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Efficiency Dynamics of Indian Public Sector Banks post-liberalisation: A DEA and Tobit Analysis (1991-2024)

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Abstract
This study examines the operational efficiency and reform-induced performance dynamics of Indian public sector banks in the post-liberalisation era. We use Data Envelopment Analysis (DEA) under Constant and Variable Returns to Scale to evaluate the trends in technical, pure technical, and scale efficiency over the period 1991-2024, with particular emphasis on the impact of large-scale bank mergers. A second-stage Tobit regression model is employed to identify the financial determinants influencing efficiency scores during 1996-2024. The results reveal persistent input-oriented inefficiencies in the pre-merger period, followed by a marked improvement in efficiency and convergence among banks after consolidation. Capital adequacy emerges as the most significant positive determinant of efficiency, highlighting the role of strong capitalisation in enhancing operational performance. In contrast, return on assets exhibits a statistically significant and negative association with efficiency, while bank size shows a negative but statistically insignificant relationship. The findings provide empirical evidence on the effectiveness of banking reforms and consolidation policies in improving the efficiency of public sector banks in India, and offer policy-relevant insights for strengthening resilience, resource allocation, and long-term stability in the public banking system.

Keywords: Market Efficiency Score, Public Sector Banks, NPA, Capital Adequacy Ratio, Merger and Acquisition

1. Introduction
The Indian banking sector's evolution over recent decades is deeply intertwined with the foundational role of public sector banks and the far-reaching economic liberalisation of 1991. Public sector banks (PSBs), defined as banks where the majority stake is owned by the government, have long been recognized as the backbone of India's financial system. Their significance extends beyond basic financial intermediation: PSBs serve as vital conduits for mobilizing savings, facilitating credit to priority sectors, advancing financial inclusion, and supporting government-led development initiatives. In India's mixed economy, these institutions are pivotal in ensuring equitable distribution of financial resources and stabilizing the system during periods of financial stress, making their sustained efficiency and resilience a matter of national importance.
The onset of economic liberalisation in 1991 marked a transformative chapter in India's economic history. Economic liberalisation refers to a series of policy measures aimed at reducing state intervention, deregulating industries, liberalizing trade and capital flows, and

opening up the economy to globalization. For the banking sector, this watershed moment initiated an era of unprecedented reforms that fundamentally reshaped its architecture. The banking sector reforms following 1991 encompassed a broad spectrum: deregulation of interest rates, reduction of statutory pre-emption (SLR and CRR), introduction of prudential norms, phased entry for private and foreign banks, and adoption of international best practices in risk management and corporate governance. These reforms were implemented through recommendations of expert committees such as Narasimham Committee I (1991) and II (1998), which advocated for operational autonomy, recapitalisation, improved asset quality norms, and measures to strengthen the overall prudential framework.

As liberalisation dismantled the barriers of the previous highly regulated era, public sector banks faced new challenges and opportunities. While competition, technological progress, and a broadened mandate brought prospects for modernization and growth, these banks also became exposed to greater operational risk, efficiency imperatives, and vulnerabilities to asset quality shocks. Despite successive waves of reforms including capital infusion programs, recapitalisation schemes, asset quality reviews, and ambitious consolidation through mergers structural inefficiencies and crisis episodes persisted, most notably in the form of mounting non-performing assets (NPAs) and frequent recapitalisation needs.
This study is motivated by three factors: the central role of public sector banks, the long-term impact of post-1991 banking reforms, and the persistent challenge of improving efficiency in a dynamic regulatory environment. By employing Data Envelopment Analysis (DEA) to measure technical, pure technical, and scale efficiencies across an extended period (1991-2024), the study probes whether the intended gains of reforms, particularly those arising from major post-2015 recapitalisation and the wave of mergers post-2020, have materialized for India's PSBs.

The study further applies a Tobit regression model to examine how selected financial determinants namely bank size, capital adequacy, profitability, and asset quality—are associated with efficiency outcomes across public sector banks. This enables a systematic assessment of the factors that explain variations in efficiency beyond the measurement of efficiency levels themselves.

Overall, the study seeks to provide empirical evidence on how Indian public sector banks have responded to post-liberalisation reforms and consolidation by comparing efficiency performance over time and identifying key determinants of operational efficiency. The findings aim to support policymakers and banking practitioners in designing informed strategies for improving performance, strengthening capital positions, and enhancing governance and operational practices in the public sector banking system

Objectives of this study are

- To estimate the technical, pure technical, and scale efficiency of Indian public sector banks for the period 1991-2024 using Data Envelopment Analysis (DEA).
- To compare efficiency performance between the pre-merger period (1991-2020) and the post-merger period (2021-2024) in order to assess the impact of consolidation on bank efficiency.
- To examine the determinants of bank efficiency by applying a Tobit regression model, focusing on the roles of capital adequacy, profitability, asset quality, and bank size.

