n.d.). The model is applied to 195 transport analysis zones covering the urban and periurban area of both agglomerations — the corridor where the accessibility gain is largest, where the urban structure supports the model's assumptions, and where the data inputs are most reliable. Baseline data combines employed and workplace populations from the national commuter matrix, travel times from a national transport model (pre- and post-CBT), floorspace stock from the federal building register, and wages constructed from sectoral wage averages and local employment composition.

Results

Both a baseline (pre-CBT) and a counterfactual (post-CBT) equilibrium have been solved.[3] The scenario perturbs only the travel time matrix, holding all other inputs and fundamentals fixed.

The model predicts that the CBT strengthens Lugano's role as the central business district while Bellinzona specialises as a residential location. In aggregate, the Lugano agglomeration gains approximately 3,200 workers (+5%) and loses roughly 500 residents (-1%); the Bellinzona agglomeration shows the mirror image, gaining about 500 residents (+2%) while losing approximately 3,200 workers (-14%). This pattern is consistent with the standard prediction of urban economic models: a commuting cost reduction strengthens the dominant employment centre while enabling residential decentralisation — a mechanism demonstrated empirically by Heblich, Redding, and Sturm n.d. for the London underground expansion.

Figure 1 shows the spatial distribution of these changes across the four main outcome variables: residential population, workplace population, average floorspace prices, and wages. Wages decline slightly across both agglomerations (Bellinzona –1.4% on average, Lugano –0.8%), reflecting the increase in effective labour supply at each workplace as commuting costs fall. Average floorspace prices (combining residential and commercial uses) rise in Lugano (+2.0%), where the concentration of economic activity increases demand, and fall in Bellinzona (–7.1%), where the loss of workers reduces commercial floorspace demand by more than the residential gain from new residents. The spatial reallocation of workers also feeds back into productivity through agglomeration externalities: total factor productivity rises in Lugano (+0.3%) as employment concentrates, and falls in Bellinzona (–0.9%) as it thins out — a channel that reinforces the initial concentration effect.

Figure 2 shows the distribution of changes in the endogenous marginal value of time Δv_{ij} across all origin-destination pairs, weighted by counterfactual commuting flows. The bulk of OD pairs experience a small decline in v_{ij}, driven by the general equilibrium wage adjustment: as effective labour supply rises at each workplace, wages fall, reducing the numerator of $v_{ij} = (w_j - \tau_{ij})/(T + t_{ij})$. A visible positive tail reflects the tunnel-affected pairs where the reduction in commuting time dominates the wage decline. The average VoT experienced by commuters falls from 17.7 to 17.4 CHF/hr, because workers sort into longer-commute pairs that carry a lower v_{ij}.

This compositional shift does not imply a welfare loss. In the Fréchet framework, expected utility before drawing taste shocks is (Hörcher & Graham, n.d., eq. 47):

$$E[U] = \Gamma\left(\frac{\epsilon - 1}{\epsilon}\right)\left[\sum_{i,j} X_i E_j \left(\frac{v_{ij}}{p_i^{\beta}\, q_i^{1-\beta}}\right)^{\gamma\epsilon}\right]^{1/\epsilon}, \tag{7}$$

which accounts for the full location choice problem, not just the marginal value of time on a single pair. This measure registers a positive welfare gain of +0.08%. Workers

[3] A *counterfactual* scenario changes one or more model inputs while holding structural fundamentals fixed, isolating the causal effect of an intervention. In this paper, *scenario* refers to a counterfactual scenario unless stated otherwise.

