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Efficiency and productivity of community rehabilitation centres during service expansion in Shanghai, China: a longitudinal data envelopment analysis

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Abstract

Objectives: To assess efficiency and productivity during community rehabilitation expansion, regional variation, and associations with service integration.

Study design: Longitudinal ecological panel study.

Methods: A balanced panel included 48 centres in Shanghai during 2020–2024 (240 centre-years). A super-efficiency slacks-based measure estimated overall technical, pure technical and scale efficiency. A global Malmquist index decomposed total factor productivity change (TFPCH) into efficiency change (EFFCH) and technical change (TECHCH). Non-parametric tests assessed temporal and regional differences; centre- and year-fixed-effects models explored associations with medical-alliance participation and two-way referral.

Results: Equipment value, treatment area and workforce increased by 80.8%, 65.7% and 87.5%, respectively. Mean overall technical efficiency fell from 0.558 in 2020 to 0.410 in 2024 ($P<0.001$); mean pure technical efficiency (0.526) was below scale efficiency (0.885), while centres with decreasing returns rose from 52.1% to 72.9%. Mean annual TFPCH was 0.970 and cumulative change was 0.884; TECHCH (0.972) was weaker than EFFCH (0.998). Productivity declined during the first two transitions and improved thereafter. Regional mean differences were not significant. Alliance and referral adoption increased, but neither showed a clear within-centre association with efficiency (all $P\geq0.114$).

Conclusions: Productivity remained below its 2020 level despite capacity expansion and post-2022 recovery. Policy should shift from construction targets and binary network membership towards centre-specific diagnosis, capability transfer, closed-loop referral measures and equity-adjusted monitoring.

Introduction

Rehabilitation is essential to universal health coverage, and about 2.4 billion people may benefit as ageing, chronic disease and disability increase need.[1,2] Community provision may improve access and continuity, but value depends on converting resources into effective, acceptable care.

China has prioritised tiered rehabilitation and primary care.[3] Shanghai expanded community rehabilitation facilities, equipment and staffing.[4,5] Medical alliances and two-way referral were intended to link community centres with hospitals.[6] Investment changes production potential; integration may change access to patients, information and expertise.

Capacity may precede demand, equipment may be underused, and competencies, scheduling or referral may constrain activity. Efficiency must therefore be read alongside quality, access and equity. Data envelopment analysis (DEA) handles multiple inputs and outputs without a parametric production function. Chinese primary-care studies mainly use provincial, hospital or cross-sectional community data.[7–9] Static DEA cannot separate catch-up from frontier movement.

Governance, resource-dependence and transaction-cost theories suggest that integration acts through joint decisions, scarce capability and lower coordination burdens, not membership alone.[10–13] Alliance variation supports examining implementation.[14]

We estimated static efficiency, returns to scale and productivity change in a five-year Shanghai panel, characterised centre and regional heterogeneity, and explored whether changing alliance or referral status tracked within-centre efficiency.

Methods

Study design, setting and data

We conducted a longitudinal ecological study of public community rehabilitation centres in Shanghai during 2020–2024. Sixteen districts were stratified as central-urban, inner-suburban or outer-suburban, and four to five eligible centres per district were randomly sampled. Eighteen of 66 centres with missing core inputs or outputs in at least two consecutive years were excluded. The balanced panel contained 48 centres (240 centre-years; 192 adjacent periods), without imputation. The centre-year was the decision-making unit; no individual patient records were used.

Variables and preparation

Sources were municipal statistics, centre reports, the annual capacity survey, and financial and service records. Inputs were equipment value, treatment area and rehabilitation workforce; outputs were service items, visits, treatment effectiveness, revenue and patient satisfaction. Revenue represented activity/value, not direct social value (Table S1).

Alliance participation denoted membership by year-end; two-way referral denoted an operational pathway with a higher-level hospital. These indicators did not capture implementation intensity, referral completion or capability transfer. The archived DEA panel used affine min–max scaling to 0.1–1.0. Raw variables were unavailable for re-estimation, but centre-year keys and model identities reconciled across files.

Efficiency and productivity analysis

DEA was used because three inputs and five heterogeneous outputs lacked defensible common price weights. Constant-returns CCR and variable-returns BCC technologies yielded overall technical efficiency (OTE) and pure technical efficiency (PTE); scale efficiency (SE) was OTE/PTE. A non-oriented slacks-based measure captured input excesses and output shortfalls, while super-efficiency excluded the evaluated frontier observation. Neither input reduction nor output expansion alone represented the

service objective.[15,16] All centre-years formed the global reference set; no undesirable outputs were specified. Supplementary Methods provide the full specification and editable identities.

