

# Connectivity is not enough: digital infrastructure, human capital, and regional business dynamism in Türkiye

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## Research Article

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# Abstract

Regional policy often assumes that expanding digital infrastructure stimulates local business formation. This study examines that assumption in a balanced panel of Türkiye's 81 provinces over 2020–2025, linking formal company births and closures to one-year-lagged fixed broadband, fibre, and mobile broadband indicators and to provincial human capital. Because entry and exit are counts, fixed-effects Poisson pseudo-maximum-likelihood (PPML) models with population offsets are estimated alongside conventional rate-based regressions. Three results emerge. First, within-province growth in fibre and fixed broadband is associated with lower, not higher, proportional company entry—about  $-3.3\%$  per within-province standard deviation of fibre penetration—whereas mobile broadband shows a positive association; the negative fibre association survives subsample restrictions, province-specific trends, and human-capital controls, although timing tests show the one-year lag carries little identifying information. Second, the provincial higher-education graduate share moderates the relationship: the negative association is largest in low-education provinces and attenuates, without reversing, as skills rise—suggestive evidence of skill complementarity. Third, neighbouring provinces' infrastructure shows no spillover under three spatial weight matrices, although spatially correlated unobservables remain in entry and churn. A rate-based specification instead produces a positive fibre–closure association that disappears under count models and multiple-testing correction, illustrating how scale choices can manufacture creative-destruction narratives. Connectivity alone is not an entry engine; skills and complementary capabilities condition its regional footprint.

**JEL Classification** C23 · J24 · L26 · L96 · O18 · R11

## 1 Introduction

Digital connectivity is now treated as basic economic infrastructure, and its expansion carries an intuitively compelling policy promise: broadband should lower search, coordination and market-access costs and thereby stimulate new business formation, especially outside major urban centres. The proposition is salient for Türkiye, where national development policy links digital transformation with productivity, entrepreneurship and regional development (Presidency of Strategy and Budget 2024), provincial fibre infrastructure has expanded rapidly, and recent evidence indicates that high-speed connectivity can raise formal employment and wages (Demir and Grover 2026).

Whether connectivity creates *firms* is a different question. Infrastructure becomes an entrepreneurial resource only in combination with skills, finance, organisational capability and market opportunity, and several mechanisms point the other way: better-connected markets attract remote competitors, digital tools facilitate consolidation and reduce the number of legal entities a business requires, and connectivity can channel activity into employment, platform work or self-employment rather than formal company registration. Entry and exit must therefore be studied jointly, and on a scale that respects their nature as counts.

This paper does so for all 81 Turkish provinces over 2020–2025, linking company births and closures from official registry statistics to one-year-lagged provincial indicators of fixed broadband, fibre subscriptions, mobile broadband and physical fibre length, with income, credit and population controls and a provincial higher-education series. The empirical strategy has four elements. Fixed-effects Poisson pseudo-maximum-likelihood (PPML) count models with population offsets serve as the primary specification, estimated alongside the conventional rate-based two-way fixed-effects models for comparison. Interactions with the province's baseline higher-education graduate share test the skill-complementarity hypothesis directly. Spatial-lag-of-X models under three contiguity matrices and a fixed-effects spatial error model separate cross-border spillovers from spatially correlated unobservables. Timing (lead) tests, minimum-detectable-effect and equivalence calculations, and false-discovery-rate corrections discipline the inference.

The findings run against the infrastructure-as-entry-engine view. On the proportional scale, within-province growth in fibre and fixed broadband is associated with *lower* company entry—roughly – 3.3% per within-province standard deviation of fibre penetration—while mobile broadband is positively associated with entry; the three entry coefficients jointly survive false-discovery-rate correction. The negative fibre association strengthens with province-specific trends and holds in subsamples, though lead tests show the lag structure provides little temporal identification, so the estimates remain associations. Human capital conditions the relationship: the negative association shrinks from – 9.4% to – 6.0% per standard deviation between the 10th and 90th percentiles of the baseline education distribution, without changing sign anywhere in the observed range. Neighbouring provinces' infrastructure shows no spillover under any of three weight matrices, even though outcomes are strongly clustered and spatially correlated shocks remain in entry and churn. Finally, the rate-based specification produces a positive fibre–closure coefficient that a spatial error model appears to confirm, yet count models, a log transformation and multiple-testing adjustment all dissolve it: the exit margin supports no stable conclusion in either direction.

The paper contributes in three ways. It provides a direct test of skill complementarity in an emerging-economy setting, using registry entry data rather than survey outcomes. It separates spatial clustering from infrastructure spillovers, showing that shared unobservables rather than measured connectivity account for the geography of dynamism. And it demonstrates, within a single dataset, how the choice between rate-based and count-based specifications can manufacture or dissolve a creative-destruction narrative—a methodological caution for regional dynamism research generally.

## 2 Conceptual framework and research questions

### 2.1 Why connectivity could raise entry

Digital technologies alter the boundaries, timing and location of entrepreneurial action (Nambisan 2017), and entrepreneurial ecosystem theory treats connectivity as an affordance whose value depends on local institutions, skills, finance and demand (Autio et al. 2018; Stam 2015; Sussan and Acs 2017).

Broadband lowers information and coordination costs, widens the customer and supplier base, supports remote delivery, and can accelerate the knowledge spillovers that entrepreneurship commercialises (Acs et al. 2009). Cross-country evidence relates broadband diffusion to growth (Czernich et al. 2011), local evidence links expansion to employment and business growth (Kolko 2012), firm-level work finds speed improvements raise small-firm sales and productivity (Koutroumpis and Sarri 2024), and broadband availability shapes new establishment location (McCoy et al. 2018), with strong rural entry effects for particular founder groups (Conroy and Low 2022). Sectoral studies find entry effects concentrated in digitally intensive activities and favourable environments (Chen et al. 2023; Drilo et al. 2022).

## **2.2 Why it might not—and the formal-registration margin**

Three families of mechanisms weaken or reverse the prediction for formal company entry. First, complementarity: broadband complements skilled labour and substitutes for routine work (Akerman et al. 2015), and digital entrepreneurship appears to require both infrastructure and highly skilled human capital (Bergholz et al. 2024); where complementary skills are scarce, connectivity may deliver little entrepreneurial benefit. Second, competition and consolidation: connectivity lets firms in stronger regions serve weaker ones remotely, raises price transparency, and makes it easier to run multi-province operations through fewer legal entities, all of which can depress local registration. Third, the outcome margin: a formal company birth is only one form of entrepreneurial response. Connectivity may raise employment within incumbents, self-employment, or platform-mediated activity without producing a registered company—consistent with Turkish evidence that fibre expansion improves employment and wages (Demir and Grover 2026) and with African evidence on employment effects of fast internet (Hjort and Poulsen 2019). Exit is equally ambiguous: broadband could reduce closures through efficiency, or raise recorded closures through selection and reorganisation in the Schumpeterian sense (Schumpeter 1942), and the registry records administrative closure, not failure.

Technology type matters for these mechanisms. Fibre proxies high-capacity connectivity for data-intensive business functions; mobile broadband proxies mass consumer access and platform participation. If the registration margin responds mainly to consumer-market reach, mobile and fixed technologies need not carry the same sign.