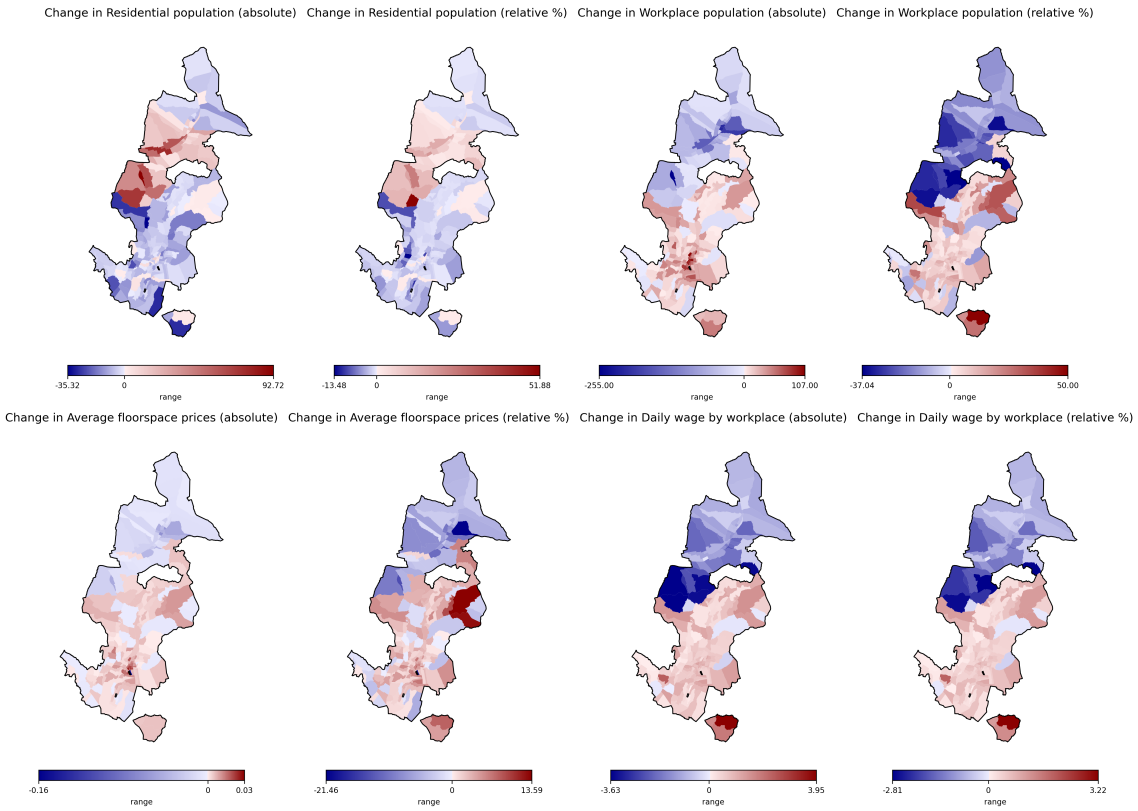


Figure 1: Bellinzona–Lugano corridor (195 zones): predicted changes in residential and workplace population, floorspace prices, and wages following the Ceneri Base Tunnel opening. Left column: absolute changes. Right column: percentage changes.

voluntarily sort into pairs with lower v_{ij} because the overall utility — combining access to the Lugano labour market and lower housing costs in Bellinzona — is higher on the new pair than on the old one. The VoT distribution illustrates both the direct benefit of reduced commuting times and the general equilibrium adjustment that partially offsets it, but it is not itself a sufficient welfare statistic.

5 Discussion

The results demonstrate that a QSM can produce internally consistent general equilibrium predictions for a real transport investment in Switzerland. The predicted spatial pattern — employment concentration in the dominant centre, residential redistribution towards the newly accessible periphery — aligns with the theoretical expectations of urban economics and with the direction of effects found in comparable QSM applications to Berlin Ahlfeldt, Redding, et al. (n.d.) and London Heblich, Redding, et al. (n.d.); Hörcher & Graham (n.d.). The wage response illustrates a channel absent from partial equilibrium analysis. The inflow of commuters into Lugano increases effective labour supply, which puts downward pressure on wages through the production function. This adjustment partially offsets the direct benefit of reduced commuting costs.

The endogenous value of time is the model's most distinctive output for transport applications. The dual budget constraint produces a v_{ij} that varies by origin-destination pair and responds to the transport intervention itself. The VoT distribution (Figure 2) shows that the average VoT experienced by commuters falls from 17.7 to 17.4 CHF/hr, yet the structural welfare measure (equation 7) registers a positive gain (+0.08%). This distinction — between a partial indicator (v_{ij}) and the structural welfare measure — connects to the theoretical literature on the value of travel time savings Jara-Díaz (2007) and has

