Why benchmark of local infrastructure should account for population growth

Analysis of the Swedish electricity distribution firms

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Xilu Pty Ltd

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Executive Summary

Efficiency calculations based on benchmarking require that material exogenous heterogeneity across firms is accounted for; otherwise, measured efficiency may partly reflect differences in operating environments rather than controllable performance, with implications for incentives and welfare. One potentially important factor that is left out in the benchmarking of Swedish electricity distribution system operators (DSOs) is population growth. Sweden's population development is highly uneven across space. The municipal map (Figure 1) shows strong growth in many urban centres and suburbs, alongside stagnation and decline in many rural and remote areas. In the data, about one third of Sweden's 290 municipalities experienced population decline over 2019–2023. This matters for local infrastructure because distribution networks are capital-intensive and costs do not fall proportionally when the customer base shrinks, which can contribute to "death spiral" dynamics in depopulating areas.

The report develops a theoretical model showing that DSOs facing different population trends will optimally follow different capital paths due to (i) a binding universal service obligation and (ii) long-lived, partly irreversible network capital. The key prediction is that the relationship between population growth and benchmark-based efficiency is inverted U-shaped: measured efficiency is highest when population is stable, and lower when population is either shrinking (stranded/excess capacity) or rapidly growing (convex expansion and adjustment costs).

Empirically, the report assembles data for 147 regulated Swedish DSOs (with efficiency scores available for 145 firms) and measures local population trends using Statistics Sweden, mapped from municipalities to concession areas using population-weighted aggregation. Descriptively, the efficiency score averages 0.858 (min 0.583, max 1.000), and concession-area population growth spans roughly –2.1% to +2.0% per year in the DSO sample. The econometric analysis estimates a quadratic relationship between efficiency and population growth. The quadratic term is negative and strongly significant across model variants, indicating that the association is not well approximated by a linear trend and is consistent with the predicted inverted-U mechanism. The estimated turning point is small and not robustly different from zero at the 5% level, implying that the peak is close to stable population.

The findings imply that current benchmarking may systematically favour DSOs operating under stable demographic conditions and penalise firms in shrinking or fast-growing areas, even when effort and competence are identical. This leaves the Swedish regulator with two practical policy choices: (i) adjust calculated efficiency scores ex post to correct for population-growth effects, or (ii) benchmark only DSOs exposed to similar population growth regimes. The first option allows the regulator to retain the existing procedure and therefore minimises regulatory risk.

Sammanfattning (Summary in Swedish)

Effektivitetstal som bygger på benchmarking förutsätter att viktig exogen heterogenitet mellan företag beaktas. Om relevanta omvärldsfaktorer utelämnas riskerar beräknad effektivitet att delvis spegla skillnader i verksamhetsmiljö snarare än påverkbar prestation, vilket kan ge snedvridna incitament och välfärdsförluster. En faktor som i dagsläget inte beaktas i benchmarkingen av svenska elnätsföretag (lokalnäten) är befolkningstillväxt. Sveriges befolkningsutveckling är starkt geografiskt varierande. Kommun-kartan (Figur 1) visar tydlig tillväxt i många större städer och förorter, samtidigt som många glesa och perifera områden uppvisar stagnation eller minskning; i data framgår att ungefär en tredjedel av Sveriges 290 kommuner hade befolkningsminskning under 2019–2023. Detta är centralt för lokal infrastruktur eftersom elnät är kapitalintensiva och kostnader inte faller proportionellt när kundbasen krymper, vilket kan bidra till så kallade *death spiral*-processer i avfolkningskommuner.

Rapporten utvecklar en teoretisk modell som visar att elnätsföretag som möter olika befolkningstrender kommer att ha olika optimala kapitalbanor, givet (i) ett bindande leveransansvar (*universal service obligation*) och (ii) långlivat, delvis irreversibelt nätkapital. Modellens huvudprediktion är att sambandet mellan befolkningstillväxt och beräknad effektivitet är inverterat U-format: effektiviteten är högst vid stabil befolkning och lägre vid både befolkningsminskning (överkapacitet/*stranded assets*) och snabb tillväxt (konvexa expansions- och anpassningskostnader).

Empiriskt sammanställs data för 147 reglerade svenska DSO:er (effektivitetsmått finns för 145 företag). Lokala befolkningstrender hämtas från SCB och översätts från kommunnivå till koncessionsområden via befolkningsviktad aggregering. Deskriptivt är den genomsnittliga effektivitetspoängen 0,858 (min 0,583, max 1,000) och koncessionsområdenas befolkningstillväxt spänner ungefär från –2,1% till +2,0% per år. Den ekonometriska analysen estimerar ett kvadratiskt samband mellan effektivitet och befolkningstillväxt. Den kvadratiska termen är negativ och starkt signifikant i flera specifikationer, vilket visar att sambandet inte kan beskrivas med en enkel linjär trend utan är förenligt med det inverterat U-formade mönstret. Den skattade vändpunkten är liten och kan inte med 5%-nivå fastställas vara skild från noll, vilket innebär att maximum ligger nära stabil befolkningsnivå.