## **2.3 Spatial dependence versus spillovers**

Provincial outcomes are unlikely to be spatially independent: neighbours share labour markets, corridors, supplier networks and macro-regional shocks, and one province's infrastructure could serve entrepreneurs across its border. Yet spatial autocorrelation can arise purely from shared unobservables, and attributing it to measured infrastructure risks misinterpretation (Anselin 1988; Elhorst 2014; LeSage and Pace 2009). The design therefore estimates observable neighbour effects (spatial-lag-of-X) separately from residual dependence (spatial error).

## **2.4 Research questions**

RQ1. Is within-province growth in digital infrastructure followed by higher formal company entry, and does the answer depend on whether entry is measured as a population rate or as a count? RQ2. Does provincial human capital condition the infrastructure–entry relationship? RQ3. Do infrastructure–dynamism associations differ across the exit and turnover margins? RQ4. Does neighbouring provinces’ infrastructure spill over, or does spatial dependence reflect shared unobservables?

## 3 Data and methods

### 3.1 Sample and data sources

The unit of analysis is the province-year: all 81 NUTS 3 provinces and six outcome years, 2020–2025, giving a balanced panel of 486 observations with no missing cells. Company births and closures come from the official company establishment and closure statistics of the Union of Chambers and Commodity Exchanges of Türkiye, using the December cumulative workbook of each year and the company category only (TOBB 2025). One province-year records zero closures and none records zero births. A recorded closure is an administrative company closure, not necessarily bankruptcy or the destruction of productive capacity.

Digital infrastructure and population are from the provincial statistical bulletins of the Information and Communication Technologies Authority (BTK 2025): fixed broadband, fibre and mobile broadband subscriptions per 100 residents, and fibre length in km per 1,000 residents, all lagged one year (2019–2024). Controls are lagged GDP per capita in euros from Eurostat NUTS 3 accounts (Eurostat 2025), lagged cash credit per resident from the Banks Association of Türkiye Risk Centre (TBB 2025), and lagged population, entered in logarithms where the specification requires them. Year fixed effects absorb common national shocks, including inflation and the pandemic calendar; province fixed effects absorb persistent structural differences.

Human capital is measured as the share of higher-education graduates (two-year college and above) in the population aged six and over with known educational attainment, from the Turkish Statistical Institute’s provincial education statistics (TURKSTAT 2026), 2019–2024. The lagged share averages 15.50% (overall SD 3.37; within-province SD 1.12). The 2019 baseline share averages 13.65% and ranges from 7.44% to 24.26%; it correlates at 0.79 with baseline log GDP per capita, which motivates the income-proxy check reported below. Spatial weights derive from Eurostat GISCO NUTS 2024 geodata under queen contiguity (Eurostat GISCO 2024): 199 undirected pairs, no isolates, an average of 4.91 neighbours.

Table 1 reports definitions and descriptive statistics. Mean annual rates per 100,000 residents are 74.28 births, 13.13 closures, 61.14 net formations and 87.41 churn (births plus closures). The principal exposure, lagged fibre subscriptions per 100 residents, averages 4.35 with a within-province SD of 1.57—the variation that identifies the fixed-effects estimates.

Table 1  
Variable definitions and descriptive statistics

| Variable                                                                                                                         | Definition                                                                                | Source          | Mean      | SD        | Within SD |
|----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----------------|-----------|-----------|-----------|
| Company births per 100,000                                                                                                       | Newly established companies per 100,000 residents                                         | TOBB; BTK       | 74.28     | 47.92     | 14.01     |
| Company closures per 100,000                                                                                                     | Closed companies per 100,000 residents                                                    | TOBB; BTK       | 13.13     | 10.97     | 4.96      |
| Net formation per 100,000                                                                                                        | Births minus closures per 100,000 residents                                               | Constructed     | 61.14     | 39.52     | 14.14     |
| Business churn per 100,000                                                                                                       | Births plus closures per 100,000 residents                                                | Constructed     | 87.41     | 57.20     | 15.55     |
| Lagged fixed broadband per 100                                                                                                   | One-year-lagged fixed broadband subscriptions per 100 residents                           | BTK             | 17.64     | 5.91      | 2.27      |
| Lagged fibre subscriptions per 100                                                                                               | One-year-lagged fibre subscriptions per 100 residents                                     | BTK             | 4.35      | 2.67      | 1.57      |
| Lagged mobile broadband per 100                                                                                                  | One-year-lagged mobile broadband subscriptions per 100 residents                          | BTK             | 75.59     | 9.61      | 5.16      |
| Lagged fibre km per 1,000                                                                                                        | One-year-lagged fibre length (km) per 1,000 residents                                     | BTK             | 7.49      | 3.15      | 0.96      |
| Lagged higher-education share (%)                                                                                                | One-year-lagged share of higher-education graduates, population 6 + with known attainment | TURKSTAT        | 15.50     | 3.37      | 1.12      |
| Baseline (2019) higher-education share (%)                                                                                       | Time-invariant 2019 value of the education share                                          | TURKSTAT        | 13.65     | 2.98      | —         |
| Lagged GDP per capita (EUR)                                                                                                      | One-year-lagged GDP per capita, euros                                                     | Eurostat        | 7,652.47  | 3,250.88  | 1,933.45  |
| Lagged credit (thousand TRY per capita)                                                                                          | One-year-lagged cash credit, thousand TRY per resident                                    | TBB Risk Centre | 45.30     | 45.22     | 34.11     |
| Lagged population                                                                                                                | One-year-lagged provincial population                                                     | BTK             | 1,044,787 | 1,890,003 | 29,130    |
| N = 486 province-year observations. Outcome years 2020–2025; lagged variables 2019–2024. SD standard deviation, TRY Turkish lira |                                                                                           |                 |           |           |           |

## 3.2 Estimators

The rate-based benchmark is the two-way fixed-effects model

$$y_{it} = \beta D_{i,t-1} + \gamma' X_{i,t-1} + \alpha_i + \tau_t + \epsilon_{it}$$

(1)

where  $y_{it}$  is a dynamism rate,  $D_{i,t-1}$  a lagged infrastructure indicator, and  $X_{i,t-1}$  logged population, GDP per capita and credit per capita. Standard errors are clustered by province throughout, with inference based on the  $t$  distribution with 80 degrees of freedom.

The primary specification treats births and closures as what they are—counts—via fixed-effects PPML with a population offset:

$$E[C_{it} | \cdot] = \exp\{\ln P_{it} + \beta D_{i,t-1} + \gamma' X_{i,t-1} + \alpha_i + \tau_t\}$$

(2)

where  $C_{it}$  is the count,  $P_{it}$  current population, and  $X_{i,t-1}$  the logged GDP and credit controls. PPML is consistent under correct specification of the conditional mean without distributional assumptions, accommodates zeros and heteroskedasticity, and avoids the shared-denominator problem of rate regressions, in which population enters both sides of Eq. (1) (Santos Silva and Tenreyro 2006); the fixed-effects Poisson estimator is free of the incidental-parameters problem (Wooldridge 1999). Coefficients are semi-elasticities: proportional changes in expected counts per unit of the exposure, holding population constant. The rate scale is retained throughout for comparability and because the divergence between the two scales is itself informative.

