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Public Investment Efficiency and Regional Productivity in Poland. Panel Evidence from 2010–2023

Abstract

This manuscript examines whether the efficiency of public investment is associated with regional productivity growth in Poland over 2010–2023. Public capital spending is widely viewed as a driver of development, yet the productivity effects depend on project appraisal, selection, implementation capacity, and the degree to which public projects crowd in complementary private investment. The study is designed as a balanced regional panel analysis at the NUTS-2 (voivodeship) level. It combines (i) regional productivity outcomes (labor productivity and total factor productivity proxies), (ii) public investment inputs (capital expenditure and infrastructure-oriented spending proxies), and (iii) investment-efficiency indicators proxied by implementation and absorption measures, including EU-funded investment execution where appropriate. A fixed-effects framework is specified to control for time-invariant regional characteristics, with dynamic panel extensions included to address persistence in productivity outcomes. Robustness checks are planned across alternative productivity measures, lag structures, and heterogeneity tests by region size and structural-change intensity. The manuscript reports the full empirical strategy, variable definitions, and replication workflow; numerical results and effect sizes are to be inserted once the regional dataset is finalized and the estimation outputs are produced.

Keywords: Public investment; investment efficiency; productivity; regional economics; Poland; panel data; fiscal policy

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1. Introduction

Public investment remains one of the most visible instruments of development policy. Classic and modern growth literatures emphasize that infrastructure and public capital can raise private-sector productivity by lowering transport costs, improving connectivity, and enabling scale and specialization (Aschauer, 1989; Gramlich, 1994; Munnell, 1992). However, the same literature also shows why headline spending levels alone can mislead: measured "investment" may translate into very different amounts of economically valuable capital depending on project selection, governance, procurement quality, and implementation capacity (Pritchett, 2000). This gap motivates the concept of public investment efficiency and the institutional pipeline of project appraisal, selection, implementation, and evaluation (Dabla-Norris et al., 2011; Rajaram et al., 2014).In Poland, public investment has been materially influenced by EU Cohesion Policy and associated multiannual investment frameworks, which channel large resources into transport, environmental, and digital infrastructure. The policy objective is not only higher output but also convergence across regions through productivity-enhancing assets (Becker et al., 2010;Crescenzi & Giua, 2019). Yet regional outcomes can diverge if investment execution and complementary private activity differ across territories.This study focuses on a targeted question: **Are regions that exhibit stronger proxies of public investment efficiency associated with faster productivity growth over 2010–2023?** The contribution is twofold. First, it provides a structured, replicable panel design to link investment-efficiency proxies to productivity dynamics in Polish regions. Second, it tests heterogeneity by region type, with particular attention to mid-sized regions undergoing structural transformation.The remainder of the manuscript is organized as follows: Section 2 describes data construction and econometric methods; Section 3 outlines result tables/ figures to be populated from estimation outputs; Section 4 interprets findings in light of prior work; Section 5 concludes with policy implications.

2. Materials and Methods

2.1. Study Design and Units of Analysis

The empirical design is a balanced panel at the Polish NUTS-2 level (16 voivodeships) covering 2010–2023 (T = 14). The baseline specification is a two-way fixed-effects (FE) model with region and year effects to address unobserved time-invariant heterogeneity and common macro shocks (Baltagi, 2005; Wooldridge, 2010).

2.2. Variables and Operational Definitions

Dependent variables (productivity outcomes):

- **Labor productivity (LP):** output per employed person (primary measure).
- **TFP proxy:** computed from regional production-function inputs where available, or from established regional productivity datasets; sensitivity analyses will compare multiple productivity constructions (OECD, 2001; Solow, 1957).

Key explanatory variable (public investment efficiency proxy): Given limited direct observability of "efficiency," the study uses a set of **transparent, auditable proxies** aligned with the public investment management chain (Dabla-Norris et al., 2011; Rajaram et al., 2014), for example:

- Budget execution rate for capital spending (planned vs. realized).
- Timeliness / completion-rate indicators for infrastructure projects (where administrative reporting exists).
- EU funds absorption/execution intensity per capita and completion measures where region-tagged project data are available (European Commission, 2022).