Resultaten innebär att dagens benchmarking riskerar att systematiskt gynna företag i demografiskt stabila områden och missgynna företag i krympande eller snabbväxande områden, även om ansträngning och kompetens är likvärdig. Rapporten pekar därför på två huvudsakliga regulatoriska handlingsalternativ: (i) justera effektivitetspoängen i efterhand (ex post) för att korrigera för befolkningsutveckling, eller (ii) endast jämföra företag som möter liknande befolkningstillväxtregimer. Det första alternativet gör det möjligt att behålla nuvarande procedur och minimerar därmed den regulatoriska risken.

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1. Introduction

Regulatory benchmarking plays a central role in the economic regulation of electricity distribution system operators (DSOs). By comparing firms' observed costs to those of their peers, regulators aim to distinguish efficient from inefficient performance and to set revenue allowances that incentivise cost minimisation while safeguarding service quality (Jamasb and Pollitt, 2003; Bogetoft and Otto, 2011). A fundamental requirement for such benchmarking exercises is that all relevant exogenous heterogeneity across firms is properly accounted for. If material differences in operating environments are ignored, measured efficiency will not solely reflect managerial performance but may instead capture structural conditions beyond the firm's control. This, in turn, risks biased regulatory outcomes and welfare losses.

One potentially important source of exogenous heterogeneity that has so far received limited attention in regulatory benchmarking of Swedish electricity DSOs is local population growth. Sweden exhibits pronounced regional demographic divergence: while some urban and peri-urban areas experience sustained population growth, many rural and remote regions face long-term stagnation or decline. Electricity distribution networks are inherently local and capital-intensive, and DSOs' concession areas differ markedly in their exposure to these demographic trends. Yet current benchmarking practice treats firms as broadly comparable, without explicitly adjusting for differences in population dynamics. This raises the question of whether efficiency scores produced by the regulatory model systematically reflect demographic conditions rather than underlying efficiency.

Why does this matter? Electricity distribution networks are characterised by long-lived, quasi-irreversible capital and a universal service obligation: DSOs must maintain sufficient network capacity to supply all connected customers at all times. As a result, network costs do not adjust proportionally to changes in population or demand. In areas with declining population, networks that were built to serve a larger customer base continue to incur capital and maintenance costs even as the number of customers falls. These costs must be spread over fewer users, mechanically raising unit costs. In fast-growing areas, by contrast, DSOs must expand capacity to accommodate new customers. Such expansion involves planning, construction, and coordination frictions and typically entails convex adjustment costs, particularly when growth is rapid (Joskow, 2008). Both situations, sustained decline and rapid growth, therefore generate cost pressures that are largely outside the firm's short-run control.

This report develops a simple theoretical framework that formalises this intuition and shows how population dynamics translate into differences in measured efficiency under benchmarking. The key insight is that, when network capital is long-lived and only slowly adjustable, firms facing different population trends will optimally follow different capital paths. DSOs serving areas with stable population can operate close to a steady state, where investment largely offsets depreciation and network capacity is well aligned with demand. In contrast, DSOs in shrinking areas accumulate excess (stranded) capacity that cannot be rapidly removed, while DSOs in expanding areas incur higher costs due to accelerated investment and adjustment. When benchmarking is based on observed unit costs, these structural cost differences are mapped directly into efficiency scores. The model therefore predicts a non-linear, inverted U-shaped relationship between population growth and measured efficiency: efficiency is highest for firms facing stable population levels and lower for firms exposed to either population decline or rapid population growth.

The empirical analysis in this report provides strong support for this prediction. Using data for 147 regulated Swedish electricity DSOs, we document a statistically significant concave relationship between local population growth and benchmark-based efficiency scores. Firms operating in concession areas with near-zero population growth tend, on average, to exhibit higher measured efficiency, while firms in both shrinking and fast-growing areas score lower. Importantly, this pattern persists after controlling for firm size and other observable characteristics. The results therefore suggest that current efficiency scores systematically reflect demographic conditions, rather than purely differences in managerial performance.

These findings have important implications for regulatory practice. If benchmarking outcomes are influenced by population dynamics in this way, DSOs operating under unfavourable demographic conditions may be unduly penalised, while firms in stable areas may be implicitly favoured, even when effort and competence are identical. Such bias undermines the fairness and credibility of the regulatory regime and may distort investment incentives. In growing regions, underestimating the cost impact of expansion risks discouraging timely network reinforcement, while in shrinking regions, failing to account for stranded assets may jeopardise the financial sustainability of network provision. From a welfare perspective, ignoring population growth in benchmarking can therefore lead to inefficient pricing signals, suboptimal investment, and uneven service quality across regions.

The analysis presented in this report points to two broad regulatory responses. One option is to adjust calculated efficiency scores ex post to account for the systematic cost effects associated with population growth and decline. This approach allows the regulator to retain the existing benchmarking framework while correcting for a clearly identified source of bias, thereby limiting regulatory risk. An alternative is to restrict benchmarking comparisons to firms exposed to similar demographic conditions, for example by grouping DSOs according to population growth regimes. Both approaches seek to ensure that efficiency assessments better reflect controllable performance rather than structural differences driven by demographic change.

By highlighting the role of population development in shaping measured efficiency, this report contributes to the broader literature on infrastructure regulation and benchmarking under heterogeneous operating conditions (Farrell, 1957; Aigner et al., 1977; Jamasb and Pollitt, 2003; Bogetoft and Otto, 2011). More importantly, it provides concrete evidence that demographic trends deserve explicit consideration in the regulation of electricity distribution networks, particularly in countries such as Sweden where population change is both persistent and spatially uneven.