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2. Review of Literature

The literature on banking crises and efficiency in India provides valuable insights into the various structural, institutional, and macroeconomic factors that have shaped the performance of public sector banks in the post-liberalisation era. Mishkin (1992) [15] conceptualized financial crises as systemic disruptions that hinder efficient resource allocation, necessitating central banks to play an expanded stabilizing role. Empirical studies using Data Envelopment Analysis (DEA), such as Bhattacharyya *et al*. (1997), Mohan (2002), and Sathye (2003) [2, 17, 22], have shown that while public sector banks initially performed competitively, over time they lagged behind private and foreign banks due to regulatory burdens and operational inefficiencies. Further research (Kumar and Gulati, 2010; Goyal *et al*., 2018) [14, 9] distinguishes efficiency from effectiveness, suggesting that PSBs need to prioritize income generation alongside efficiency improvements. The pervasive impact of non-performing assets (NPAs) on bank performance is well documented by Gupta (2012) [10], Rajeev and Mahesh (2010) [19], and Rawat and Sharma (2023) [20], highlighting their distortionary effects on efficiency measures.

In addition to financial factors, political instability, regulatory delays, and weak credit assessment processes have been identified (Enoch *et al*. (2001) and Chakraborty and Mohapatra (2009) [8, 4] as exacerbating banking sector vulnerabilities. Though some studies (Nayak and Nahak, 2011; Das, 2012) [18, 7] record modest improvements in resilience, cost-efficiency remains a challenge. Regulatory reforms guided by Basel norms, as discussed by Jayadev (2013), Boora and Angra (2018) [12, 3], and Mishra and Mohanty (2024) [16], have enhanced solvency and governance, while forensic investigations by Kamal *et al*. (2025) [13] reveal the complex linkages between inefficiencies, corporate governance failures, and technological risks. Collectively, this body of work underscores the need for integrated analytical frameworks that combine DEA and Tobit regression to comprehensively evaluate and improve the efficiency and robustness of India's public sector banking system under liberalised economic conditions.

3. Research Methodology

3.1 Data Collection and Variable Specification

This study adopts a rigorous quantitative and econometric approach to analyse the operational efficiency and performance dynamics of Indian public sector banks (PSBs) over the period 1991 to 2024. The dataset is drawn from multiple authoritative secondary sources including the Reserve Bank of India's *Statistical Tables Relating to Banks in India*, the *Handbook of Statistics on the Indian Economy*, the Ministry of Finance's annual *Economic Surveys*, and Indian Banks' Association reports. Constructed as an unbalanced panel, the data encompass annual observations for varying numbers of PSBs, capturing over three decades marked by significant liberalization, regulatory reforms, recapitalization initiatives, and consolidation activities.

The study adopts the intermediation approach to select input and output variables, which is widely recognized for effectively representing banking operations by emphasizing banks as financial intermediaries mobilizing deposits and channelling them into lending and other income-generating activities. Inputs variables include total deposits (capturing the scale of resource mobilization), number of employees (reflecting human capital and operational scale), and capital-related expenses (operating and interest expenses representing financial costs). Outputs variables comprise interest income (primary revenue from lending) and non-interest income (fee-based and ancillary earnings), capturing the income spectrum attributable to

banking intermediation and services. This selection aligns with global standards in banking efficiency measurement, enabling comprehensive assessment of resource usage and income generation.

3.2 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA), a non-parametric linear programming technique pioneered by Charnes, Cooper, and Rhodes (1978) and extended by Banker, Charnes, and Cooper (1984) [5], is employed as the primary tool to calculate efficiency scores. DEA models construct an empirical "best practice" frontier based on observed input-output combinations of banks, against which each bank's relative efficiency is benchmarked. Unlike parametric frontier approaches, DEA imposes no a priori assumptions regarding functional form or input-output relationships, which is advantageous for accommodating the heterogeneity and multifaceted operations of Indian PSBs.

Two DEA variants are applied: the CCR model assumes constant returns to scale and measures overall technical efficiency encompassing both managerial effectiveness and scale factors, providing a large-scale performance benchmark appropriate for banks operating near optimal size. The BCC model relaxes this assumption, allowing variable returns to scale and isolating pure technical efficiency by excluding scale effects, which is critical given the structural diversity among PSBs, especially post-merger. An input-oriented DEA approach is selected consistent with policy imperatives emphasizing the minimization of resource inputs (such as deposits, labour, costs) to maintain output levels, reflecting the importance of cost containment in the public sector banking environment.

Computation involves treating each bank-year combination as a Decision-Making Unit (DMU), with efficiency scores bounded between zero and one. The DEA solves a linear programming problem annually for each DMU, providing efficiency measures along with slack assessments that indicate input excess or output shortfall. Scale efficiency is computed as the ratio of CCR to BCC scores, thereby identifying whether banks operate at the optimal scale or face size-related inefficiencies.