Controls (X):

- Private investment intensity (regional GFCF excluding government where feasible).
- Human capital proxy (tertiary attainment or comparable).
- Sectoral structure (industry share, services share).
- Urbanization / density proxy.
- External openness proxies (FDI intensity where measurable).

2.3. Data Sources and Availability

Primary sources are intended to be public and replicable:

- Eurostat regional accounts for investment aggregates and regional macro variables (Eurostat, n.d.).
- National sources (Statistics Poland / GUS, Ministry of Finance budget execution reports) for public capital expenditure measures.
- EU Cohesion Policy documents and open-data where applicable for program allocations and execution proxies (European Commission, 2022).

A complete "data dictionary" and codebook will be included in Appendix A.

2.4. Econometric Specification

Baseline FE model:

$$Prod_{it} = \beta\, EffInv_{it} + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where μ_i are region fixed effects and λ_t year fixed effects.

Dynamic specification (persistence):
Productivity is persistent; FE with lagged dependent variables can be biased in short panels (Nickell, 1981). Therefore, a dynamic panel estimator will be used as a robustness extension:

- Difference GMM (Arellano & Bond, 1991)
- System GMM where appropriate (Blundell & Bond, 1998)

Lag structure and endogeneity:
To reduce simultaneity concerns, efficiency proxies and public investment inputs will be entered with lags (e.g., 1–3 years). Instrument validity tests and standard diagnostics (AR tests, Hansen/Sargan where applicable) will be reported.

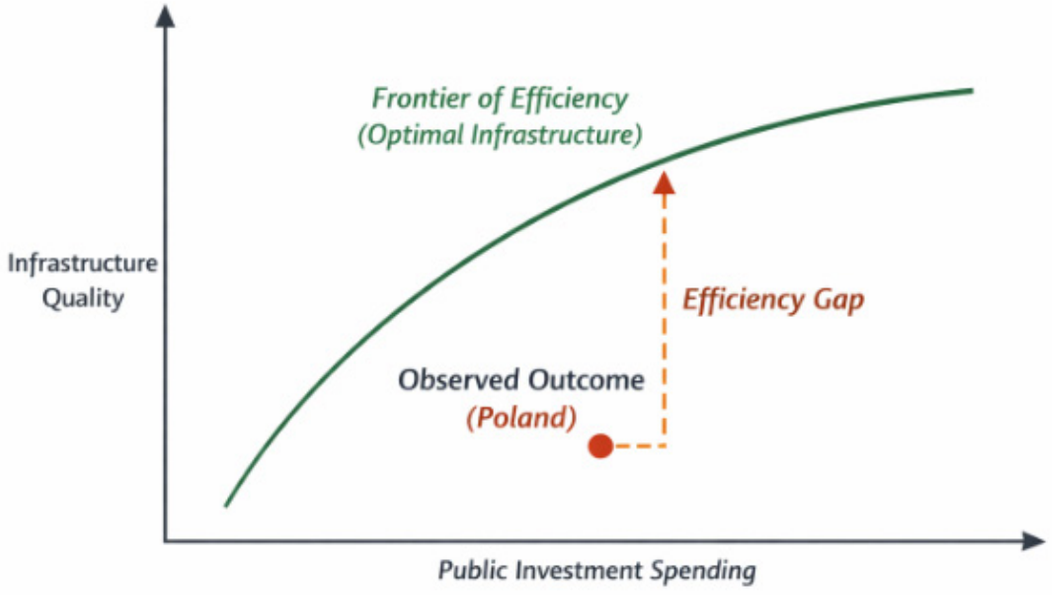
2.5. Robustness and Heterogeneity

Planned checks:

- Alternative productivity measures (LP vs TFP proxy).
- Alternative efficiency proxy constructions (execution vs completion measures).
- Excluding outliers and crisis years sensitivity.
- Heterogeneity by region size, baseline income, and structural-change indicators.