2. Population growth in Sweden

As illustrated by the municipal population map in Figure 1, Sweden is experiencing highly heterogeneous population growth across regions. Some municipalities, particularly urban centers and their suburbs, are growing strongly, while many rural and remote areas are facing population stagnation or decline. For example, certain suburbs in the Stockholm region have seen annual population increases above 2%, whereas some small northern municipalities are losing around 2% of their residents per year. This divergence reflects a long-running trend: our data reveals that about one third of Sweden's 290 municipalities have experienced population decline from 2019 to 2023. In short, the country's population is concentrating in key growth hubs while steadily draining in large parts of the northern inland, areas around Värnern (the largest lake) and the south-east.

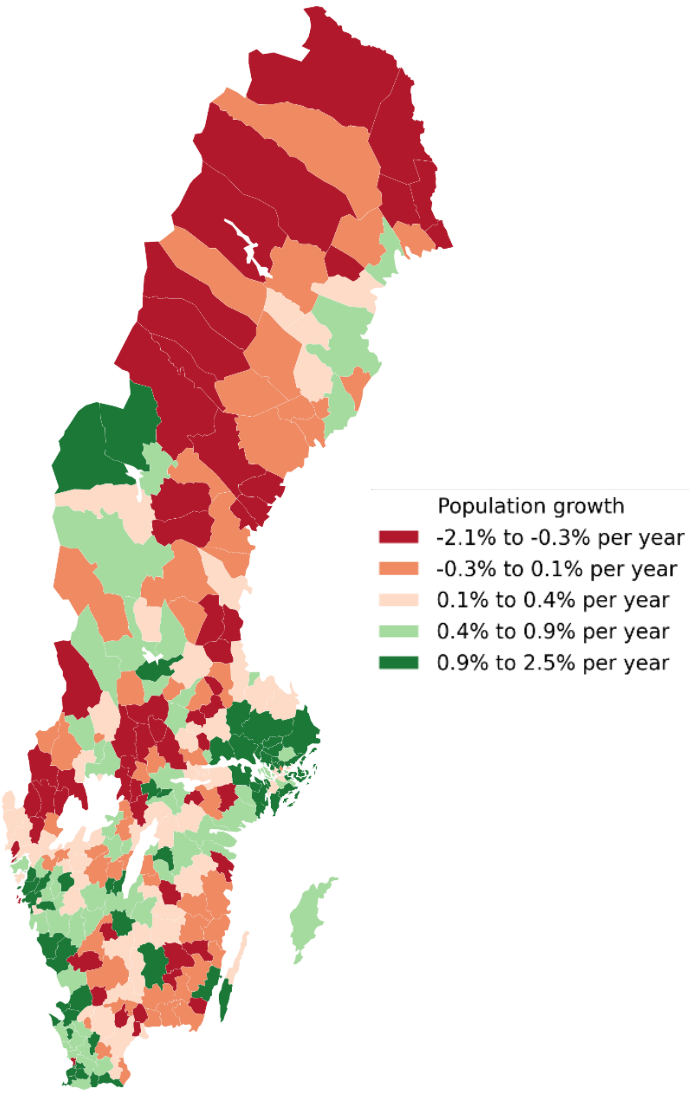

Figure 1. Average population growth per year in Swedish municipalities from 2019 to 2023. Source: Statistics Sweden and own analyses.

Multiple factors drive these uneven demographic developments. Urbanization and internal migration are primary forces: young adults frequently leave smaller towns for larger cities to pursue higher education, jobs, and urban amenities. The three metropolitan regions Stockholm, Göteborg, and Malmö, along with other regional cities attract the majority of migrants, as well as most international immigrants, fueling their growth. By contrast, many rural municipalities experience an aging population and youth out-migration, leading to natural decrease (an excess of deaths over births) and a shrinking workforce. Economic centralization reinforces this pattern: jobs in knowledge-intensive industries and public services are increasingly clustered in urban areas, while peripheral regions have seen traditional industries decline without equivalent replacement. Overall, the promise of greater opportunities in cities is pulling people in, while outlying areas are left with demographic headwinds.

In municipalities with declining populations, the erosion of human capital and fiscal capacity creates serious difficulties for local development. As educated and working-age individuals depart, local employers, from schools and hospitals to businesses and utility providers, struggle to recruit and retain qualified staff, undermining service delivery. At the same time, a falling population means fewer local taxpayers or ratepayers to fund the fixed costs of infrastructure. Many systems end up over-dimensioned relative to current demand, resulting in higher per-capita costs for maintenance and operations (Syssner and Jonsson, 2020). Shrinking municipalities often must defer upgrades and maintenance of facilities due to budget constraints, which can lead to a gradual deterioration of infrastructure quality. Local officials face an unenviable dilemma: either raise taxes and fees on a dwindling base, potentially encouraging more people to leave, or allow public services and infrastructure to decay. This vicious cycle is sometimes described as a community "death spiral," wherein declining population and service cuts reinforce one another (Syssner, 2020).