### 3.3 Human capital interactions

Skill complementarity is tested by interacting the exposure with the baseline (2019) education share, centred at its sample mean:

$$E[C_{it} | \cdot] = \exp\{\ln P_{it} + \beta_1 D_{i,t-1} + \beta_2 (D_{i,t-1} \times \tilde{H}_i) + \gamma' X_{i,t-1} + \alpha_i + \tau_t\}$$

(3)

where  $\tilde{H}_i$  is the demeaned baseline share. The time-invariant main effect is absorbed by the province fixed effects;  $\beta_1$  is the marginal association at the mean baseline share (13.65%). Using the pre-period share avoids conditioning on contemporaneous education, which may respond to the same shocks as entry. A variant with the time-varying lagged share, and an income-proxy check interacting fibre with log GDP per capita, are reported as robustness.

### 3.4 Spatial models

Global Moran's  $I$  is computed annually for raw outcomes and selected residuals with 999-permutation inference (Moran 1950), and local clustering of the period-average birth rate is classified with local

indicators of spatial association (LISA; Anselin 1995) using 999 conditional permutations. Observable spillovers are tested with spatial-lag-of-X (SLX) terms,  $\theta W D_{i,t-1}$ , added to Eq. (1), under three matrices: row-standardised queen contiguity, row-standardised strictly second-order contiguity (average 9.31 neighbours), and binary queen contiguity, whose coefficients scale with the neighbour sum rather than the average. SLX coefficients are directly interpretable as local indirect effects (LeSage and Pace 2009). Residual dependence in the rate-based models is assessed with a fixed-effects spatial error model,  $\epsilon_t = \lambda W \epsilon_t + u_t$ , estimated by profiling the quasi-log-likelihood over  $\lambda$  after the within transformation, with province-clustered coefficient standard errors conditional on  $\hat{\lambda}$ .

## 3.5 Diagnostics and analytical transparency

Timing is probed by including the contemporaneous exposure alongside the lag, and a two-period lag structure. Statistical power is summarised by the minimum detectable effect (MDE) at 80% power, and null results are additionally assessed with two-one-sided equivalence tests (TOST; Lakens 2017). Multiple testing is addressed with Benjamini–Hochberg false-discovery-rate corrections (Benjamini and Hochberg 1995), applied separately to the eleven pre-specified rate-based tests and the six primary count-model tests.

Statistical estimation code for the models reported here—fixed-effects PPML, spatial diagnostics and weight-matrix construction, power and equivalence calculations, and false-discovery-rate corrections—was developed with the assistance of a large language model (Claude, Anthropic), which was also used in editing the manuscript text. All specifications were chosen by the author, executed on the author’s assembled panel, verified against independently reproduced benchmark estimates, and interpreted by the author, who takes full responsibility for the analysis, the results and the manuscript. Replication code and data are deposited as described in the data availability statement.

The analytical sequence is disclosed for transparency. The directional expectations of the original design—positive entry and net-formation associations, a fibre–mobile contrast favouring fibre, and positive spillovers—were specified before estimation on the rate scale. The rate-based results motivated three subsequent extensions: the count-model re-specification, the timing and equivalence diagnostics, and the human-capital interaction analysis using an education series added after the first round of estimation. The count model is presented as primary on methodological rather than empirical grounds, and both scales are reported in full. Sensitivity checks follow the original protocol: excluding 2020–2021, excluding Istanbul, Ankara and Izmir, excluding the 11 provinces most affected by the February 2023 earthquakes (AFAD 2023), and adding province-specific linear trends.

## 4 Results

### 4.1 Spatial clustering and the rate-based benchmark

Figure 1 maps the identifying variation: mean fibre penetration nearly tripled between the first and last lag years, from 2.35 to 6.77 subscriptions per 100 residents, with expansion reaching every region.

Business dynamism, meanwhile, is strongly clustered: Moran's  $I$  for raw birth rates lies between 0.299 and 0.332 across 2020–2025 (permutation  $p \leq 0.002$ ) and between 0.283 and 0.352 for net formation, and the period-average birth rate has  $I = 0.325$  ( $p = 0.001$ ). Figure 2 pairs its geography with the LISA classification: high–high provinces flanking Istanbul (Tekirdağ and Kocaeli) together with Konya, a 17-province low–low belt across the northern and northeastern interior, three low–high provinces (Burdur, Karaman and Niğde) and no high–low outliers. Provinces resemble their neighbours long before any model is estimated.

Table 2 reports the eleven pre-specified rate-based estimates with 95% confidence intervals and false-discovery-rate  $q$ -values. No positive entry or net-formation association appears: the fixed-broadband entry coefficient is negative and marginal ( $-1.790$ ,  $p = 0.087$ ), fibre and physical fibre are null for births, and fibre is null for net formation. Two coefficients reach conventional significance—fibre–closures ( $2.243$ ,  $p = 0.041$ ) and, marginally, fibre–churn ( $3.137$ ,  $p = 0.060$ )—but no coefficient in the table survives the Benjamini–Hochberg correction; the smallest  $q$ -value is 0.22. Power is moderate: the MDE at 80% power for the fibre–births model is 4.58 rate points, or 9.7% of the mean birth rate per within-province SD of fibre. Equivalence testing supports only a  $\pm 7.6\%$  band around zero for that coefficient; a  $\pm 5\%$  band is not supported ( $p = 0.18$ ). The rate-based evidence is thus a set of nulls with one fragile exit-side signal—a signal Sect. 4.5 shows a spatial error model appears to confirm and Sect. 4.2 shows the count model dissolves.

Table 2  
Rate-based two-way fixed-effects benchmark (level rates per 100,000)

| Model | Outcome       | Focal exposure                        | Coefficient (SE)            | 95% CI           | <i>p</i> | BH <i>q</i> |
|-------|---------------|---------------------------------------|-----------------------------|------------------|----------|-------------|
| M1    | Births        | Lagged fixed broadband per 100        | -1.790 (1.032)              | [- 3.84, 0.26]   | 0.087    | 0.238       |
| M2    | Births        | Lagged fibre subscriptions per 100    | 0.895 (1.614)               | [- 2.32, 4.11]   | 0.581    | 0.893       |
| M3    | Births        | Lagged fibre km per 1,000             | 0.020 (3.451)               | [- 6.85, 6.89]   | 0.995    | 0.996       |
| M4    | Closures      | Lagged fibre subscriptions per 100    | 2.243 (1.082) <sup>b</sup>  | [0.09, 4.40]     | 0.041    | 0.222       |
| M5    | Net formation | Lagged fixed broadband per 100        | -2.404 (1.111) <sup>b</sup> | [- 4.62, - 0.19] | 0.034    | 0.222       |
| M6    | Net formation | Lagged fibre subscriptions per 100    | -1.348 (2.200)              | [- 5.73, 3.03]   | 0.542    | 0.893       |
| M7    | Births        | Lagged fibre subscriptions per 100    | 0.921 (1.448)               | [- 1.96, 3.80]   | 0.526    | 0.893       |
| M7    | Births        | Lagged mobile broadband per 100       | 0.059 (0.954)               | [- 1.84, 1.96]   | 0.951    | 0.996       |
| M8    | Births        | Neighbours' lagged fibre per 100      | -1.265 (3.657)              | [- 8.54, 6.01]   | 0.730    | 0.893       |
| M9    | Net formation | Neighbours' lagged fibre km per 1,000 | -2.058 (4.667)              | [- 11.35, 7.23]  | 0.660    | 0.893       |
| M10   | Churn         | Lagged fibre subscriptions per 100    | 3.137 (1.647) <sup>c</sup>  | [- 0.14, 6.41]   | 0.060    | 0.222       |