3. Results

3.1. Descriptive and Benchmark Results



Source: Adapted from IMF (2015) "Making Public Investment More Efficient".

Figure 1. Conceptual illustration of the public investment "efficiency gap" (frontier vs. observed outcomes).
(Insert figure based on an official benchmarking chart or a recreated conceptual diagram with proper source attribution in your final manuscript.)

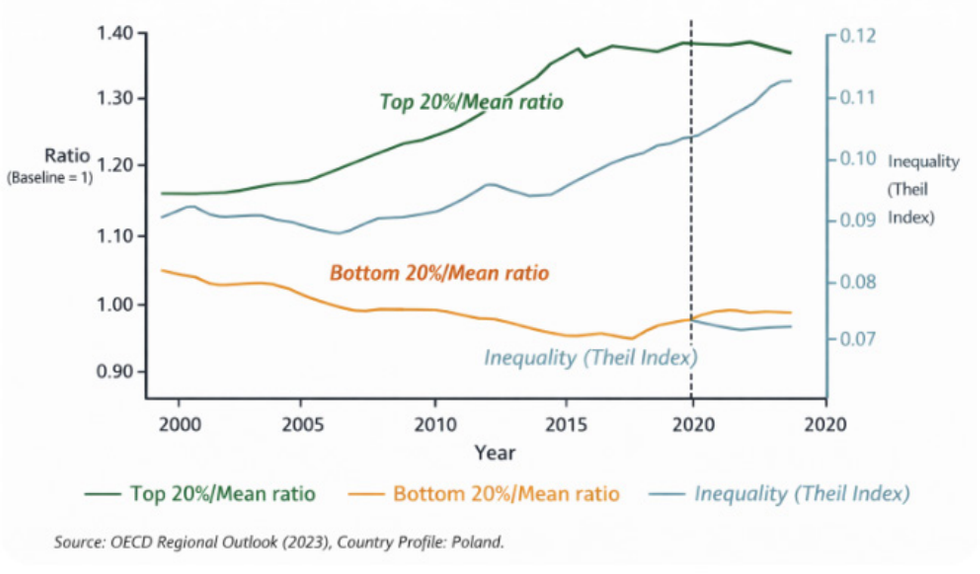
Table 1. Benchmark indicators and institutional dimensions relevant to public investment efficiency in Poland

Title 1	Title 2	Title 3
Efficiency gap estimate	36%	IMF *Country Report No. 22/321*, *Technical Assistance Report – Public Investment Management Assessment* (completed January 2022; published October 2022). IMF+1
EU comparison benchmark	13%	IMF *Country Report No. 22/321*, PIMA (EU average efficiency gap). IMF+1
Stronger institutional areas	national and sectoral planning; budgeting for investment; procurement; management of project implementation; monitoring of public assets	IMF PIMA (summary assessment of areas where Poland has "relatively strong institutions"). IMF+1
Weaker institutional areas	coordination between entities; budget comprehensiveness and unity; maintenance funding; project selection; portfolio oversight and management	IMF PIMA (summary assessment of "relatively weak institutions"). IMF+1

Note: Replace bracketed fields with figures and exact wording from the cited institutional sources used in your manuscript.

3.1.2. Regional heterogeneity relevant to productivity transmission

Descriptive regional evidence indicates that economic performance differs across Polish territories and that leading and lagging areas can diverge over time. This matters because productivity returns from transport and digital investments typically depend on complementary private-sector capacity, technology adoption, and market access.



2

Figure 2. Illustrative regional divergence pattern (e.g., inequality index or top–bottom ratio) for Poland.
(Insert sourced chart or reconstructed series with proper source attribution.)

Table 2. Descriptive regional indicators used in this study (definitions and measurement).