These demographic trends have direct repercussions for Sweden's electricity distribution sector. Power distribution networks are capital-intensive and largely characterized by costs that do not shrink in proportion to a declining customer base. In low-density and depopulating areas, there are fewer consumers among whom to spread the fixed expenses of poles, wires, and substations. Thus, the cost per customer of delivering electricity tends to rise in rural and shrinking municipalities. This is evident even at a national scale. Countries or regions with low population density require more extensive networks and accordingly face higher grid costs per user than dense urban areas (Eurostat, 2025). Under Sweden's regulated tariff system, distribution companies are allowed to recover their necessary costs, but if local energy demand falls sharply, the remaining customers may still see significantly higher network charges. Such disparities raise concerns about affordability and equity between growing and declining regions.

There is also a risk of a utility "death spiral" in the energy sector. As network tariffs climb or service quality potentially declines in a shrinking community, more consumers might reduce their reliance on the grid or even relocate. Analysts warn that this can become a self-reinforcing downward spiral for utilities: falling usage by customers leads to revenue shortfalls, prompting further tariff increases which in turn incentivize additional customers to cut back or defect (Biggar, 2022). While going completely off-grid in Sweden's climate is uncommon, well-off households could invest in solar panels and batteries to partially supply themselves if grid electricity becomes too expensive, exacerbating the utility's revenue losses (Olsson & Barquet, 2021). Meanwhile, maintaining reliable service quality in depopulated areas becomes more challenging if investments are postponed. Longer rural feeder lines are more vulnerable to outages, yet network operators may struggle to justify costly upgrades for a shrinking customer base. Ensuring that residents in all regions enjoy reliable and reasonably priced electricity thus remains a key regulatory challenge amid these demographic shifts.

3. Theory

Time is discrete and indexed by $t = 0,1,2, \dots$ Firm i faces an exogenous number of connected customers (or population served), denoted N_{it}. Population, which is considered outside firm's control, evolves according to

$$N_{it} = N_{i0}(1 + g_i)^t, \tag{1}$$

where $g_i \in (-1, \infty)$ and $g_i$is the firm's underlying population trend:

- $g_i = 0$: stable population
- $g_i > 0$: increasing population
- $g_i < 0$: decreasing population

Universal service obligation (USO)
The electricity distribution firm is subject to a universal service obligation: it must be able to serve all customers at all times.

Let K_{it} denote the firm's effective network capacity or capital stock (lines, transformers, substations, etc.). To serve N_{it}, capacity must satisfy the engineering and reliability constraint

$$K_{it} \geq \kappa N_{it}, \kappa > 0. \tag{USO}$$

The parameter κ represents required network capacity per customer, or more generally, per connected load unit. Similar capacity–demand constraints are standard in models of regulated networks and infrastructure provision (Joskow, 2008; Crew and Kleindorfer, 2012).

Long-lived, quasi-irreversible capital
Network assets are long-lived and adjust slowly. Capital evolves according to

$$K_{i,t+1} = (1 - \delta)K_{it} + I_{it}, \delta \in (0,1), \tag{2}$$

where I_{it}denotes gross investment and δ is the depreciation rate. A small δ reflects long asset lifetimes typical of electricity distribution infrastructure. To capture the fact that network assets are difficult to shrink once installed, impose irreversibility:

$$I_{it} \geq 0. \tag{IRR}$$

Thus, the firm can expand or replace capital but cannot rapidly disinvest or scrap assets when population declines. This reflects both physical irreversibility and political or regulatory constraints on asset removal and follows the standard treatment of irreversible investment (Dixit and Pindyck, 1994; Guthrie, 2006).

Costs and managerial effort

Total expenditure (TOTEX) for firm i in period t is given by

$$C_{it} = rK_{it} + cN_{it} + \frac{\phi}{2} I_{it}^2 - e_{it}, \tag{3}$$

where:

- rK_{it}: cost of owning, financing, and maintaining network assets
- cN_{it}: baseline operating and customer-related costs
- $\frac{\phi}{2} I_{it}^2$: convex adjustment cost of investment
- $-e_{it}$: controllable cost reduction through managerial effort

Convex investment costs capture planning, construction, and coordination frictions associated with rapid network expansion, which are widely documented in electricity networks (Joskow, 2008; Cambini et al., 2016).

Effort is privately costly to the firm. Managerial disutility is

$$\text{disutility of effort} = \frac{\psi}{2} e_{it}^2, \qquad \psi > 0. \tag{4}$$

Given the exogenous population path $\{N_{it}\}$, the firm chooses $\{I_{it}, e_{it}\}$ to minimise discounted total cost:

$$\min_{\{I_{it}, e_{it}\}_{t \geq 0}} \sum_{t=0}^{\infty} \beta^t [rK_{it} + cN_{it} + \frac{\phi}{2} I_{it}^2 - e_{it} + \frac{\psi}{2} e_{it}^2], \tag{P}$$

subject to (2), (USO), and (IRR), where $\beta \in (0,1)$ is the discount factor.

Effort enters the objective function only contemporaneously and does not affect constraints. The first-order condition with respect to e_{it} is

$$1 - \psi e_{it} = 0,$$

Implying

$$e_{it}^* = \frac{1}{\psi}. \tag{5}$$

Effort is therefore constant across firms and time. This ensures that differences in observed cost and measured efficiency arise from structural factors, e.g. population dynamics and capital adjustment, rather than behavioural heterogeneity (Bogetoft and Otto, 2011).