OTE measures overall conversion, PTE performance conditional on scale, and SE proximity to productive scale. Increasing returns may favour expansion; decreasing returns favour realignment. Scores above one identify super-efficient observations.

The output-oriented CCR global Malmquist index used a common reference technology across periods.[17,18] Total factor productivity change was decomposed as TFPCH=EFFCH×TECHCH, with EFFCH=PECH×SECH. Values above one indicate improvement; transition indices were geometrically averaged and multiplied for cumulative change.

Statistical analysis

Friedman tests compared annual OTE, PTE and SE and four productivity transitions. Regional Kruskal–Wallis tests used one centre-level five-year arithmetic mean for static scores and four-transition geometric mean for productivity. Returns-to-scale variation used each centre's proportion of years with decreasing returns.

Pooled Mann–Whitney comparisons were descriptive. Exploratory log-linear models included centre and year fixed effects with centre-clustered standard errors; integration indicators were fitted separately and jointly, and exponentiated as percentage differences. Fixed effects address stable centre and common annual factors, not time-varying confounding. Overlap and status switching were reported because identification used within-centre change.

Estimates were interpreted as associations because fixed effects do not remove time-varying confounding, reverse causation or measurement error. Two-sided $P < 0.05$ was used without multiplicity adjustment; exact P values and confidence intervals are reported. DEA estimates came from DEARUN; checks and statistics used Python 3.12.

Results

Sample characteristics and resource trends

The 48 centres contributed 240 centre-years and 192 adjacent-period observations; integration records were complete.

From 2020 to 2024, mean equipment value, treatment area and workforce increased by 80.8%, 65.7% and 87.5%, respectively, while service breadth rose from 40.1 to 52.5 items. Visits increased to 72,262 in 2021, fell to 44,729 in 2022 and recovered to 90,600 in 2024; revenue followed the same pattern. Treatment effectiveness increased from 86.7% to 96.2% and satisfaction from 95.5 to 98.4 (Table 1).

Table 1. Annual input and output means, 2020–2024

Indicator (unit)	Type	2020	2021	2022	2023	2024
Rehabilitation equipment value (RMB 10,000)	Input	138.1	229.6	219.6	236.3	249.7
Treatment area (m²)	Input	338.2	386.5	431.1	501.9	560.4
Rehabilitation workforce (full-time equivalents)	Input	10.8	13.0	15.9	18.5	20.3
Service items delivered (number)	Output	40.1	42.4	43.5	49.9	52.5
Annual rehabilitation visits (visits)	Output	64,104	72,262	44,729	80,760	90,600
Treatment effectiveness rate (%)	Output	86.7	89.2	91.2	92.1	96.2
Annual rehabilitation revenue (RMB 10,000)	Output	134.8	167.8	123.1	206.3	223.9
Patient satisfaction score (0–100)	Output	95.5	95.8	95.8	96.1	98.4

Note. Values are arithmetic means across 48 centres. RMB, renminbi.

Static efficiency and returns to scale

Across 240 centre-years, mean OTE was 0.450, PTE 0.526 and SE 0.885. OTE fell from 0.558 in 2020 to 0.386 in 2022, recovered to 0.440 in 2023 and was 0.410 in 2024. Friedman tests were significant for OTE (χ^2=47.97, P<0.001), PTE (χ^2=32.18, P<0.001) and SE (χ^2=17.06, P=0.002) (Table 2; Figure S1A).

Table 2. Annual static efficiency and returns to scale, 2020–2024

Year	OTE	PTE	SE	CRS, n	DRS, n	IRS, n
2020	0.558	0.607	0.923	6	25	17
2021	0.453	0.552	0.856	4	32	12
2022	0.386	0.447	0.907	4	35	9
2023	0.440	0.519	0.881	8	33	7
2024	0.410	0.502	0.857	5	35	8
All years	0.450	0.526	0.885	—	—	—
Friedman P	<0.001	<0.001	0.002	—	—	—

Note. Values are means across 48 centres; the all-years row covers 240 centre-years. P values are from Friedman tests. CRS, constant returns to scale; DRS, decreasing returns to scale; IRS, increasing returns

to scale; OTE, overall technical efficiency; PTE, pure technical efficiency; SE, scale efficiency.

Five-year mean OTE ranged from 0.166 to 1.006; 36 centres were below 0.6 and three were at least 0.8. PTE was below 0.6 at 28 centres, whereas SE was at least 0.8 at 39 (Table S3). Decreasing returns rose from 25/48 centres (52.1%) in 2020 to 35/48 (72.9%) in 2024, when eight had increasing and five constant returns. The taxonomy identified one frontier, five scale-constrained, five management-limited, eight expansion-potential and 29 combined-constraint centres (Tables S2–S4).