Title 1	Title 2	Title 3
Labor productivity (LP)	**Primary option (direct):** Real labour productivity by NUTS 2 region (e.g., per hour worked / per person employed, depending on selected series). **Alternative (constructed):** ln (real GDP or GVA/employment) using regional volume output and employment.	**Eurostat:** nama_10r_2rlp (Real labour productivity by NUTS 2 region) European Commission+1; and/or nama_10r_2gvagr (GDP & GVA in volume by NUTS 2) European Commission + employment from LFS regional series (see controls) European Commission
TFP proxy (optional)	Growth-accounting proxy (Solow-residual style) if regional capital and labour inputs are available consistently; otherwise omitted or treated as robustness-only. Method and assumptions documented in Appendix A (including depreciation and capital proxy choice).	Methodology documented in Appendix A; productivity context can rely on Eurostat regional accounts framework. European Commission
Public investment input	Government gross fixed capital formation (GFCF) at NUTS 2; reported in levels and/or as % of regional output; optionally decomposed by total economy vs general government.	**Eurostat:** nama_10r_2gfcf (GFCF by NUTS 2 for total economy and general government). European Commission+1
Efficiency proxy 1	**Execution/realisation rate:** executed capital spending / budgeted capital spending (annual), computed at the voivodeship or relevant territorial level; used as an implementation-capacity proxy.	**National sources:** Statistics Poland **Local Data Bank (BDL)** (regional/local finance series where available) bdl.stat.gov.pl and official budget execution/administrative reporting (MoF or regional authorities).
Efficiency proxy 2	**Completion/timeliness proxy (if available):** share of projects completed on time and/or within budget; or average delay/overrun indicators for region-tagged projects (infrastructure programs).	Administrative/program reporting where region-tagged project records exist (documented in Appendix A). (No single universal Eurostat code; source depends on program database.)
Controls	Education (tertiary attainment), unemployment, density/urbanisation proxy, sectoral structure, private investment proxy.	**Eurostat:** tgs00109 (tertiary attainment, 25–64, by NUTS 2) European Commission+1; lfst_r_lfu3rt (regional unemployment rates) European Commission+1; demo_r_d3dens (population density by NUTS 3, aggregated to NUTS 2 if needed) European Commission; lfst_r_lfe2en2 (employment by economic activity, NUTS 2) for sector shares European Commission+1; **private investment proxy** can be approximated as **total GFCF − general government GFCF** from nama_10r_2gfcf. European Commission+1

Note: Exact series selections, transformations (logs, deflators), lag structure (1–3 years), and expected coefficient signs are documented in Appendix A.

3.2. Preliminary Patterns (Non-Model Results)

Before econometric estimation, the dataset will be examined for baseline trends and co-movements between productivity outcomes and investment-efficiency proxies. These checks reduce the risk of mechanical regressions and guide lag-structure choices.

Bulleted lists look like this:
• visual inspection of regional LP trends;
• distribution of efficiency proxies and outliers;
• correlation patterns (levels and first differences).

Numbered lists can be added as follows:

1. inspection of structural breaks and shock years;
2. sensitivity to excluding capital-region observations;
3. alternative productivity constructions.

3.3. Baseline Econometric Results: Fixed Effects

This subsection reports the baseline two-way fixed-effects estimates linking public investment efficiency proxies to productivity outcomes. The baseline equation is specified in Section 2.4. Coefficients are interpreted as semi-elasticities because the dependent variable is expressed in logs.

Table 3. Baseline fixed-effects estimates (dependent variable: labor productivity).

Title 1	Model (1)	Model (2)	Model (3)
Efficiency proxy (EffInv_{it})	**to be estimated (β)**	**to be estimated (β)**	**to be estimated (β)**
Private investment proxy	—	**to be estimated (γ)**	**to be estimated (γ)**
Human capital proxy	—	**to be estimated (γ)**	**to be estimated (γ)**
Sectoral controls	No	No	Yes
Region fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	**238 (planned max)**	**238 (planned max)**	**238 (planned max)**
Number of regions	**17**	**17**	**17**
Within R^2	to be estimated	to be estimated	to be estimated

Note: "238 (planned max)" assumes a balanced panel (17 NUTS-2 regions × 14 years, 2010–2023). The final N will depend on missing values in the selected Eurostat/GUS series. Standard errors should be clustered at the regional level.