Benchmarking and measured efficiency

Regulatory benchmarking is based on observed unit cost, defined as

$$u_{it} = \frac{C_{it}}{N_{it}}. \tag{6}$$

The benchmark (best-practice) unit cost in period $t$is

$$u_t^* = \min_j \ u_{jt}. \tag{7}$$

Measured efficiency is defined as

$$\eta_{it} = \frac{u_t^*}{u_{it}}, 0 < \eta_{it} \leq 1. \tag{8}$$

This reduced-form representation captures the logic of DEA, SFA, and yardstick regulation, where firms are evaluated relative to the lowest observed cost conditional on outputs (Farrell, 1957; Aigner et al., 1977; Jamasb and Pollitt, 2003).

Capital paths under different population trends

This allows us to formulate what the optimal capital paths look like under different population trends.

Lemma 1 (Stable population)

If $g_i = 0$, population and required capacity are constant over time. The USO binds with equality:

$$K_{it} = \kappa N_{it}.$$

Investment offsets depreciation:

$$I_{it} = \delta\kappa N_{it}. \tag{9}$$

Lemma 2 (Growing population)

If $g_i > 0$, required capacity increases over time. Combining (2) with a binding USO yields

$$I_{it} = \kappa N_{it}(g_i + \delta). \tag{10}$$

Investment exceeds replacement levels, and convex adjustment costs increase unit cost.

Lemma 3 (Shrinking population)

If $g_i < 0$, required capacity declines, but irreversibility prevents proportional disinvestment.

Define excess (i.e. stranded) capacity as

$$S_{it} = K_{it} - \kappa N_{it}. \tag{11}$$

Then $S_{it} \geq 0$for all t, and excess capacity persists until depreciated.

Unit cost decomposition

Substituting optimal effort and dividing by population yields

$$u_{it} = r\kappa + c + r\frac{S_{it}}{N_{it}} + \frac{\phi}{2}\frac{I_{it}^2}{N_{it}} - \frac{1}{\psi N_{it}}. \tag{12}$$

The last term vanishes asymptotically and does not affect rankings. This allows us to formulate an important proposition:

Proposition 1 (Population trends and efficiency ranking)

Under benchmarking based on unit cost,

$$u_i^{\text{shrinking}} > u_i^{\text{growing}} > u_i^{\text{stable}},$$

and therefore

$$\eta_i^{\text{stable}} > \eta_i^{\text{growing}} > \eta_i^{\text{shrinking}}.$$

The justification for this is that stable firms avoid both excess investment and stranded capital. Growing firms incur convex expansion costs. Shrinking firms spread excess capital costs over a declining customer base. Benchmarking maps these structural cost differences directly into efficiency scores.

This mechanism is consistent with the notion that demographic trends affect measured efficiency in electricity distribution and with the broader literature on irreversible investment and regulated infrastructure (Dixit and Pindyck, 1994; Guthrie, 2006).

4. Data

This report combines demographic data at the municipality level with firm-level information for Sweden's regulated electricity distribution system operators (DSOs). The empirical unit in Chapter 5 is the DSO. However, because local network concession areas do not generally coincide with municipality borders, a key task is to translate municipality-level variables (population growth and wages) into concession-area measures that are comparable across DSOs.

4.1 Sample and main variables

The analysis covers 147 regulated Swedish electricity DSOs, for which we construct a concession-area population growth and, where relevant, additional controls. The main outcome variable in Chapter 5 is a benchmark-based efficiency score, bounded between 0 and 1, where 1 indicates best practice in the benchmarking set, consistent with the reduced-form benchmarking logic described in Section 3. In the dataset used for estimation, efficiency is available for 145 firms, while the remaining variables are available for 147 DSOs. In addition to the concession-area population growth, the firm-level control set includes the number of customers and a rural network indicator (defined below). Summary statistics are reported in Table 1.

Table 1. Descriptive statistics

Variable	# obs	Mean	Std. dev.	Min	Max
Efficiency	145	0.8576	0.1165	0.5829	1
# Customers	147	37 980	137 700	20	1 035 000
Population growth (percent)	147	0.3292	0.7556	-2.1000	1.9470
Wage (real)	147	28 590	1 112	25710	33 700
Rural	147	0.1769	0.3829	0	1

4.2 Municipality population data (2010–2024) and growth rates (2020–2023)

Population data are collected from Statistics Sweden (SCB) at the municipality-year level for the period 2010–2024. The population measure is the total population recorded on 1 November each year. While the longer panel is assembled for transparency and potential robustness work, e.g., alternative growth windows, the baseline population trend used in the empirical analysis is the average annual population growth rate over 2020–2023, computed separately for each of Sweden's municipalities.

4.3 Translating municipality growth to DSO concession areas

Because DSO concession areas do not align with municipality borders, we construct a DSO-level (concession-area) population growth using a population-weighted mapping procedure.

As a first step, relevant municipalities/localities are identified for each DSO. For each local network company, we first identify which municipalities (and, where needed, which localities) the concession area covers. If a concession area covers two or more municipal central localities, the DSO's population growth is calculated as the population-weighted average of the corresponding municipalities' growth rates. The weighting uses municipality populations to reflect that the effective scale of the concession area's demand base is larger where more residents live.