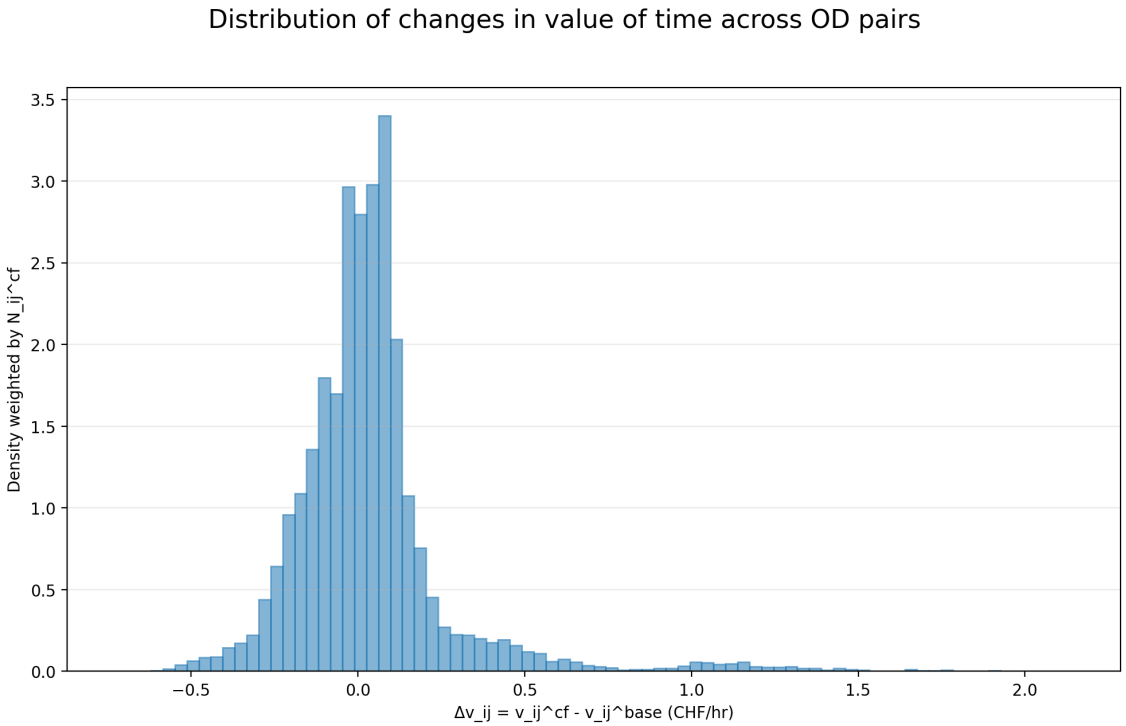


Figure 2: Distribution of changes in the endogenous marginal value of time across origin-destination pairs, weighted by counterfactual commuting flows. Aggregate welfare change computed from the Fréchet expected utility is +0.08%.

implications for how transport investments are evaluated.

The aggregate welfare gain of +0.08% is modest, reflecting in part the restricted geographic scope: zones outside the Bellinzona–Lugano corridor that also benefit from reduced travel times — including the Locarno region and cross-border commuters from Italy — are excluded. The absence of explicit mode choice means that travellers who switch from road to rail cannot be represented, so a potentially important demand response is missing Herzog (n.d.); Tsivanidis (n.d.); Barwick, Li, et al. (n.d.). Structural parameters are adopted from a London calibration Hörcher & Graham (n.d.), and the floorspace stock-inversion procedure introduces noise in the price signal. These limitations compress the welfare estimate but do not affect the qualitative spatial patterns, which are governed by the model's equilibrium structure rather than by specific parameter values. The results demonstrate what a QSM delivers beyond conventional appraisal: spatially disaggregated predictions of population redistribution, wage adjustment, floorspace price response, and a distributional account of how the value of time changes across commuter pairs.

6 Conclusion

This paper has applied a quantitative spatial model to the Ceneri Base Tunnel, producing general equilibrium predictions of population redistribution, wage adjustment, and floorspace price response across the Bellinzona–Lugano corridor. The model captures mechanisms absent from partial equilibrium appraisal: wages decline as the tunnel increases effective labour supply, and workers sort into commuting pairs that offer higher overall utility despite a lower marginal value of time — the average experienced VoT falls from 17.7 to 17.4 CHF/hr even as aggregate welfare rises by +0.08%. The endogenous, pair-specific value of time produced by the dual budget constraint Hörcher & Graham (n.d.) is a distinctive output for transport applications, connecting structural welfare measurement to the theoretical literature on the value of travel time savings. The current

application uses structural parameters from a London calibration; estimating these on Swiss data and extending the model with explicit mode choice are the immediate next steps.