To capture the dynamic impact of regulatory and structural reforms, the DEA results are analysed over three defined periods: the full study period (1991-2024), the pre-merger phase (1991-2020), and the post-merger phase (2021-2024). This segmentation allows for detailed temporal comparison, attributing efficiency changes to distinct reform waves and consolidation events.

3.3 Tobit Regression Analysis for Determinants of Efficiency

Recognizing that DEA efficiency scores are bounded between 0 and 1 and thus censored, the study employs a Tobit regression model as a second-stage analysis to examine the determinants influencing bank efficiency. The Tobit model, first introduced by Tobin (1958) [23], is specifically designed to handle limited dependent variables with censoring, providing consistent and efficient parameter estimates where ordinary least squares (OLS) would be inappropriate. Explanatory variables included in the Tobit regression are total assets (a proxy for bank size, capturing potential scale economies or diseconomies), return on assets (ROA, representing profitability and operational success), capital adequacy ratio (CAR, indicative of regulatory capital and solvency strength), and non-performing assets (NPA) ratio (reflecting asset quality and credit risk). The model examines the associations between efficiency and CAR, ROA, NPA, and bank size without imposing directional restrictions.

3.4 Econometric Model

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To examine the determinants of efficiency, a Tobit regression model is specified as follows:

$EFF_{\{it\}} = \beta_0 + \beta_1 SIZE_{\{it\}} + \beta_2 CAR_{\{it\}} + \beta_3 ROA_{\{it\}} + \beta_4 NPA_{\{it\}} + \varepsilon_{\{it\}}$ (Eq. 1)

where EFF_{it}represents the DEA efficiency score of banks *i* in year *t*, *SIZE*denotes total assets, *CAR*is the capital adequacy ratio, *ROA*is return on assets, and *NPA*represents the non-performing assets ratio.

Maximum likelihood estimation techniques were used to fit the model to the full sample and also within sub-periods (pre-merger and post-merger), enabling identification of temporal variations in determinants' influence. The regression results provided marginal effects that inform the relative importance of each variable on efficiency, guiding policy prescriptions targeting capital strengthening, asset quality improvement, profitability enhancement, and effective scale management.

3.5 Justification and Limitations

The combined use of Data Envelopment Analysis (DEA) and Tobit regression provides a flexible and widely accepted framework for evaluating banking efficiency and its determinants (Berger and Humphrey, 1997; Sathye, 2003) [22]. DEA is particularly suitable for analysing multi-input and multi-output institutions without imposing restrictive functional assumptions (Charnes *et al*., 1978) [6], while Tobit regression appropriately accounts for the bounded nature of efficiency scores (Tobin, 1958; Haralayya and Aithal, 2021) [23, 11]. However, DEA results may be sensitive to variable selection and extreme observations, and Tobit estimates rely on standard distributional assumptions. These limitations should be considered when interpreting the findings.

4. Empirical Results

This section presents the outcomes of the Data Envelopment Analysis (DEA) and Tobit regression applied to Indian public sector banks (PSBs) over the period 1991 to 2024. The results reveal the levels and progression of technical, pure technical, and scale efficiencies before and after the 2020 merger wave, alongside key determinants influencing bank efficiency.

4.1 Technical Efficiency of Indian Public Sector Banks under Constant Returns to Scale (CRS)

Table 1: Efficiency Score under Constant Returns to Scale (CRS) of public sector banks during the period 1991-2024 and Pre-merger period (1991-2020) and Post-merger period (2021-2024).

Year	No. of banks	No. of efficient banks (CRS)	Average Overall Technical Efficiency (AOTE) (M)	Standard deviation (σ)	Coefficient of variation (C.V.)	I= [M-σ, M +σ] σ = S.D.	% of banks in I
1991	27	7	0.849	0.135	15.855	[0.714, 0.983]	48.148
1992	27	8	0.878	0.105	11.972	[0.773, 0.983]	62.963
1993	27	6	0.819	0.150	18.284	[0.669, 0.969]	59.259
1994	27	7	0.837	0.141	16.818	[0.696, 0.977]	59.259
1995	27	6	0.822	0.150	18.208	[0.673, 0.972]	59.259
1996	27	8	0.822	0.149	18.084	[0.673, 0.971]	51.852