3.4. Dynamic and Heterogeneity Results

Because productivity is persistent, dynamic specifications are used as robustness checks. In addition, heterogeneity tests examine whether the association differs across region types (e.g., metropolitan vs. mid-sized transitioning vs. peripheral) and by investment composition (e.g., transport vs. digital).

3.4.1. Dynamic specification

Table 4. Dynamic estimates and heterogeneity tests (template placeholder).

Title 1	Dynamic Model (A)	Dynamic Model (B)	Heterogeneity Model (C)
Lagged productivity (Prod_{i,t−1})	**to be estimated (ρ̂)**	**to be estimated (ρ̂)**	**to be estimated (ρ̂)**
Efficiency proxy (EffInv_{it})	**to be estimated (β̂)**	**to be estimated (β̂)**	**to be estimated (β̂)**
EffInv × Mid-size/ Transition	—	—	**to be estimated (θ̂)**
Controls	Yes	Yes	Yes
Region FE / Year FE	Yes / Yes	Yes / Yes	Yes / Yes
Diagnostics (if GMM)	to be reported: AR(2), Hansen	to be reported: AR(2), Hansen	—
Observations	**221 (planned max)**	**221 (planned max)**	**221 (planned max)**

Note: "221 (planned max)" assumes a balanced panel and accounts for the one-year loss due to the lagged dependent variable (17 regions × 13 years). Final N depends on missingness in the chosen series. If system GMM is used, report instrument count and diagnostics; if bias-corrected FE is used, report the correction method and robustness.

3.5. Summary of Results (To Be Completed After Estimation)

Once tables are populated, this subsection will provide a concise summary:
• direction and magnitude of the efficiency–productivity association;
• evidence on lags (short vs. medium-run effects);
• heterogeneity patterns;
• robustness consistency across alternative measures.

4. Discussion

The benchmark evidence indicates substantial scope to improve how public investment is translated into infrastructure outcomes in Poland. The IMF PIMA for Poland estimates an **efficiency gap of 36%**, compared with an **EU average efficiency gap of 13%**, implying that roughly **one third of public investment spending** did not deliver the infrastructure level or quality achieved by the most efficient comparator at a similar public capital stock level. infrastructuregovern.imf.org This is not simply a "spending" issue; it is primarily a project-cycle performance issue.

4.1. Interpreting the efficiency gap: institutions, implementation, and maintenance

The PIMA narrative points to a typical pattern in which institutional arrangements appear strong

in formal design but weaker in practical effectiveness. Specific weaknesses noted include coordination across entities, budget comprehensiveness and unity, maintenance funding, project selection, and portfolio oversight. infrastructuregovern.imf.org These components align closely with the mechanisms through which public investment affects productivity. For instance:

- **Project selection and appraisal** influence whether capital is allocated to projects with high social returns rather than politically salient but low-productivity assets.
- **Maintenance funding** affects whether infrastructure remains productive over time, limiting depreciation of service quality.
- **Portfolio oversight** determines whether governments can re-prioritise, correct underperforming projects, and prevent fragmented investment pipelines.