Productivity change and centre-level profiles

Mean annual TFPCH was 0.970, with EFFCH 0.998 and TECHCH 0.972. Cumulative 2020–2024 TFPCH was 0.884 (−11.6%); corresponding EFFCH and TECHCH were 0.990 and 0.893, indicating that frontier movement accounted for most productivity loss (Table 3).

Table 3. Global Malmquist productivity change and decomposition

Transition	EFFCH	TECHCH	PECH	SECH	TFPCH
2020–2021	0.945	0.943	1.002	0.944	0.892
2021–2022	1.008	0.941	1.000	1.008	0.949
2022–2023	1.031	1.002	0.997	1.034	1.033
2023–2024	1.008	1.003	1.003	1.005	1.011
Mean annual	0.998	0.972	1.000	0.997	0.970
Cumulative 2020–2024	0.990	0.893	1.001	0.989	0.884

Note. Transition and annual values are geometric means; cumulative values multiply the four transitions. EFFCH, efficiency change; PECH, pure technical efficiency change; SECH, scale efficiency change; TECHCH, technical change; TFPCH, total factor productivity change.

TFPCH was below one in 2020–2021 (0.892) and 2021–2022 (0.949), then above one in 2022–2023 (1.033) and 2023–2024 (1.011), without significant transition differences (all P≥0.419; Figure S1B). In the first transition EFFCH was 0.945 and TECHCH 0.943; EFFCH exceeded one in 2021–2022 while TECHCH remained 0.941, and both exceeded one in 2022–2023. Centre-level mean annual TFPCH ranged from 0.786 to 1.214; 28 centres were below one (Tables S5 and S6).

Regional heterogeneity

Regional differences were not significant for OTE (P=0.701), PTE (P=0.806), SE (P=0.058), TECHCH (P=0.604) or TFPCH (P=0.535). The mean proportion of years with decreasing returns was 84.0% in

central-urban, 76.7% in inner-suburban and 48.6% in outer-suburban centres (P=0.007), indicating different scale constraints (Tables S7 and S12).

Service integration and efficiency

Alliance participation increased from 58.3% to 83.3%, and referral from 68.8% to 91.7%; only 13 and 12 centres changed status, respectively (Table S8). Pooled adopter observations had lower efficiency, but ignored timing and centre selection (Table S9).

Neither indicator was clearly associated with efficiency after centre and year fixed-effects adjustment (Table 4). Alliance participation corresponded to −11.1% OTE (95% CI −26.6% to 7.6%; P=0.221) and referral to −8.3% (95% CI −22.4% to 8.4%; P=0.302). PTE and SE estimates were also non-significant (all P≥0.114), as were joint models (all P≥0.213; Table S10).

Table 4. Service-integration adoption and within-centre associations with efficiency

Integration indicator	Adoption 2020→2024	Outcome	% difference	95% CI	P
Medical-alliance participation	58.3→83.3%	OTE	-11.1	-26.6 to 7.6	0.221
		PTE	-19.2	-38.1 to 5.5	0.114
		SE	+10.0	-14.4 to 41.3	0.447
Functioning two-way referral	68.8→91.7%	OTE	-8.3	-22.4 to 8.4	0.302
		PTE	-13.5	-27.9 to 3.9	0.118
		SE	+6.0	-4.2 to 17.2	0.254

Note. Log-linear models included centre and year fixed effects and centre-clustered standard errors (240 centre-years). Percentage difference=100×[exp(β)−1]. CI, confidence interval; OTE, overall technical efficiency; PTE, pure technical efficiency; SE, scale efficiency.

Discussion

Capacity and reported quality increased and activity recovered after 2022, yet 2024 efficiency remained below its 2020 level and cumulative TFPCH was 0.884. Frontier movement explained most productivity loss; lower PTE and increasing decreasing returns indicated concurrent process and scale constraints.

Interpretation of efficiency and productivity

The findings do not imply that investment was unnecessary. DEA is relative to the observed frontier; capacity may precede demand or workflow development, and reserves may protect access and resilience. Low OTE should prompt review of process, scale, need and omitted outputs, not automatic input reduction.

Lower PTE than SE points to scheduling, skill mix, equipment use and service design. Scale also mattered: over 70% of centres had decreasing returns in 2024. Low PTE near optimal scale calls for process support; low SE with decreasing returns calls for demand–capacity realignment. Expansion requires documented unmet need.