1997	27	8	0.855	0.139	16.258	[0.716, 0.993]	51.852
1998	27	9	0.875	0.136	15.494	[0.739, 1.010]	81.481
1999	27	6	0.852	0.128	14.973	[0.724, 0.979]	51.852
2000	27	9	0.840	0.146	17.391	[0.694, 0.986]	51.852
2001	27	7	0.830	0.134	16.209	[0.695, 0.964]	55.556
2002	27	5	0.817	0.141	17.303	[0.676, 0.959]	59.259
2003	27	7	0.811	0.136	16.804	[0.675, 0.947]	55.556
2004	27	6	0.882	0.106	12.059	[0.776, 0.989]	55.556
2005	28	7	0.887	0.094	10.546	[0.793, 0.981]	53.571
2006	28	4	0.807	0.166	20.578	[0.641, 0.973]	57.143
2007	28	7	0.885	0.108	12.154	[0.777, 0.992]	57.143
2008	28	9	0.921	0.079	8.603	[0.842, 1.000]	82.143
2009	27	8	0.939	0.076	8.046	[0.863, 1.014]	81.481
2010	27	5	0.918	0.066	7.216	[0.852, 0.984]	62.963
2011	26	6	0.922	0.066	7.200	[0.856, 0.989]	57.692
2012	26	5	0.921	0.065	7.067	[0.856, 0.986]	61.538
2013	26	9	0.954	0.050	5.250	[0.903, 1.004]	76.923
2014	27	11	0.952	0.061	6.366	[0.892, 1.013]	85.185
2015	27	11	0.952	0.061	6.366	[0.892, 1.013]	85.185
2016	27	10	0.935	0.063	6.784	[0.872, 0.999]	44.444
2017	27	11	0.944	0.069	7.261	[0.875, 1.013]	85.185
2018	21	7	0.913	0.073	7.997	[0.840, 0.986]	47.619
2019	20	7	0.952	0.048	5.066	[0.903, 1.000]	90.000
2020	18	6	0.936	0.065	6.924	[0.871, 1.000]	77.778
2021	12	7	0.977	0.040	4.126	[0.937, 1.018]	83.333
2022	12	6	0.982	0.027	2.717	[0.955, 1.009]	91.667
2023	12	6	0.976	0.029	2.970	[0.947, 1.005]	91.667
2024	12	4	0.974	0.026	2.701	[0.948, 1.000]	83.333
AOTE (1991-2024)	24.6	7.206	0.895	0.095	12.780	-	66.462
Pre-merger (1991-2020)	26.3	7.400	0.884	0.103	11.971	-	63.657
Post-merger (2021-2024)	12	5.750	0.977	0.031	18.847	-	87.500

Source: Author's computation based on the Statistical table related to various issues related to Banks in India, RBI.

As shown in Table 1, the average overall technical efficiency (AOTE) of PSBs under CRS during 1991-2024 stands at 0.895, indicating that these banks could, on average, reduce their input usage by approximately 17.1% without compromising output levels. Annual efficiency scores ranged from a low of 0.811 in 2003 to a high of 0.982 in 2022, illustrating a general upward trend in efficiency across the decades. The number of banks assessed each year

varied, reflecting sectoral consolidation, decreasing from 27 in the early years to 12 in the post-merger period. The count of fully efficient banks fluctuated annually, with peaks such as 11 banks in 2014 and 2015.

The coefficient of variation and standard deviation metrics reveal a convergence trend, especially post-merger, where 87.5% of banks fell within one standard deviation of the mean efficiency score compared to 63.7% during the pre-merger phase. This indicates that efficiency levels became more uniform among PSBs following mergers and reform initiatives. The data demonstrate a marked improvement in average efficiency post-merger, rising from 0.884 during 1991-2020 to 0.977 in 2021-2024, signifying the beneficial impact of structural reforms and consolidation on input utilisation and operational performance.

4.2 Pure Technical Efficiency under Variable Returns to Scale (VRS)

Table 2: Efficiency Score under Variable Returns to Scale (VRS) during the period 1991-2024 and the Pre-merger period (1991-2020) and Post-merger period (2021-2024).

Year	No. of banks	No. of efficient banks (VRS)	Average Pure Technical Efficiency (APTE)	Standard deviation	Coefficient of variation	I= [M-σ, M +σ]	Percentage of banks in I
			(M)	(σ)	(C.V.)	σ = S.D.	
1991	27	13	0.930	0.096	10.300	[0.834, 1.026]	81.481
1992	27	13	0.928	0.093	10.020	[0.835, 1.021]	81.481
1993	27	12	0.881	0.145	16.459	[0.736, 1.026]	85.185
1994	27	12	0.882	0.136	15.415	[0.746, 1.018]	81.481
1995	27	12	0.877	0.134	15.254	[0.743, 1.011]	77.778
1996	27	10	0.869	0.134	15.426	[0.735, 1.003]	81.481
1997	27	11	0.897	0.120	13.346	[0.777, 1.017]	85.185
1998	27	13	0.924	0.110	11.879	[0.815, 1.034]	77.778
1999	27	13	0.919	0.108	11.787	[0.811, 1.028]	81.481
2000	27	15	0.927	0.104	11.214	[0.823, 1.031]	74.074
2001	27	12	0.912	0.106	11.570	[0.806, 1.018]	77.778
2002	27	12	0.906	0.110	12.199	[0.795, 1.016]	81.481
2003	27	11	0.895	0.114	12.742	[0.781, 1.009]	81.481
2004	27	13	0.941	0.079	8.439	[0.862, 1.020]	77.778
2005	28	13	0.927	0.094	10.125	[0.833, 1.021]	78.571
2006	28	10	0.868	0.139	16.056	[0.729, 1.007]	85.714
2007	28	13	0.933	0.094	10.119	[0.838, 1.027]	82.143
2008	28	13	0.943	0.077	8.127	[0.867, 1.020]	82.143
2009	27	13	0.958	0.067	7.042	[0.890, 1.025]	85.185
2010	27	12	0.946	0.065	6.823	[0.881, 1.010]	85.185
2011	26	17	0.961	0.064	6.659	[0.897, 1.025]	76.923
2012	26	15	0.967	0.055	5.721	[0.911, 1.022]	84.615
2013	26	20	0.982	0.037	3.746	[0.945, 1.019]	80.769
2014	27	16	0.966	0.057	5.893	[0.909, 1.022]	85.185
2015	27	16	0.966	0.057	5.893	[0.909, 1.022]	85.185