If a concession area does not cover any municipal central locality, we compile the set of localities served by the network and compute a population-weighted average growth rate across those localities. In these cases, the report documents the use of ChatGPT 5.2 to support the identification and weighting of localities, and these DSOs are classified as rural networks (by utilizing the indicator variable Rural) in the Chapter 5. The resulting distribution of concession-area population trends across all regulated DSOs is summarised in Figure 2.

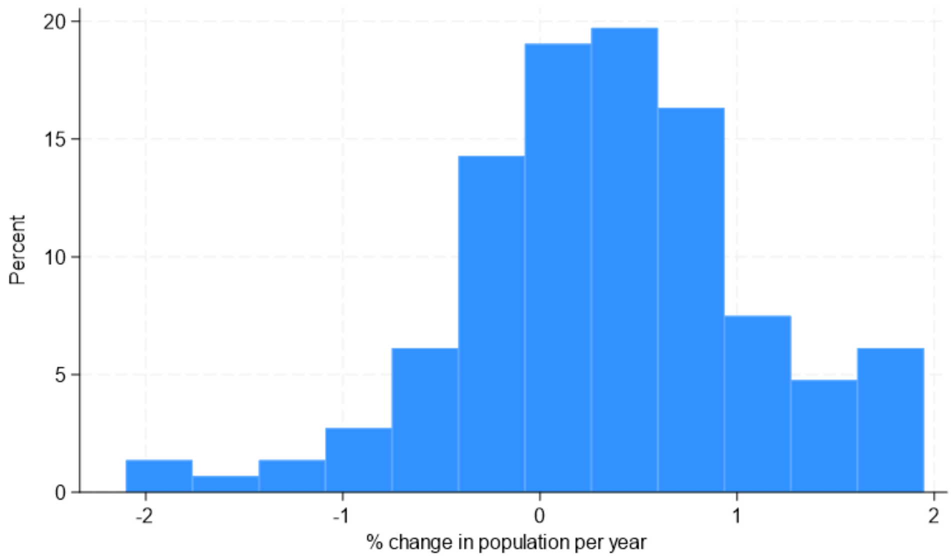

Figure 2. Average population growth per year for the 147 regulated Swedish electricity DSOs. Source: Statistics Sweden and own analyses.

4.4 Wage data and concession-area wages

To proxy local input-cost conditions, we also collect average monthly wages at the municipality level.

The wage variable is transformed into a concession-area measure using the same mapping logic as for population: if a concession spans multiple municipalities, wages are aggregated using population weights to reflect the composition of the labour market relevant to the concession area.

4.5 Descriptive statistics

Table 1 reports descriptive statistics for the variables used in Chapter 5. The efficiency score has a mean of 0.858 (min 0.583, max 1.000) across the 145 DSOs with available efficiency data. DSOs vary substantially in size: the number of customers ranges from 20 to 1,035,833 (mean 37,978). The concession-area population growth has a mean of 0.00329 (about 0.33% per year), with values spanning -0.021 to 0.01947, about -2.1% to +2.0% per year, underscoring the heterogeneity highlighted earlier at the municipality level. Finally, the rural-network indicator equals 1 for roughly 17.7% of DSOs, consistent with a non-trivial subset of concessions being dominated by smaller localities rather than municipal central towns.

5. Analysis

This section tests the main empirical implication of the framework in Section 3: benchmark-based efficiency scores should be systematically related to local population trends, because DSOs in shrinking areas carry “excess” (stranded) network capacity that cannot be reduced proportionally, while DSOs in fast-growing areas face expansion and adjustment costs. The prediction is therefore non-linear: efficiency should be highest around *stable* population, and lower for both sustained decline and rapid growth.

5.1 Econometric specification

We estimate a reduced-form relationship between a DSO’s benchmarking-based efficiency score and the population trend in its concession area, allowing for non-linearity through a quadratic term. The empirical model is specified as:

$$Efficiency_i = \alpha + \beta_0 Cust_i + \beta_1 Pop\ growth_i + \beta_2 Pop\ growth_i^2 + \boldsymbol{\gamma}\boldsymbol{X}_i + \varepsilon_i$$

where variables are those included in Table 1. The vector X includes the control variables: none in Model (1), $Wage$ in Model (2) and $Wage$ and $Rural$ in Model (3). ε is the random noise. Estimated parameters are α, β_0, β_1, β_2 and the vector $\boldsymbol{\gamma}$. As shown, population growth is included both as a linear and as a quadratic term, to capture the predicted inverted-U pattern.

Control variables are included progressively across three models, using the variables summarised in Table 1. Concretely, Model (1) is the baseline specification, Model (2) adds the concession-area real wage proxy, and Model (3) additionally includes the rural network indicator. All models include the number of customers (a scale proxy), and the error term is treated as potentially heteroskedastic; reported standard errors are robust to arbitrary heteroskedasticity. The estimation sample comprises 145 DSOs, reflecting the availability of efficiency scores.