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A Production and wages

Firms in zone j produce a single freely traded good with a Cobb-Douglas production function in aggregate effective labour supply M_j^W and commercial floorspace H_j^W, scaled by local productivity A_j:

$$Y_j = A_j (M_j^W)^{\alpha} (H_j^W)^{1-\alpha}. \tag{A1}$$

Aggregate effective labour supply $M_j^W = \sum_i \lambda_{ij} x_{ij} N$ differs from workplace population N_j^W because individual labour supply x_{ij} varies with commuting costs. Perfect competition, free entry, and zero trade costs within the study area allow normalising the consumption price to $p_i = 1$ for all i. The zero-profit condition pins down wages as a function of productivity and the commercial floorspace price Q_j:

$$w_j = \alpha \, A_j^{1/\alpha} \left(\frac{1-\alpha}{Q_j} \right)^{(1-\alpha)/\alpha}. \tag{A2}$$

Local productivity is augmented by agglomeration externalities that depend on access to economic mass, with an elasticity that can be estimated from the model's structure given sufficient exogenous variation.

B Floorspace supply and inversion

Total floorspace H_i is produced from capital Z_i and land L_i, subject to a capacity ceiling $\bar{H}_i$ that captures zoning and geographical constraints Delventhal & Parkhomenko (n.d.):

$$H_i = Z_i^{1-\psi} \left(\phi_i(H_i) \, L_i \right)^{\psi}, \qquad \phi_i(H_i) = 1 - H_i / \bar{H}_i. \tag{B1}$$

As H_i approaches $\bar{H}_i$, the effective land input $\phi_i L_i$ vanishes, so that local supply is effectively capped. A spatial general equilibrium simultaneously clears the labour, goods, and floorspace markets. A distinctive strength of QSMs relative to the SCGE tradition is that several key elasticities — including $\nu = \gamma\epsilon$ and the agglomeration externalities — can in principle be identified directly from the model's equilibrium equations, given sufficient exogenous variation.

For the Ticino prototype, no floorspace price index with sufficient zonal coverage could be obtained. The inversion direction is therefore reversed: floorspace stock, taken from the Federal Register of Buildings and Dwellings Bundesamt für Statistik (BFS) (n.d.), is the observed input, and prices are recovered by rearranging the equilibrium demand conditions. Residential floorspace demand in zone i equals $H_i^R = N_i^R (1-\beta) \gamma \bar{L} \, \overline{v}_i / q_i$, where $\overline{v}_i = \sum_j \lambda_{j|i} \, v_{ij}$ is the mean value of time for residents of zone i. Rearranging gives the inverted residential price:

$$q_i = \frac{(1-\beta) \, \gamma \, \bar{L} \, N_i^R \, \overline{v}_i}{H_i^R}. \tag{B2}$$

Commercial prices follow from the cost-share condition: $Q_j = \frac{(1-\alpha)}{\alpha} \, w_j \, \frac{M_j^W}{H_j^W}$. The capacity ceiling $\bar{H}_i$ recovered from the supply equation (B1) is well-defined only when $\Omega_i = [(1-\psi)\bar{q}_i]^{(1-\psi)/\psi} \cdot L_i > H_i$, where $\bar{q}_i$ is the average floorspace price and H_i is the observed total stock. This stock-inversion workaround produces a complete price vector but makes the

model sensitive to floorspace stock data quality, which motivates the restriction to the urban study area.

C Data sources

Table 1: Data inputs for the Ticino prototype. Baseline period: 2017–2019, pre-Covid.

Input	**Source**	**Notes**
Employed population	BFS commuter matrix 2020	By origin zone; disaggregated to NPTM zones using synthetic population marginals Bundesamt für Raumentwicklung (ARE) (n.d.)
Workplace population	BFS commuter matrix 2020	By destination zone
Travel times	SIMBA MOBi 2017 and 2023	Shortest time across modes, by OD pair[4]
Floorspace stock	RegBL 2019 Bundesamt für Statistik (BFS) (n.d.)	Buildings existing pre-Covid
Wages	BFS wages by NOGA sector + STATENT jobs by sector and zone	Captures sector mix, not within-sector wage differences