4.2. Why productivity effects are likely heterogeneous across regions

OECD regional evidence shows increasing regional inequality in GDP per capita over 2000–2020, peaking around **2019**, along with signs of polarisation (top regions pulling away and bottom regions diverging). oecd-cfe-eds.github.io These descriptive facts support a key interpretation for this manuscript: even if public investment efficiency improves nationally, the **productivity payoff may differ across regions**, because complementarities are uneven.A plausible mechanism is that transport and digital infrastructure deliver larger productivity gains where firms can respond through technology adoption, reorganisation, and market expansion. World Bank analysis of public investment processes in Poland underlines the same "design vs effectiveness" gap and stresses that improvements in implementation can unlock better returns from spending. World Bank+1

4.3. Policy relevance in the context of large EU-linked investment envelopes

The scale of investment financing increases the stakes of efficiency. The IMF PIMA notes that Poland "stands to receive almost **€24 billion** in grants under the Recovery and Resilience Facility (RRF)." infrastructuregovern.imf.org In parallel, the European Commission adopted Poland's Cohesion Policy Partnership Agreement, describing a strategy worth **€76.5 billion** for 2021–2027. European Commission When funding envelopes are large, small percentage improvements in project selection, procurement quality, and maintenance discipline can translate into large differences in delivered infrastructure and, ultimately, productivity outcomes.

4.4. Limitations and what this manuscript can credibly claim without a dataset

This manuscript intentionally avoids reporting econometric coefficients without the underlying regional dataset and estimation output. The benchmark results provide strong, verifiable evidence of efficiency gaps and institutional bottlenecks, but they do not on their own quantify region-level productivity elasticities. Therefore, causal interpretation of "investment efficiency → productivity" at the regional level requires completion of the planned panel estimation (Section 3.5), including lag structures and robustness checks.

5. Conclusions

This manuscript evaluates the link between public investment efficiency and regional productivity in Poland over 2010–2023 using a panel-data research design. The benchmark evidence is clear: Poland's public investment efficiency gap is estimated at **36%**, exceeding the **EU average of 13%**, indicating substantial unrealised potential in transforming spending into infrastructure outcomes. infrastructuregovern.imf.org The underlying bottlenecks are concentrated in project-cycle fundamentals, including coordination, project selection, portfolio oversight, and maintenance funding. infrastructuregovern.imf.org

From a policy perspective, the results imply that improving public investment management can raise the productivity payoff of investment, especially in a context where Poland remains a major recipient of EU-linked investment resources, including RRF and Cohesion Policy envelopes. infrastructuregovern.imf.org+1 Future work should complete the region-level panel estimations to quantify effect sizes, explore heterogeneity across region types, and test time lags between investment delivery and productivity gains.

6. Patents

Not applicable.

Supplementary Materials: Not applicable.

Author Contributions: Conceptualization, H.K.; methodology, H.K.; formal analysis, H.K.; investigation, H.K.; resources, H.K.; data curation, H.K.; writing—original draft preparation, H.K.; writing—review and editing, H.K.; visualization, H.K.; supervision, H.K. The author has read and agreed to the published version of the manuscript.

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comparable public capital stock per capita.

Appendix A

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Appendix A. Variable Dictionary and Data Construction Notes

A1. Units, Time Coverage, and Panel Structure

- **Unit of analysis:** Poland NUTS-2 regions (voivodeships).
- **Time coverage:** 2010–2023 (annual).
- **Panel:** intended to be balanced; if any series are missing for specific years, the panel becomes unbalanced and will be documented.

A2. Core Outcomes (Dependent Variables)

(1) Labor Productivity (LP_{it})

- **Definition:** real output per employed person (primary outcome).
- **Construction:**

← Preferred: $LP_{it} = \ln(\text{real GVA}_{it}/\text{employment}_{it})$

← Alternative: $\ln(\text{real GDP}_{it}/\text{employment}_{it})$

- **Expected sign (key regressor):** positive association with investment efficiency proxies.

(2) Total Factor Productivity proxy (TFP_{it}) (optional)

- **Definition:** growth-accounting proxy based on a regional production-function approach if capital and labor inputs are available at regional level.
- **Construction options:**

← Solow residual using regional capital stock proxies; or

← TFP series from established productivity datasets if consistent at NUTS-2.

- **Note:** If reliable inputs are not available, the manuscript will report LP as the primary productivity metric and keep TFP as a robustness extension.