*N* = 486. All models include province and year fixed effects and logged lagged population, GDP per capita and credit per capita; province-clustered standard errors; *t*(80) intervals. M7 includes fibre and mobile jointly; M8 and M9 are SLX models whose own-exposure coefficients are 1.062 (*p* = 0.573) and 0.609 (*p* = 0.876). BH *q* is the Benjamini–Hochberg false-discovery-rate value across the eleven tests; none is significant at *q* = 0.05

<sup>b</sup> *p* < 0.05, <sup>c</sup> *p* < 0.10

## 4.2 Count-model results: entry falls with fixed technologies, rises with mobile

Table 3 presents the primary PPML estimates. Lagged fibre subscriptions are negatively associated with company births:  $-0.0213$  ( $p = 0.007$ ), i.e.  $-3.3\%$  per within-province SD of fibre penetration (95% CI  $-5.6\%$  to  $-0.9\%$ ). Lagged fixed broadband is also negative ( $-0.0303$ ,  $p = 0.016$ ;  $-6.6\%$  per within SD), while lagged mobile broadband is positive ( $+0.0104$ ,  $p = 0.007$ ;  $+5.5\%$  per within SD) and physical fibre length is null. Applying Benjamini–Hochberg across the six tests in the table, the three subscription-based entry coefficients remain significant ( $q \leq 0.032$ ). Closures show no association with fibre ( $-0.0126$ ,  $p = 0.277$ ), and churn is marginally negative ( $-0.0111$ ,  $p = 0.057$ ).

Table 3  
Primary fixed-effects PPML estimates (counts with log-population offset)

| Outcome                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Focal exposure                     | Coefficient (SE)                   | 95% CI                    | <i>p</i> | BH <i>q</i> | % per within-SD [95% CI]      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|------------------------------------|---------------------------|----------|-------------|-------------------------------|
| Births                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Lagged fibre subscriptions per 100 | $-0.0213$<br>(0.0077) <sup>a</sup> | $[-0.0365,$<br>$-0.0060]$ | 0.007    | 0.021       | $-3.3$ [ $-5.6,$<br>$-0.9$ ]  |
| Births                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Lagged fixed broadband per 100     | $-0.0303$<br>(0.0123) <sup>b</sup> | $[-0.0548,$<br>$-0.0058]$ | 0.016    | 0.032       | $-6.6$ [ $-11.7,$<br>$-1.3$ ] |
| Births                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Lagged mobile broadband per 100    | $0.0104$<br>(0.0038) <sup>a</sup>  | $[0.0028,$<br>$0.0180]$   | 0.007    | 0.021       | $+5.5$ [ $+1.5,$<br>$+9.7$ ]  |
| Births                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Lagged fibre km per 1,000          | $0.0077$<br>(0.0297)               | $[-0.0514,$<br>$0.0668]$  | 0.796    | 0.796       | $+0.7$ [ $-4.8,$<br>$+6.6$ ]  |
| Closures                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Lagged fibre subscriptions per 100 | $-0.0126$<br>(0.0115)              | $[-0.0355,$<br>$0.0103]$  | 0.277    | 0.332       | $-2.0$ [ $-5.4,$<br>$+1.6$ ]  |
| Churn                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Lagged fibre subscriptions per 100 | $-0.0111$<br>(0.0058) <sup>c</sup> | $[-0.0226,$<br>$0.0004]$  | 0.057    | 0.086       | $-1.7$ [ $-3.5,$<br>$+0.1$ ]  |
| <p><i>N</i> = 486. All models include province and year fixed effects, a log current-population offset, and logged lagged GDP per capita and credit per capita; province-clustered standard errors; <i>t</i>(80) intervals. Coefficients are semi-elasticities per unit of the exposure; the final column converts them to percentage changes per one within-province SD (fibre 1.57, fixed broadband 2.27, mobile 5.16, fibre km 0.96). BH <i>q</i> across the six tests in this table</p> |                                    |                                    |                           |          |             |                               |
| <p><sup>a</sup> <math>p &lt; 0.01</math>, <sup>b</sup> <math>p &lt; 0.05</math>, <sup>c</sup> <math>p &lt; 0.10</math></p>                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                    |                           |          |             |                               |

Table 4 probes robustness. The negative fibre–births coefficient holds when 2020–2021 are excluded ( $-0.0311$ ,  $p = 0.024$ ) and when the earthquake provinces are excluded ( $-0.0194$ ,  $p = 0.025$ ); it retains its magnitude but loses precision without Istanbul, Ankara and Izmir ( $-0.0273$ ,  $p = 0.121$ ); and it strengthens when province-specific linear trends are added ( $-0.0435$ ,  $p = 0.005$ ), indicating the association is not an artefact of divergent provincial trajectories. Timing, however, is weakly identified: when contemporaneous and lagged fibre enter together, both are null for births, and for closures the two terms are large and offsetting ( $-0.055$  and  $+0.054$ ). On the rate scale, contemporaneous fibre predicts

closures as strongly as lagged fibre (1.387 versus 1.438). The one-year lag therefore carries little temporal information, and the estimates are interpreted as conditional associations, not causal effects.

Table 4  
PPML robustness and timing tests (lagged fibre subscriptions per 100)

| Specification                                                                                                                                                                                                                                                                                                                                                                                        | Births                        | Closures                      |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------------------------|
| R1 Baseline                                                                                                                                                                                                                                                                                                                                                                                          | -0.0213 (0.0077) <sup>a</sup> | -0.0126 (0.0115)              |
| R2 Exclude 2020–2021                                                                                                                                                                                                                                                                                                                                                                                 | -0.0311 (0.0135) <sup>b</sup> | 0.0008 (0.0115)               |
| R3 Exclude Istanbul, Ankara, Izmir                                                                                                                                                                                                                                                                                                                                                                   | -0.0273 (0.0174)              | 0.0339 (0.0321)               |
| R4 Exclude 11 earthquake provinces                                                                                                                                                                                                                                                                                                                                                                   | -0.0194 (0.0084) <sup>b</sup> | -0.0187 (0.0118)              |
| R5 Add province-specific linear trends                                                                                                                                                                                                                                                                                                                                                               | -0.0435 (0.0150) <sup>a</sup> | 0.0577 (0.0240) <sup>b</sup>  |
| R6 Contemporaneous fibre (with lag)                                                                                                                                                                                                                                                                                                                                                                  | -0.0124 (0.0290)              | -0.0545 (0.0280) <sup>c</sup> |
| R6 Lagged fibre (with contemporaneous)                                                                                                                                                                                                                                                                                                                                                               | -0.0053 (0.0378)              | 0.0543 (0.0323) <sup>c</sup>  |
| Cells report the fibre coefficient (province-clustered SE). R1–R5: $N = 486, 324, 468, 420$ and $486$ . R6 includes fibre at $t$ and $t - 1$ jointly ( $N = 405$ , outcome years 2020–2024). The offsetting R6 closure terms and the sign instability of the closure column across R1, R5 and the rate scale indicate that no stable exit association exists; the birth column is uniformly negative |                               |                               |
| <sup>a</sup> $p < 0.01$ , <sup>b</sup> $p < 0.05$ , <sup>c</sup> $p < 0.10$                                                                                                                                                                                                                                                                                                                          |                               |                               |