TECHCH denotes movement of best observed practice, not technology adoption. Its deterioration may reflect disruption among high performers, uneven diffusion or measurement change. Early contractions coincided with the pandemic period and lower 2022 activity, but causation cannot be assigned without a counterfactual. Non-significant transition tests make these phases descriptive, not distinct regimes.

Wide centre-level ranges make citywide averages insufficient. Joint EFFCH and TECHCH deterioration calls for operational and best-practice review; divergence may signal limited capacity to absorb or catch up with practice. Profiles should initiate peer review, not punitive ranking, because scores are sensitive to case mix and outputs.

Regional mean scores did not differ significantly. More frequent decreasing returns in central and inner-suburban centres may reflect scale pressure, but case complexity and access capacity were unmeasured. Regional targets should incorporate need, disability complexity and travel burden, not efficiency alone.

Service integration and explanatory mechanisms

Lower pooled efficiency among adopters was compatible with confounding: adoption increased while efficiency fell, and weaker centres may have been targeted first. Fixed-effects estimates were imprecise and non-significant. This does not prove ineffectiveness; binary indicators and few status changes limited inference.

Formal membership is a structural condition, not the intervention itself. Collaborative governance requires shared decisions and accountability;[10,11] resource dependence falls when teams gain specialist capability, and transaction costs fall when eligibility, records, appointments and feedback are coordinated.[12,13] Administrative steps may instead raise costs. Staff rotations, competencies, specialist response, completed referrals and feedback are more informative than membership.

WHO's people-centred care framework and English integrated care systems combine governance, coordination and place-based responsibility.[19,20] Accountable care organisations add contractual and financial accountability.[12] These examples support Figure 1, but its unmeasured links remain hypotheses.

Figure 1. Framework linking capacity and service integration to governance, capability transfer, coordination costs, efficiency and public-health performance. Mechanisms and patient outcomes were not measured.

Policy implications and implementation

Monitoring should replace binary adoption with a scorecard covering referral acceptance/completion, waiting time, record transfer, feedback, continuity and functional change. Capability measures should include rotations, joint conferences, supervised cases and demonstrated competencies. Lead hospitals should be accountable for specialist response, teaching and closed-loop referral. Payment incentives require piloting before citywide adoption.

A common dashboard should link PTE, SE, returns to scale, EFFCH and TECHCH with need, access and pathway outcomes. Managers should use service-line costs, equipment logs and workflow review, while protecting necessary low-volume services after equity assessment. Deterioration should trigger review of data quality, case mix, demand and workflow, not league-table quotas. Staged implementation with baselines could support interrupted time-series or difference-in-differences evaluation. Responsibilities and indicators appear in Table S11.

Strengths and limitations

Strengths include a balanced five-year panel, multidimensional inputs/outputs, static and dynamic models, centre-level regional tests and fixed-effects sensitivity analysis. DEA measures relative performance and is sensitive to variables, outliers and error. Affine scaling may affect non-translation-invariant technologies; raw data were unavailable for re-estimation, and super-efficiency and uncertainty could not be assessed by influence analysis or bootstrap.

Revenue was nominal; reported effectiveness and satisfaction may contain error. Case mix, need, waiting time, continuity, referral volume and post-transfer function were unavailable. Complete-case selection may bias results; anonymised codes reduced geographic resolution and power. Only 12–13 centres changed integration status, and fixed effects did not remove time-varying confounding or reverse causation. Analyses were exploratory and ecological; generalisability is uncertain.

Future studies should retain auditable raw data, assess outliers and bootstrap uncertainty, measure need and implementation intensity, and link stronger designs to patient-level function.

Conclusions

Capacity expanded substantially, but recovery did not erase the productivity decline. Policy should replace uniform construction targets and organisational labels with centre-specific diagnosis, capability transfer, completed pathways and equity-adjusted monitoring.

Declarations

Ethics approval and consent to participate

Not applicable. This study analysed aggregate institution-level operational data and did not involve human participants, identifiable personal data, human tissue or animals.

Consent for publication

Not applicable.

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Ethical approval:

Informed consent was waived because only anonymised administrative and survey data without individual patient records were used.

Competing interests:

Declarations of interest: none.