2016	27	16	0.958	0.061	6.382	[0.897, 1.019]	81.481
2017	27	19	0.973	0.052	5.320	[0.921, 1.025]	77.778
2018	21	14	0.959	0.061	6.339	[0.899, 1.020]	71.429
2019	20	11	0.963	0.049	5.048	[0.914, 1.012]	85.000
2020	18	9	0.957	0.058	6.019	[0.899, 1.014]	83.333
2021	12	10	0.988	0.037	3.728	[0.951, 1.025]	91.667
2022	12	7	0.986	0.025	2.530	[0.961, 1.011]	91.667
2023	12	8	0.988	0.019	1.930	[0.969, 1.007]	75.000
2024	12	7	0.982	0.027	2.783	[0.955, 1.009]	83.333
APTE (1991-2024)	24.6	12.676	0.937	0.082	8.892	-	81.713
Pre-merger (1991-2020)	26.3	13.300	0.930	0.089	9.712	-	81.219
Post-merger (2021-2024)	12	8.000	0.986	0.027	2.743	-	85.417

Source: Author's computation based on the Statistical table related to various issues related to Banks in India, RBI.

The Pure Technical Efficiency (PTE) analysis, conducted under the Variable Returns to Scale (VRS) framework, captures substantial improvement in managerial practices among India's public sector banks throughout the liberalisation period. Across the full span (1991-2024), the average PTE stood at 93.7%, suggesting that inefficiencies attributable specifically to management and operational tactics were relatively limited. During the pre-merger period (1991-2020), average PTE was 93.0% with a coefficient of variation of 9.71%, indicating moderate heterogeneity among decision-making units. This phase saw consistent clustering, with 81.2% of banks positioned within the one standard deviation interval—a sign of broadly shared managerial capabilities despite systemic constraints. Post-merger (2021-2024), however, reveals a marked shift in performance quality, as average PTE jumped to 98.6% while standard deviation plummeted to just 0.027. The coefficient of variation declined to 2.74%, and banks within the efficiency interval rose to 85.4%, with record uniformity observed in 2022 and 2023 (91.7%). These figures underscore the critical impact of consolidation, digitalisation, and reform measures undertaken post-merger, aligning operational strategies across formerly heterogeneous banking entities and substantially reducing managerial slack. Thus, the post-merger landscape represents a more refined and disciplined operational regime, bringing enhanced consistency in internal decision-making and resource use efficiency.

4.3 Scale Efficiency of Indian Public Sector Banks

Table 3: Scale Efficiency Score during the period 1991-2024 and the Pre-merger period (1991-2020), and the post-merger period (2021-2024).