The exit margin is unstable in every direction. Fibre–closures is positive on the level-rate scale, absent in baseline PPML, positive again once province trends are added to the count model (+ 0.0577,  $p = 0.019$ ), and sign-reversed under a log-rate transformation in the original sensitivity protocol. Figure 4 visualises the contrast: every birth estimate lies at or below zero, while the closure estimates straddle it with alternating signs. No specification-invariant conclusion about exit is available, and the paper draws none.

## 4.3 Human capital conditions the entry association

Table 5 reports the interaction results (RQ2). In the preferred specification, the fibre–births association at the mean baseline education share is - 0.0518 ( $p = 0.001$ ) and the interaction with the baseline share is + 0.0035 ( $p = 0.021$ ): each percentage point of baseline higher-education share attenuates the negative fibre association. The same pattern holds for churn (- 0.0338 and + 0.0026, both significant) and with the time-varying education share (interaction + 0.0026,  $p = 0.031$ ). The interaction is technology-specific—null for fixed broadband (+ 0.0005,  $p = 0.529$ ) and mobile (+ 0.0004,  $p = 0.255$ )—and it is not an income effect in disguise: the fibre  $\times$  log GDP interaction is null in PPML (+ 0.0119,  $p = 0.403$ ) despite the 0.79 correlation between baseline education and income. Adding the education share as a control leaves the entry results intact (fibre - 0.0190,  $p = 0.003$ ; mobile + 0.0098,  $p = 0.013$ ).

**Table 5** Human capital and the infrastructure–entry association (PPML)*Panel A: interactions with the baseline (2019) higher-education share (demeaned)*

| Outcome  | Exposure                           | Exposure coefficient (SE)     | Interaction (SE)             |
|----------|------------------------------------|-------------------------------|------------------------------|
| Births   | Lagged fibre subscriptions per 100 | −0.0518 (0.0147) <sup>a</sup> | 0.0035 (0.0015) <sup>b</sup> |
| Births   | Lagged fixed broadband per 100     | −0.0313 (0.0127) <sup>b</sup> | 0.0005 (0.0008)              |
| Births   | Lagged mobile broadband per 100    | 0.0097 (0.0035) <sup>a</sup>  | 0.0004 (0.0003)              |
| Closures | Lagged fibre subscriptions per 100 | 0.0053 (0.0173)               | −0.0022 (0.0021)             |
| Churn    | Lagged fibre subscriptions per 100 | −0.0338 (0.0105) <sup>a</sup> | 0.0026 (0.0011) <sup>b</sup> |

*Panel B: marginal fibre–births association across the baseline education distribution*

| Percentile | Education share (%) | d ln(births)/d fibre (SE) | <i>p</i> | % per within-SD of fibre |
|------------|---------------------|---------------------------|----------|--------------------------|
| p10        | 10.46               | −0.0630 (0.0191)          | 0.001    | −9.4                     |
| p25        | 11.56               | −0.0591 (0.0175)          | 0.001    | −8.9                     |
| p50        | 13.57               | −0.0521 (0.0148)          | 0.001    | −7.9                     |
| p75        | 15.31               | −0.0461 (0.0125)          | <0.001   | −7.0                     |
| p90        | 17.30               | −0.0391 (0.0101)          | <0.001   | −6.0                     |

*N* = 486 throughout; specifications as in Table 3. In Panel A the exposure coefficient is the marginal association at the mean baseline share (13.65%); the time-invariant education main effect is absorbed by the province fixed effects. The time-varying-share variant yields an interaction of 0.0026 (*p* = 0.031); the fibre × log GDP interaction is 0.0119 (*p* = 0.403). The implied sign crossover lies at a 28.5% share, above the observed maximum (24.3%)

<sup>a</sup> *p* < 0.01, <sup>b</sup> *p* < 0.05

Panel B of Table 5 and Fig. 3 translate the interaction into marginal associations across the observed education range. Moving from the 10th to the 90th percentile of the baseline education distribution (10.5% to 17.3%), the fibre–births association per within-province SD shrinks from − 9.4% to − 6.0%, remaining significantly negative throughout. The implied crossover to a positive association lies at a 28.5% education share—beyond the highest observed value (Ankara, 24.3%). Human capital therefore softens the negative relationship but does not reverse it anywhere in the observed range. Two honest caveats apply. A median split does not reproduce the linear interaction: the below-median subsample yields + 0.016 with a standard error (0.040) too large to distinguish anything, and the above-median subsample yields − 0.019 (*p* = 0.096); the split lacks power rather than contradicting the interaction,

but the linear form is doing real work. The evidence is accordingly characterised as suggestive of skill complementarity, not definitive.

## 4.4 No spillovers, but spatially correlated shocks

Table 6 addresses RQ4. Panel A shows that neighbours’ lagged fibre is unrelated to a province’s births or net formation under all three weight matrices: queen (– 1.265 and – 2.740), strictly second-order (– 5.937 and – 7.691) and binary queen (– 0.052 and – 0.102), with  $p$  values from 0.21 to 0.92; the fibre-length variant for net formation is equally null (– 2.058,  $p = 0.660$ ). Whatever generates the strong raw clustering, it is not measured digital infrastructure crossing borders.

**Table 6** Spatial spillovers and error dependence

*Panel A: SLX neighbour coefficients (neighbours’ lagged fibre subscriptions per 100)*

| Weight matrix                           | Births         | Net formation  |
|-----------------------------------------|----------------|----------------|
| Queen contiguity, row-standardised      | –1.265 (3.657) | –2.740 (3.793) |
| Strictly second-order, row-standardised | –5.937 (5.994) | –7.691 (6.122) |
| Queen contiguity, binary                | –0.052 (0.502) | –0.102 (0.529) |

*Panel B: fixed-effects spatial error model (level rates, queen contiguity)*

| Outcome       | Fibre coefficient (SE)     | $\lambda$ (SE)             | $p(\lambda)$ |
|---------------|----------------------------|----------------------------|--------------|
| Births        | 0.860 (1.780)              | 0.182 (0.071) <sup>a</sup> | 0.010        |
| Closures      | 2.223 (1.084) <sup>b</sup> | 0.061 (0.074)              | 0.411        |
| Net formation | –1.328 (2.319)             | 0.138 (0.073) <sup>c</sup> | 0.058        |
| Churn         | 3.024 (1.791) <sup>c</sup> | 0.212 (0.069) <sup>a</sup> | 0.002        |