5.2 Interpreting the quadratic relationship and the “turning point”

Let g denote population growth (in percent). With a quadratic specification, the marginal association between growth and efficiency is:

$$\frac{\partial \text{Efficiency}}{\partial g} = \beta_1 + 2\beta_2 g.$$

If $\beta_2 < 0$, the implied relationship is concave, i.e. an inverted U. A useful summary is the turning point (the value of g at which predicted efficiency is maximised):

$$g^* = -\frac{\beta_1}{2\beta_2}.$$

This turning point is reported at the bottom of Table 2 for each model. Conceptually, the theory in Section 3 suggests that g^* should be near zero, i.e., efficiency should be highest when population is stable, since stable concessions avoid both rapid expansion costs and stranded capital.

5.3 Main results

Table 2 reports the estimation results for Models (1)–(3).

Table 2. Estimation results

Variable	Model (1) Coeff. (SE)	Model (2) Coeff. (SE)	Model (3) Coeff. (SE)
# Cust	1.29E-07*** (2.10E-08)	1.13E-07*** (2.65E-08)	1.06E-07*** (2.65E-08)
Population growth	0.0227* (0.0132)	0.0150 (0.0142)	0.0110 (0.0142)
Population growth × Population growth	-0.0303*** (0.0094)	-0.0346*** (0.0098)	-0.0325*** (0.0101)
Real wage		1.33E-05 (1.05E-05)	1.43E-05 (1.06E-05)
Rural			-0.0266 (0.0293)
Constant	0.8658*** (0.0119)	0.4914* (0.2957)	0.4675 (0.3008)
Turning point	0.3745* (0.2157)	0.2173 (0.2041)	0.1686 (0.2138)
R^2	0.091	0.102	0.109
# obs	145	145	145

Notes. Standard errors are robust to arbitrary heteroscedasticity.

Four patterns stand out.

(i) Scale is positively associated with measured efficiency

Across all three models, the coefficient on # Customers is positive and statistically significant at conventional levels. This is consistent with the idea that larger DSOs may (i) exploit economies of scale in operations and maintenance and/or (ii) be advantaged by the benchmarking framework if some fixed or quasi-fixed costs are spread across a larger customer base. The point estimate is stable across specifications, indicating that the scale association is not driven by wages or rural classification.

(ii) Population growth enters non-linearly, consistent with the theoretical mechanism
The quadratic term is negative and strongly significant in all three models. This provides clear evidence that the association between demographic change and benchmarked efficiency is not well approximated by a simple linear trend. The linear growth term is positive in all models, but only weakly significant in the baseline model. Taken together, the estimates imply an inverted-U relationship: moving from population decline toward stability is associated with higher efficiency, but sufficiently rapid growth is associated with lower efficiency—exactly the qualitative pattern implied by the "shrinking vs. expanding vs. stable" capital adjustment logic in Section 3.

(iii) The estimated turning point is small and not robustly different from zero
The turning point implied by Model (1) is about 0.3745 (in percentage growth units), with corresponding values of 0.2173 and 0.1686 in Models (2) and (3). Importantly, the report's inference is that it is not established at the 5% level that the turning point differs from zero in any specification. In practical terms, the data are consistent with a peak close to stable population, which aligns with the theoretical benchmark case: stable concessions avoid both stranded capacity (depopulating areas) and costly rapid expansion (fast-growing areas).

(iv) Wages and the rural indicator do not materially affect the results
Neither real wages nor the rural dummy is statistically significant in Models (2)–(3).
Their inclusion also leaves the estimated shape of the population-growth relationship largely intact (the quadratic term remains negative and significant). On this basis, the report treats Model (1) as the preferred specification, since the added controls do not improve explanatory power in a meaningful way.

Finally, the R^2 values are in the range 0.091–0.109, which is modest but not unusual in cross-sectional comparisons of benchmarked performance where a large fraction of variation reflects unobserved heterogeneity and measurement differences across firms.

5.4 Visualising the implied relationship

Figure 3 illustrates the estimated relationship between population growth and efficiency implied by the preferred Model (1). The concave shape is the key takeaway: predicted efficiency is highest around modestly positive or near-zero population change, and declines as population growth becomes strongly negative (shrinking concessions) or strongly positive (rapidly expanding concessions). This visualisation is useful for translating the regression output in Table 2 into the intuitive comparative-statics described in Section 3: both demographic contraction and demographic pressure can mechanically worsen benchmark performance, even without differences in managerial effort, because network capital is long-lived and adjustment is asymmetric.