Year	No. of	No. of	Average	Standard	Coefficient	I= [M-σ, M	Percentage

	banks	efficient banks (Scale)	Scale Efficiency (ASE)	deviation	of variation	+σ]	of banks in I
			(M)	(σ)	(C.V.)	σ = S.D.	
1991	27	7	0.913	0.110	12.081	[0.803, 1.024]	85.185
1992	27	8	0.946	0.056	5.970	[0.889, 1.002]	81.481
1993	27	6	0.930	0.068	7.314	[0.862, 0.999]	81.481
1994	27	7	0.949	0.067	7.078	[0.882, 1.017]	81.481
1995	27	6	0.936	0.071	7.570	[0.865, 1.007]	74.074
1996	27	8	0.945	0.075	7.979	[0.870, 1.021]	85.185
1997	27	8	0.950	0.060	6.294	[0.890, 1.010]	81.481
1998	27	10	0.943	0.057	6.061	[0.886, 1.000]	85.185
1999	27	7	0.925	0.073	7.939	[0.852, 0.999]	51.852
2000	27	9	0.903	0.102	11.327	[0.801, 1.006]	81.481
2001	27	7	0.909	0.090	9.868	[0.819, 0.998]	55.556
2002	27	5	0.904	0.110	12.180	[0.794, 1.014]	77.778
2003	27	7	0.907	0.097	10.700	[0.810, 1.004]	85.185
2004	27	7	0.938	0.082	8.745	[0.856, 1.020]	88.889
2005	28	8	0.959	0.055	5.704	[0.904, 1.013]	78.571
2006	28	4	0.930	0.120	12.929	[0.810, 1.051]	85.714
2007	28	7	0.949	0.066	6.940	[0.883, 1.015]	85.714
2008	28	9	0.977	0.035	3.591	[0.942, 1.012]	89.286
2009	27	10	0.980	0.041	4.144	[0.940, 1.021]	92.593
2010	27	6	0.971	0.038	3.960	[0.933, 1.010]	88.889
2011	26	6	0.960	0.044	4.606	[0.916, 1.005]	84.615
2012	26	5	0.953	0.045	4.757	[0.908, 0.998]	61.538
2013	26	9	0.971	0.040	4.105	[0.931, 1.011]	80.769
2014	27	11	0.987	0.028	2.837	[0.959, 1.015]	88.889
2015	27	11	0.987	0.028	2.837	[0.959, 1.015]	88.889
2016	27	10	0.976	0.036	3.702	[0.940, 1.012]	85.185
2017	27	12	0.970	0.050	5.176	[0.920, 1.021]	92.593
2018	21	7	0.952	0.062	6.532	[0.890, 1.014]	76.190
2019	20	10	0.988	0.021	2.153	[0.967, 1.010]	85.000
2020	18	6	0.979	0.040	4.097	[0.938, 1.019]	94.444
2021	12	7	0.989	0.022	2.215	[0.968, 1.011]	91.667
2022	12	7	0.996	0.009	0.859	[0.988, 1.005]	91.667
2023	12	8	0.988	0.025	2.487	[0.963, 1.012]	91.667
2024	12	5	0.992	0.013	1.289	[0.979, 1.005]	91.667
ASE (1991-2024)	24.6	7.647	0.955	0.057	6.060	-	82.995
Pre-merger (1991-2020)	26.3	7.767	0.950	0.062	6.639	-	81.839
Post-merger	12.0	6.750	0.991	0.017	1.713	-	91.667

(2021-2024)							

Source: Author's computation based on the Statistical table related to various issues related to Banks in India, RBI

Table 3 depicts the year-wise and period-wise scale efficiency (ASE) of Indian public sector banks from 1991 to 2024, illustrating substantial trends and improvements in operational scale over time. The average scale efficiency across the entire period stands at 0.955, signifying that, on average, banks could have minimized input usage by about 4.5% purely by adjusting to an optimal operational scale. Yearly figures reveal progressive enhancement, with ASE ranging from 0.903 in 2000 to 0.996 in 2022.

The number of scale-efficient banks varies each year, with as few as 4 banks achieving full scale efficiency in 2006, while up to 12 banks were scale-efficient in certain years, notably 2017. Notably, the post-merger period (2021-2024) shows marked improvement with an average scale efficiency rising to 0.991, compared to 0.950 for the pre-merger years (1991-2020). This is further corroborated by the dramatic drop in standard deviation (from 0.062 pre-merger to 0.017 post-merger) and coefficient of variation, indicating greater clustering of banks around a higher efficiency mean. Additionally, the proportion of banks within one standard deviation of the mean increases to 91.67% post-merger, up from 81.84% pre-merger, signaling a heightened degree of convergence in achieving scale efficiency after sector consolidation.

4.4 Overview of Efficiency Measurement Approach

Table 4: Average Overall Technical Efficiency, Average Pure Technical Efficiency and Average Scale Efficiency of Public sector Banks during the period 1991-2024 and Pre-merger period (1991-2020) and post-merger period (2021-2024).

Year	Average Technical Efficiency	Average Pure Technical Efficiency	Average Scale Efficiency
1991	0.849	0.930	0.913
1992	0.878	0.928	0.946
1993	0.819	0.881	0.930
1994	0.837	0.882	0.949
1995	0.822	0.877	0.936
1996	0.822	0.869	0.945
1997	0.855	0.897	0.950
1998	0.875	0.924	0.943
1999	0.852	0.919	0.925
2000	0.840	0.927	0.903
2001	0.830	0.912	0.909
2002	0.817	0.906	0.904
2003	0.811	0.895	0.907
2004	0.882	0.941	0.938
2005	0.887	0.927	0.959
2006	0.807	0.868	0.930
2007	0.885	0.933	0.949