$N = 486$ . Panel A models add the spatial lag of fibre to Eq. (1); own-exposure coefficients are null throughout; binary-matrix coefficients scale with the neighbour sum (average 4.91 first-order, 9.31 second-order neighbours) rather than the average, hence their smaller magnitude;  $p$  values range from 0.21 to 0.92. The fibre-length variant for net formation under the queen matrix is –2.058 (4.667),  $p = 0.660$ . Panel B reports the rate-scale spatial error model; after filtering, annual innovation Moran tests are insignificant in every year. The Panel B closure coefficient illustrates that spatial filtering preserves, rather than corrects, the rate-scale artefact discussed in Sect. 4.5

<sup>a</sup>  $p < 0.01$ , <sup>b</sup>  $p < 0.05$ , <sup>c</sup>  $p < 0.10$

Panel B reports the rate-scale spatial error model. The error-dependence parameter is significant for births ( $\lambda = 0.182$ ,  $p = 0.010$ ) and churn ( $\lambda = 0.212$ ,  $p = 0.002$ ), marginal for net formation and absent for closures; after filtering, annual innovation Moran tests are uniformly insignificant. Shared unobserved shocks—regional industrial composition, corridors, coordinated programmes—account for the geography. Notably, the spatial error model reproduces the level-rate closure coefficient (2.223,  $p = 0.044$ ): spatial robustness machinery does not protect against a functional-form artefact, which only the change of scale reveals.

## 4.5 Why the scales disagree

The divergence between Tables 2 and 3 is systematic, not incidental. The level-rate closure association collapses when the three largest metropolitan provinces are dropped (0.717) and reverses sign under a log transformation ( $-0.021$ ), and its interaction analogues behave the same way: on the rate scale, fibre  $\times$  baseline education for closures is  $+0.263$  ( $p = 0.001$ ) and fibre  $\times$  log GDP is  $+2.02$  ( $p < 0.001$ ), yet both are null in PPML. Level-rate estimates load on provinces with large absolute rate movements—disproportionately the biggest markets—so a handful of metropolitan observations can manufacture both a “creative destruction” main effect and spuriously precise interactions. Count models with offsets, which weight proportional variation, find neither. For regional dynamism research, the practical lesson is that scale choice is a substantive modelling decision, not a presentation preference.

## 5 Discussion

### 5.1 Interpreting the negative entry association

Three readings are consistent with the pattern, and the data cannot fully separate them. The first is the registration margin: high-capacity fixed connectivity may channel economic adjustment into employment, remote work and platform activity rather than new legal entities, which squares with Turkish evidence of employment and wage gains from fibre (Demir and Grover 2026)—connectivity as a substitute for firm creation rather than its complement. The second is competition and consolidation: better-connected provinces are easier to serve remotely and easier to manage through fewer entities, depressing local registration even as activity grows. The third is targeting: fibre expansion concentrated where networks and incomes were already strong—the 2020–2025 change in fibre penetration correlates at 0.51 with its initial level and 0.56 with initial log GDP—so within-province surges partly track provider strategy. Province trends and year effects absorb much of this, and the coefficient survives both, but the weak timing identification counsels restraint: the finding is a robust conditional association whose causal content is undetermined. What the data do rule out is the policy-relevant opposite: entry-engine effects of the size the optimistic literature implies are inconsistent with these estimates on either scale.

The mobile contrast sharpens the interpretation. If the registration margin responds to mass consumer access—payments, marketplaces, customer reach—then mobile penetration is the relevant enabler for the small, consumer-facing companies that dominate registry counts, while fibre serves functions (data-intensive operations, remote management) that do not require additional local entities. The technology-

specific education interaction fits the same logic: skills condition the value of high-capacity connectivity specifically.

## 5.2 Skill complementarity, bounded

The interaction evidence gives the complementarity hypothesis (Akerman et al. 2015; Bergholz et al. 2024) direct registry-based support in an emerging economy: the higher the province's baseline graduate share, the less negative the fibre–entry association. The bound matters as much as the sign. Nowhere in the observed education range does fibre become positively associated with entry; the implied crossover lies above the best-endowed province. The defensible claim is that human capital is a necessary complement that mitigates displacement pressure, not a switch that turns infrastructure into an entry engine. For RQ2, this is suggestive rather than conclusive evidence, and the underpowered median split is reported precisely so that readers can weigh it.

## 5.3 Geography without spillovers

For RQ4, the combination of null SLX terms under three matrices and significant error dependence relocates the policy question. Maps of provincial dynamism invite infrastructure explanations, but the estimates indicate that adjacent provinces co-move because they share unmeasured conditions, not because connectivity radiates across borders. Regional strategy should therefore target functional economic areas and diagnosed bottlenecks rather than administrative broadband rankings, and no province can expect a neighbour's investment to substitute for its own capability building.

## 5.4 Policy and practice

The results counsel “infrastructure plus”, with the emphasis on the plus. Fibre deployment remains a precondition for advanced digital activity and demonstrably supports employment, but as a regional entrepreneurship instrument it should be bundled with the complements the interaction points to—digital and managerial skills, finance, adoption support—and evaluated against entry, exit, survival and employment jointly rather than subscription targets. For monitoring, the methodological finding is directly actionable: dynamism indicators built as population rates and analysed in levels can generate artefactual signals, and count-based or proportional analysis should be standard. For managers, high-capacity access is a capability platform whose competitive value depends on complementary skills that, at the regional level, remain unevenly distributed.

## 6 Conclusion

In a balanced 486-observation panel of Türkiye's 81 provinces, within-province growth in fibre and fixed broadband is associated with lower, not higher, proportional company entry, mobile broadband with higher entry, and neighbouring provinces' infrastructure with nothing at all; human capital attenuates the negative fibre association without reversing it, and the exit margin yields no stable association under any defensible specification. A rate-based analysis of the same data would instead have headlined a creative-destruction story that count models and multiple-testing discipline dissolve.

The study's limits define its research agenda: six years of data, weak timing identification, an aggregate company category, and a broad education proxy. Longer panels, sectoral splits of registry data, firm-level survival records, quasi-experimental rollout variation and travel-time-based weights can determine when connectivity creates firms, when it strengthens incumbents instead, and how much of its regional footprint runs through the skills that this paper finds doing the conditioning work.

## Declarations

## Author Contribution

Conceptualization: Sinan Apak; Methodology: Sinan Apak; Formal analysis and investigation: Sinan Apak; Data curation: Sinan Apak; Writing – original draft preparation: Sinan Apak; Writing – review and editing: Sinan Apak. The author read and approved the final manuscript.