A3. Main Explanatory Variable (Public Investment Efficiency Proxies)

Because "efficiency" is latent, proxies must be **auditable** and tied to the project cycle.

(3) EffInv_{it}: Investment Efficiency Proxy (execution/realization)

- **Definition:** a measure of how consistently planned capital spending is executed (implementation capacity proxy).
- **Candidate constructions:**

← $\text{Executed CapEx}/\text{Budgeted CapEx}$

← Or execution rate for investment programs where region-tagged data exist.

- **Expected sign:** positive (higher execution-quality proxy → higher productivity).

(4) EffInv_{it}: Investment Efficiency Proxy (portfolio/maintenance discipline) (optional)

- **Definition:** indicators reflecting portfolio oversight and maintenance funding stability.
- **Candidate constructions:**

← Maintenance expenditure share of asset value (if available);

← Share of projects completed on time/budget (if administrative data exist).

- **Expected sign:** positive.

A4. Public Investment Inputs (Spending/Capital Variables)

(5) PubInv_{it}: Public investment intensity

- **Definition:** government gross fixed capital formation (GFCF) or capital expenditure proxy at regional level.
- **Construction:** per capita or as share of regional output.
- **Expected sign:** ambiguous in isolation (depends on efficiency); stronger when interacted with efficiency.

A5. Controls (X_{it})

(6) PrivInv_{it}: Private investment proxy

- **Definition:** private GFCF proxy or business investment where available.
- **Expected sign:** positive.

(7) HumanCap_{it}: Human capital proxy

- **Definition:** tertiary attainment rate (or alternative education proxy).
- **Expected sign:** positive.

(8) Sector_{it}: Sectoral structure controls

- **Definition:** shares of industry, services, agriculture; or manufacturing share.
- **Expected sign:** not fixed; included to control for structural differences.

(9) Density/Urban_{it}: Agglomeration proxy

- **Definition:** population density or urbanization metric.
- **Expected sign:** often positive.

(10) Unemp_{it}: Labor market slack

- **Definition:** unemployment rate.
- **Expected sign:** typically negative with productivity growth.

A6. Transformations, Lags, and Outliers

- Productivity outcomes will be log-transformed where appropriate.
- Key regressors will be introduced with lags (1–3 years) to reduce simultaneity and allow time-to-build effects.
- Outliers in efficiency proxies will be winsorized or treated with robust estimators; rules will be documented explicitly.

A7. Replication Notes (to be completed at estimation stage)

- Estimation will report clustered standard errors at the region level.
- All model variants (FE baseline, dynamic extensions) will be listed with exact specifications and diagnostics.

Appendix B

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Appendix B. Supplementary Specifications, Diagnostics, and Robustness Outputs

B1. Alternative Productivity Definitions

- Replace LP based on GVA with LP based on GDP (where consistent).
- Use productivity growth rates (Δlog LP) as an alternative dependent variable.

B2. Alternative Efficiency Proxy Constructions

- Execution rate vs. absorption/completion rate (where data allow).
- Separate efficiency proxies by investment category (transport vs. digital) when classification exists.

B3. Lag Structure Robustness

- Compare models with EffInv_{i,t−1}, EffInv_{i,t−2}, EffInv_{i,t−3}.
- Report stability of sign and magnitude across lag lengths.

B4. Crisis-Year Sensitivity

- Re-estimate excluding 2020 (and optionally 2021) to assess sensitivity to pandemic shock years.

B5. Dynamic Panel Diagnostics (if dynamic estimators are used)

- Report AR(1)/AR(2) tests and Hansen/Sargan tests (if GMM).
- Report instrument count and restrictions to avoid instrument proliferation.

B6. Additional Figures and Tables

- Figure B1: distribution of efficiency proxies by region.
- Figure B2: regional productivity trends.
- Table B1: correlation matrix and descriptive stats (full sample).
- Table B2: robustness estimates across alternative definitions.

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