Author Contribution

Author contributionsLingling Li#: Conceptualization, Data curation, Formal analysis, Visualization, Writing-original draft, Writing-review & editing.Yuhang Liu#: Conceptualization, Methodology, Formal analysis, Visualization, Writing-original draft, Writing-review & editing.Weigang Wang: Resources, Investigation, Writing-review & editing.Zhenqing Tang: Data curation, Validation, Writing-review & editing.Chunlin Jin*: Conceptualization, Resources, Supervision, Project administration, Funding acquisition, Writing-review & editing.Wei Lu*: Conceptualization, Methodology, Supervision, Project administration, Funding acquisition, Writing-review & editing.# These authors contributed equally to this work (co-first authors).* These authors contributed equally as co-corresponding authors; Chunlin Jin

serves as the primary corresponding author.All authors read and approved the final version of the manuscript.

Data Availability

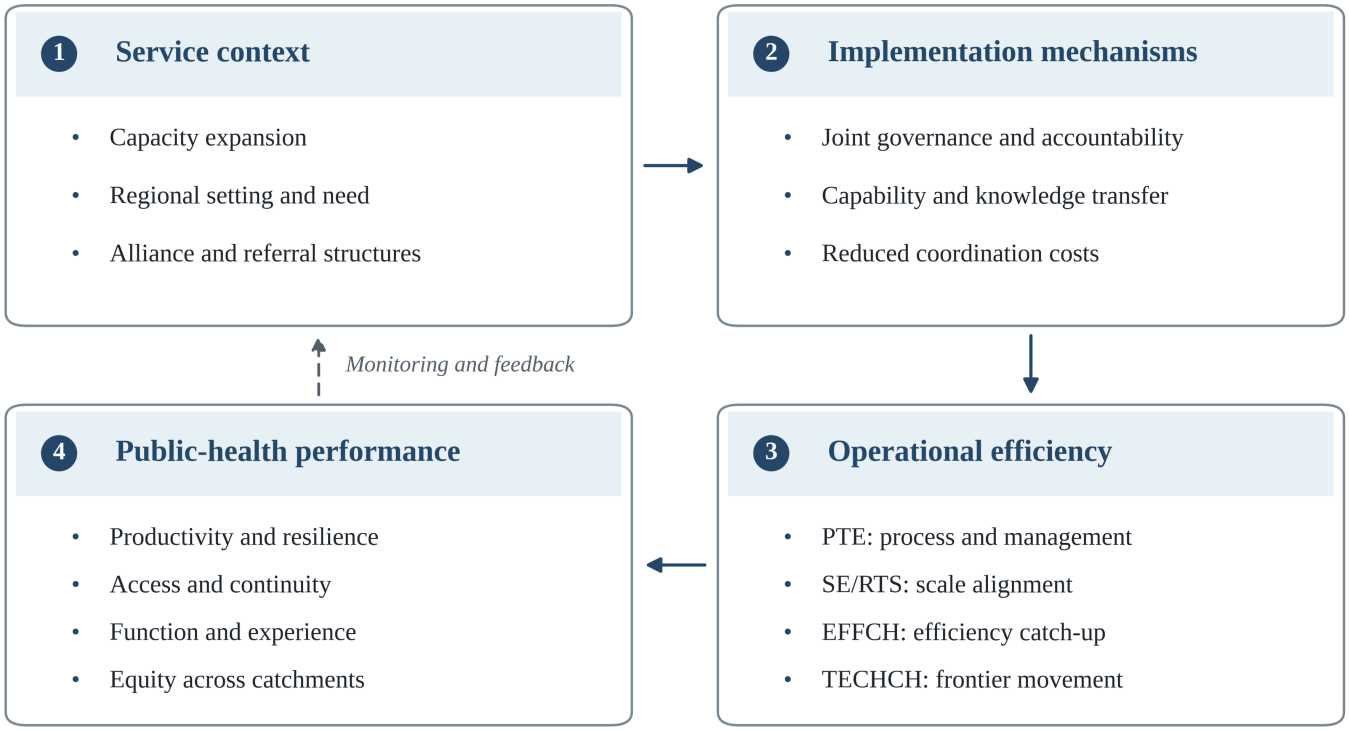
The datasets analysed during this study are de-identified institutional-level administrative data from community rehabilitation centres in Shanghai. These data are not publicly available due to local administrative regulations and data-governance restrictions. Qualified researchers may submit reasonable data-access requests to the corresponding author for review, subject to formal data-use approval from the local health authority. All aggregated results supporting the conclusions of this article are included within the paper.

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Figures



PTE, pure technical efficiency; SE, scale efficiency; RTS, returns to scale; EFFCH, efficiency change; TECHCH, technical change.

Figure 1

Framework linking capacity and service integration to governance, capability transfer, coordination costs, efficiency and public-health performance. Mechanisms and patient outcomes were not measured.

Supplementary Files

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