## Data Availability

The dataset generated and analysed in this study, "Digital infrastructure and regional business dynamism in Türkiye: province-level panel, 2019–2025", together with the queen-contiguity spatial weights matrix and the full estimation code, is openly available in the Zenodo repository at <https://doi.org/10.5281/zenodo.21824071>. The panel is derived from publicly available official statistics: company establishment and closure statistics, Union of Chambers and Commodity Exchanges of Türkiye (<https://www.tobb.org.tr/BilgiErisimMudurlugu/Sayfalar/KurulanKapananSirketistatistikleri.php>); annual provincial statistical bulletins on the electronic communication sector, Information and Communication Technologies Authority (<https://www.btk.gov.tr>); educational attainment statistics by province, Turkish Statistical Institute National Data Portal (<https://nir.tuik.gov.tr>); distribution of cash loans by province, Banks Association of Türkiye Risk Centre (<https://verisistemi.tbb.org.tr>); gross domestic product by NUTS 3 region, Eurostat, dataset nama\_10r\_3gdp ([https://doi.org/10.2908/nama\\_10r\\_3gdp](https://doi.org/10.2908/nama_10r_3gdp)); and NUTS 2024 geodata, Eurostat GISCO (<https://ec.europa.eu/eurostat/web/gisco/geodata/statistical-units/territorial-units-statistics>). No restrictions apply to the availability of these data.

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## Figures

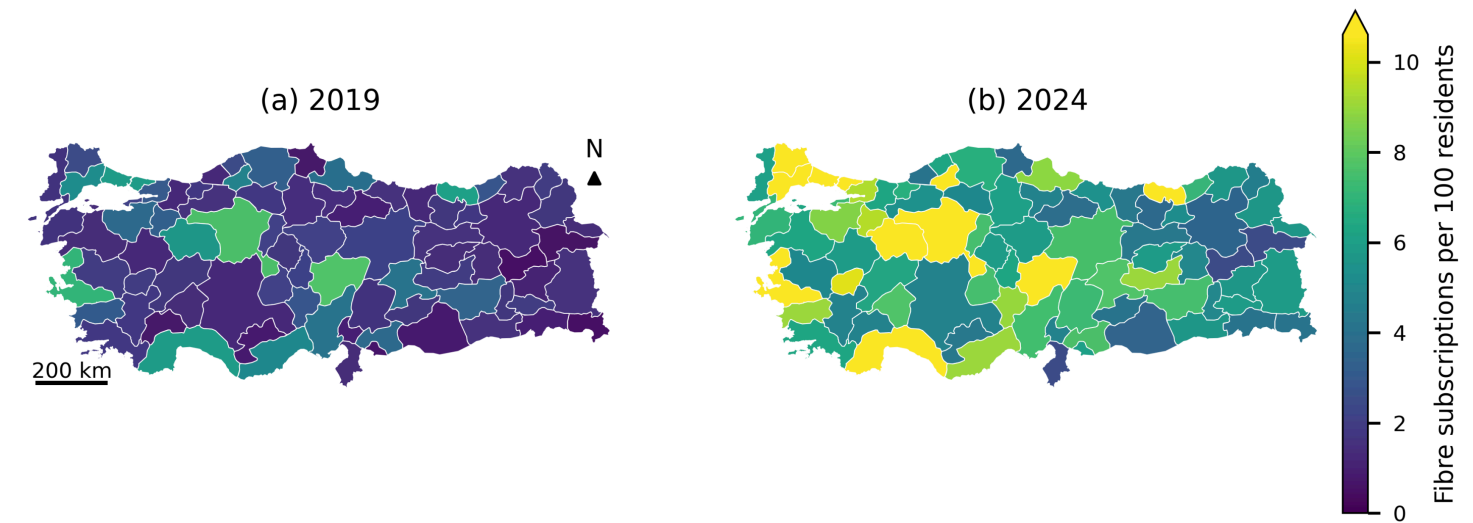


Figure 1

Diffusion of fibre connectivity across Turkish provinces. Lagged fibre subscriptions per 100 residents in 2019 (a) and 2024 (b) on a common colour scale clipped at the 95th percentile; mean penetration rose from 2.35 to 6.77 over the period. Generalised province boundaries are used for display; the contiguity weights in the analysis derive from Eurostat GISCO NUTS 2024 geodata. Scale bar approximate at 36.5° N

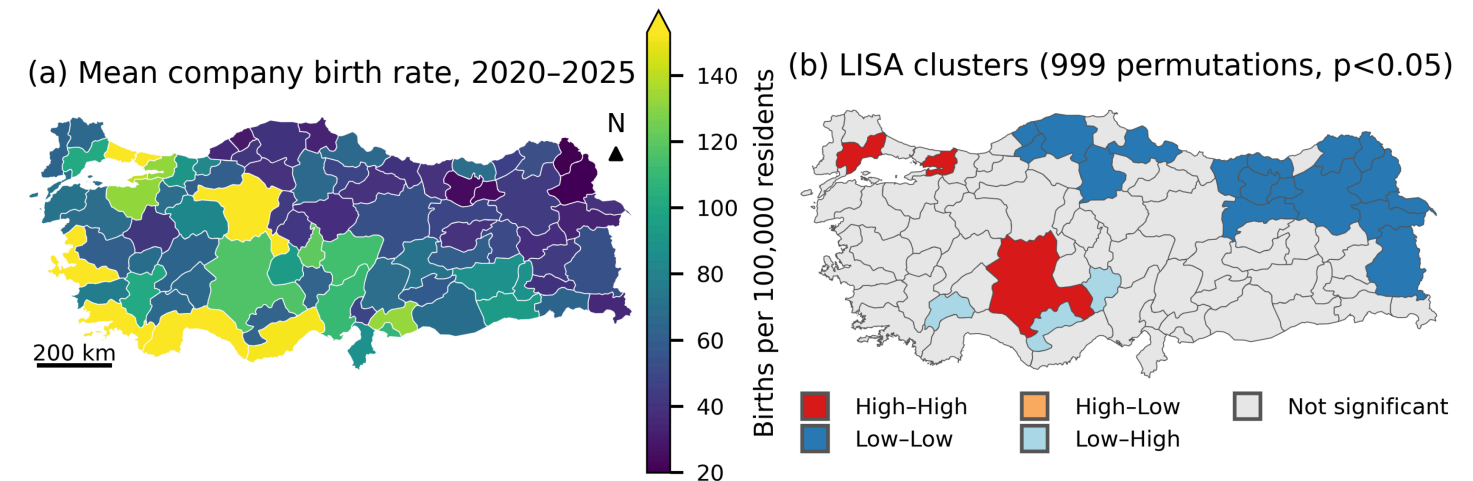


Figure 2

Geography and local clustering of company formation. **a** Mean company birth rate per 100,000 residents, 2020–2025, colour scale clipped at the 95th percentile. **b** LISA classification of the same variable (999 conditional permutations,  $p < 0.05$ ): high–high provinces flanking Istanbul (Tekirdağ, Kocaeli) and Konya; a 17-province low–low belt across the northern and northeastern interior; three low–high provinces (Burdur, Karaman, Niğde); no high–low outliers. Global Moran’s  $I = 0.325$  (permutation  $p = 0.001$ )