2008	0.921	0.943	0.977
2009	0.939	0.958	0.980
2010	0.918	0.946	0.971
2011	0.922	0.961	0.960
2012	0.921	0.967	0.953
2013	0.954	0.982	0.971
2014	0.952	0.966	0.987
2015	0.952	0.966	0.987
2016	0.935	0.958	0.976
2017	0.944	0.973	0.970
2018	0.913	0.959	0.952
2019	0.952	0.963	0.988
2020	0.936	0.957	0.979
2021	0.977	0.988	0.989
2022	0.982	0.986	0.996
2023	0.976	0.988	0.988
2024	0.974	0.982	0.992
Overall (1991-2024)	0.895	0.937	0.955
Pre-merger (1991-2020)	0.884	0.930	0.950
Post-merger (2021-2024)	0.977	0.986	0.991

Source: Author's computation based on the Statistical table related to various issues related to Banks in India, RBI

Table 4 presents the annual and period-wise averages of technical efficiency (under Constant Returns to Scale), pure technical efficiency (under Variable Returns to Scale), and scale efficiency for Indian public sector banks over the period 1991-2024. The data demonstrate clear trends and structural shifts in efficiency linked to sectoral reforms and consolidation.

Average technical efficiency began at 0.849 in 1991 and hovered in the 0.8-0.9 range throughout the 1990s and early 2000s, reaching its nadir at 0.811 in 2003. Marked improvements are evident from the mid-2000s, with efficiency rising above 0.9 in most years from 2008 onward, and peaking at 0.982 in 2022. Over the entire period, technical efficiency averaged 0.895; however, the pre-merger period (1991-2020) saw a lower mean (0.884), in contrast to a sharp rise to 0.977 during the post-merger years (2021-2024). Pure technical efficiency—capturing managerial and operational effectiveness excluding scale effects—was consistently higher than overall technical efficiency, starting from 0.930 in 1991 and generally increasing over time to a high of 0.988 in 2023. The overall average was 0.937, again with a substantial leap post-merger (0.986) compared to pre-merger (0.930). Scale efficiency, representing banks' ability to operate at an optimal size, mirrored this improvement: from 0.913 in 1991 and a low of 0.903 in 2000, it climbed steadily to a maximum of 0.996 in 2022. The overall average scale efficiency stood at 0.955, with a clear increase from 0.950 pre-merger to 0.991 after mergers and consolidations.

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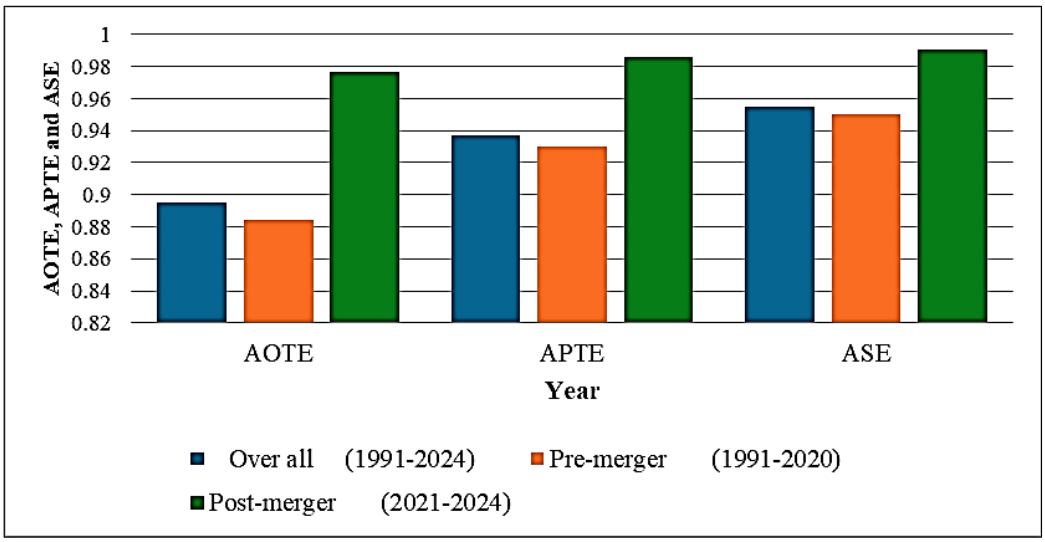

Fig 1: AOTE, APTE and ASE during 1991-2004 and Pre-merger (1991-2020) and Post-merger (2021-2024)

4.5 Tobit Regression Analysis: Determinants of Efficiency in Indian Public Sector Banks

Table 5: Tobit regression model results of combined Public sector banks' Efficiency score, Total Assets, ROA, CAR and NPA during the period 1996-2024. Dependent variable (Efficiency score)

Variable	Coefficients	St. Error	Z-Statistics	Prob
C	0.855	0.034	19.634	0.000
Total Assets	-4.732	5.532	-0.086	0.93
ROA	-0.022	0.009	-2.393	0.017
CAR	0.014	0.003	4.543	0.000
NPA	-0.003	0.002	-1.275	0.202
Mean dep = 0.939	S.D dep = 0.906	S.E Regression = 0.0887	Akaike Info Crit = 0.275	Sum Squared Res = 5.402

Schw Crit=0.315	Aver Log Likelihood = -0.129	Hannan-Quinn Criteria = 0.291 The Jarque-Bera test indicates no serious departure from normality.