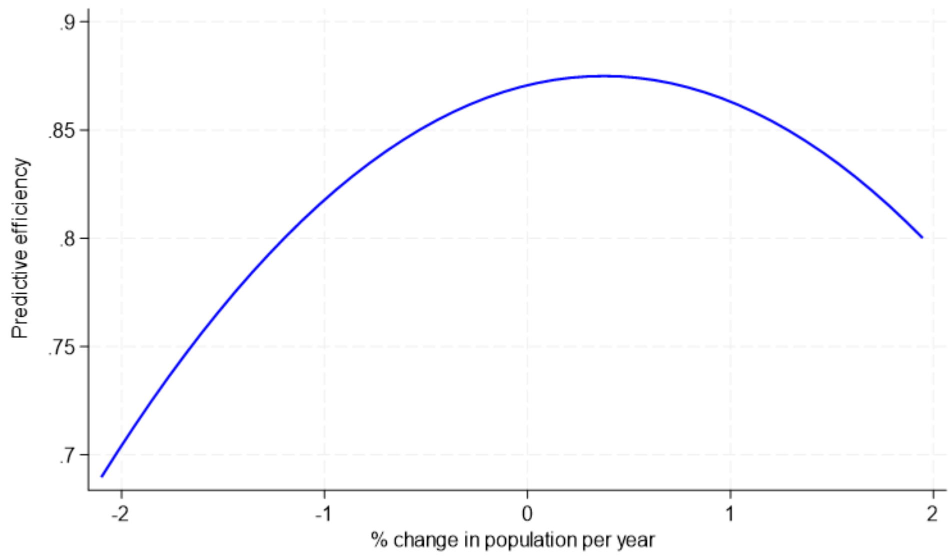

Figure 3. The estimated relationship between population growth and efficiency. Based on Model (1) in Table 2.

5.5 Discussion

The results should be read as evidence that benchmarking outcomes are correlated with demographic conditions in a way that is consistent with the report's theory: DSOs serving shrinking areas are likely to appear less efficient because fixed network costs are spread over fewer users, while DSOs in fast-growing areas may appear less efficient because expansion requires investment and incurs adjustment costs.

6. Conclusions

Benchmarking-based regulation rests on the principle that measured efficiency differences should primarily reflect controllable performance rather than structural differences in operating environments. In Sweden, however, local demographic conditions vary markedly across space and time: the municipality-level evidence shows strong divergence between growing urban/suburban areas and many rural or remote areas with stagnation or decline, with around one third of Sweden's municipalities experiencing population decline over 2019–2023. Because distribution networks are capital intensive and subject to a universal service obligation, demographic change is not merely "background noise"; it affects required capacity, the pace of investment, and the extent of stranded assets, and it therefore has the potential to systematically shape observed unit costs and, in turn, benchmark outcomes.

The theoretical model in this report formalises this mechanism. When population is stable, the firm can largely avoid both rapid expansion associated with convex adjustment costs, and excess/stranded capacity, due to irreversibility. When population grows, required capacity increases and the firm must invest beyond replacement levels, which raises unit costs through adjustment costs; when population shrinks, disinvestment cannot proceed proportionally and excess capacity persists, implying that remaining customers must carry the cost of an over-dimensioned network. The key implication is Proposition 1: under unit-cost benchmarking, measured efficiency is highest for firms facing stable population levels and lower for firms exposed to either population decline or rapid population growth—i.e., an inverted U-shaped relationship between population growth and measured efficiency.

The empirical analysis provides evidence consistent with this prediction. Using data for 147 Swedish DSOs, with benchmark-based efficiency scores bounded between 0 and 1, the report documents a statistically significant concave relationship between concession-area population growth and measured efficiency. Firms operating in areas with near-zero population growth tend, on average, to exhibit higher measured efficiency, whereas firms in both shrinking and fast-growing areas score lower, and this pattern remains when controlling for firm size and other observable characteristics. Taken together, the theory and evidence indicate that Swedish benchmarking outcomes can reflect demographic conditions in a systematic way, not only differences in managerial effort.

This has direct implications for regulatory practice. If population dynamics affect measured efficiency, firms operating under unfavourable demographic conditions risk being unduly penalised, while firms in stable areas may be implicitly favoured, even if competence and effort are identical. Such bias can undermine the perceived fairness and credibility of the regulatory regime and distort investment incentives. In growing regions, failing to account for the cost impact of expansion risks discouraging timely reinforcement and capacity upgrades; in shrinking regions, ignoring stranded assets can weaken financial sustainability and lead to deferral of maintenance and quality-enhancing investment, with potentially uneven service outcomes across regions. More broadly, when demographic trends are persistent and spatially uneven, benchmarking that does not explicitly account for population change risks producing welfare losses through inefficient pricing signals and misaligned incentives for investment and service quality.

The report points to two principal regulatory responses. The first is an ex-post adjustment of calculated efficiency scores to correct for the systematic effects of population growth and decline, thereby retaining the current benchmarking framework while reducing a clearly identified source of bias; this approach also limits regulatory risk by minimising procedural change. The second is to restrict benchmarking comparisons to firms exposed to similar demographic conditions, for instance by grouping DSOs into population-growth regimes, so that efficiency assessments more clearly reflect controllable performance rather than structural differences. Both approaches share the same objective: ensuring that benchmark outcomes do not inadvertently reward or punish firms for exogenous demographic trends.

Finally, several extensions can strengthen the evidence base for implementation. First, robustness work that varies the population-growth window, and leverages the longer municipality panel assembled in the dataset, can help assess how sensitive the estimated relationship is to alternative definitions of “trend.” Second, future analysis could explore whether the non-linear pattern differs across concession types, e.g., rural versus non-rural networks, and how population growth interacts with other environmental factors that shape network costs. Third, linking demographic change more directly to network planning pressures, through demand growth, customer composition, peak load, or connection activity, would help clarify when population is a good proxy for cost-relevant change and when additional variables are needed. These extensions do not change the core message of the report: in a setting like Sweden, where demographic change is both substantial and uneven, population development is an empirically relevant driver of measured efficiency and therefore deserves explicit consideration in benchmarking-based regulation.

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