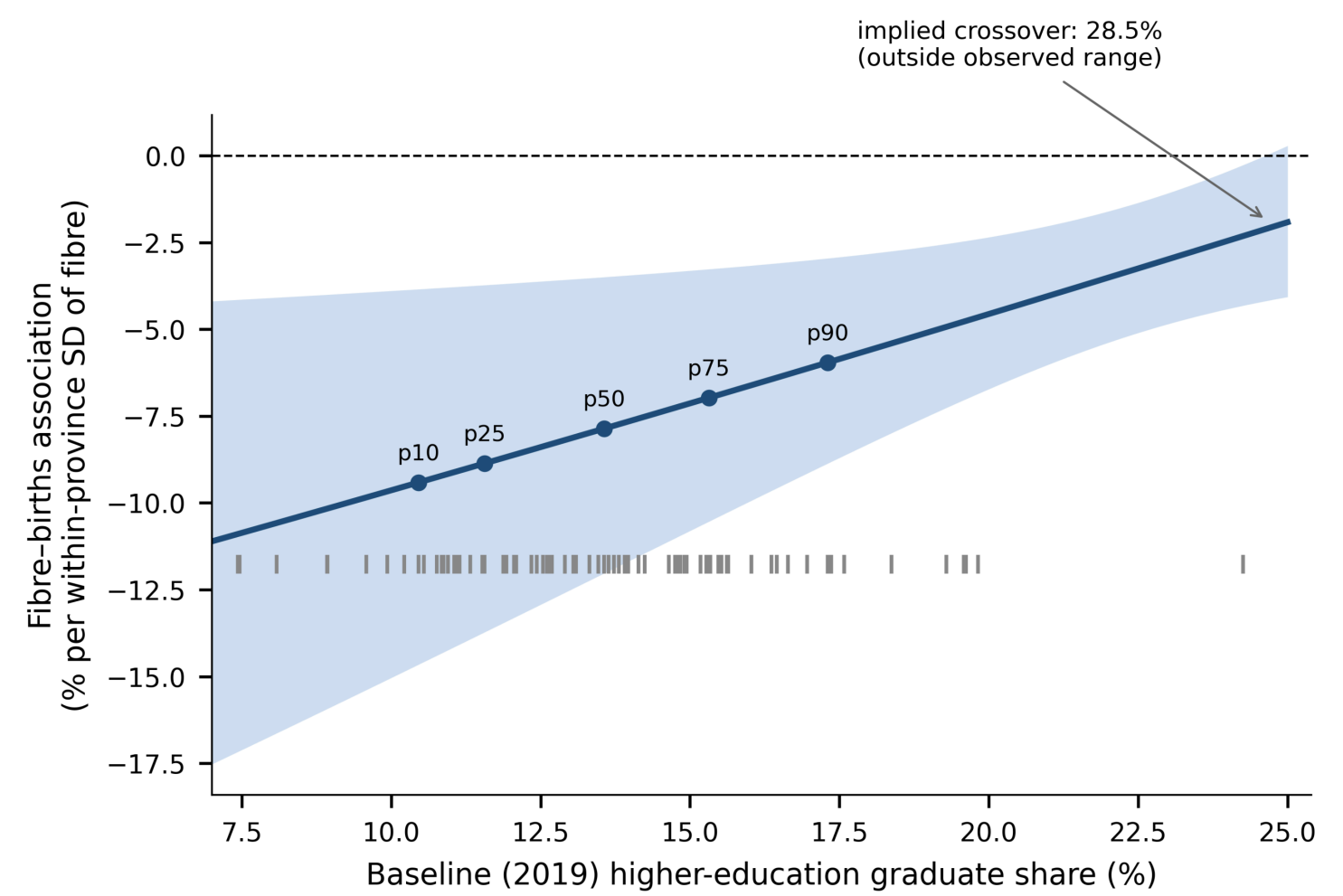


**Figure 3**

Marginal fibre–births association across the baseline education distribution. The solid line is the PPML marginal association converted to the percentage change in expected births per one within-province SD of fibre (1.57 subscriptions per 100); the shaded band is the 95% confidence interval; points mark the 10th–90th percentiles of the 2019 higher-education share and tick marks the 81 provincial values. The implied sign crossover (28.5%) lies outside the observed range (maximum 24.3%)

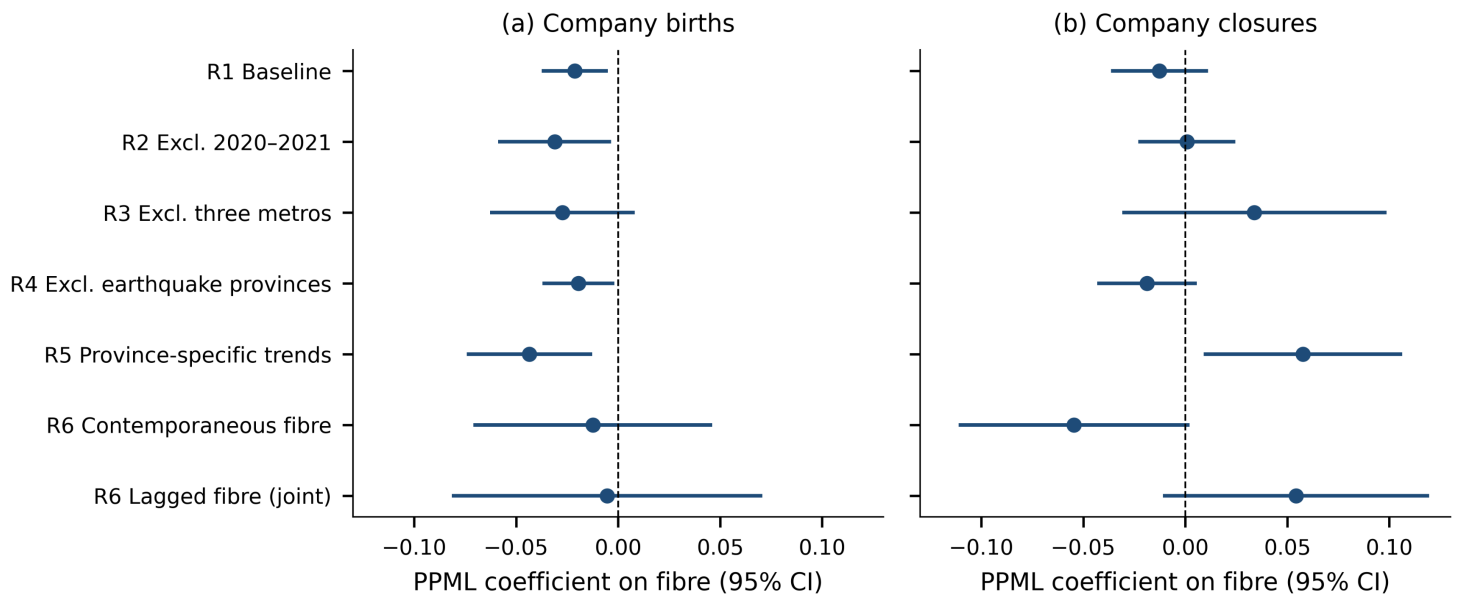


**Figure 4**

Robustness of the fibre coefficient under PPML. Point estimates and 95% confidence intervals for company births **(a)** and closures **(b)** across the specifications of Table 4. Birth estimates are uniformly negative; closure estimates change sign across specifications, indicating no stable exit association