Source: Authors computation using E-Views 11

Table 5 presents the estimated results of the Tobit regression analysis investigating the determinants of technical efficiency in Indian public sector banks (PSBs) over the period 1996 to 2024. The efficiency scores, sourced from Data Envelopment Analysis (DEA), serve as the dependent variable, while total assets, return on assets (ROA), capital adequacy ratio (CAR), and non-performing assets (NPA) are the independent variables. Although bank size is theoretically expected to influence efficiency, the results of the Tobit regression indicate that the coefficient of total assets is negative but statistically insignificant. This suggests that size alone does not directly explain efficiency variations among Indian public sector banks during the study period. The efficiency gains observed after mergers therefore appear to be driven more by capital strengthening, operational restructuring, and improvements in governance and managerial practices rather than by scale expansion per se. Likewise, ROA exhibits a significant negative coefficient (-0.022, $p = 0.017$), suggesting that elevated profitability does not necessarily translate into enhanced efficiency, potentially due to the prioritization of discretionary lending policies or short-term profit spikes rather than sustained operational optimization.

Conversely, the capital adequacy ratio demonstrates a robust positive influence on efficiency (coefficient = 0.014, $p < 0.001$), underscoring the critical role of a strong capital base in facilitating prudent risk management, credit discipline, and consequently, improved resource utilisation. The effect of non-performing assets on efficiency is negative but statistically non-significant (coefficient = -0.003, $p = 0.202$), consistent with theoretical expectations, while suggesting variability in its impact across institutions and time periods.

Model diagnostics affirm the robustness of the specification, with a standard error of regression of 0.0887 and favourable information criteria metrics (AIC = 0.275, Schwarz = 0.315). Collectively, these results emphasize that strengthening capital adequacy and improving governance and operational practices are paramount for achieving higher efficiency levels. Furthermore, the insignificant yet negative association of NPAs underscores the continuing imperative of addressing asset quality to consolidate operational performance and financial stability.

5. Conclusion and Recommendations

This study has undertaken a rigorous empirical investigation into the operational efficiency and performance dynamics of Indian public sector banks (PSBs) over the post-liberalisation era spanning 1991 to 2024. Employing a robust methodological framework combining Data Envelopment Analysis (DEA) for efficiency measurement and Tobit regression to examine determinants of efficiency, the research has provided nuanced insights into the evolving performance of PSBs amidst significant policy reforms, market liberalisation, recapitalisation drives, and sector consolidation through mergers.

The findings unequivocally indicate a progressive enhancement in the efficiency of PSBs

across multiple dimensions. The average overall technical efficiency under Constant Returns to Scale (CRS) improved from 0.884 during the pre-merger phase (1991-2020) to a remarkable 0.977 post-merger (2021-2024), underscoring the positive impact of consolidation and institutional restructuring. Pure technical efficiency (managerial and operational effectiveness) showed parallel improvements, rising from 0.930 to 0.986, while scale efficiency, the extent to which banks operate at optimal size, increased from 0.950 to 0.991 in the post-merger phase. These improvements highlight that the extensive wave of bank mergers since 2020 has not only enhanced managerial competence but also effectively addressed scale inefficiencies endemic to many PSBs.

The Tobit regression analysis reveals critical determinants underpinning these efficiency dynamics. Capital adequacy emerged as the most robust and positively significant driver of bank efficiency, emphasizing the necessity of strong capitalisation buffers to enable prudent risk management and sustainable credit extension Conversely, return on assets exhibits a significant negative relationship with efficiency, while total assets show a negative but statistically insignificant association. This indicates that efficiency in Indian public sector banks is not directly driven by size, but rather by financial strength and internal operational factors. Non-performing assets (NPAs), though exhibiting a negative coefficient, were statistically insignificant within the model, indicating complex, heterogeneous influences across banks and time, yet their broader economic and operational burden remains a pressing challenge.

These intertwined insights suggest that efficiency enhancement in Indian PSBs is multifactorial, contingent upon prudent capital management, optimized scale of operations, and refined governance practices that reconcile social objectives with performance imperatives. The significant efficiency gains post-merger affirm the merits of consolidation policies, which have facilitated economies of scale, managerial restructuring, and improved resource utilization. Although bank size shows a negative coefficient, its statistically insignificant effect suggests that efficiency gains are not directly driven by scale, but rather by capital strength and internal operational improvements.

5.1 Policy Recommendations arising from this research include:

Sustained Capital Strengthening: Regulators and policymakers should prioritize further strengthening capital adequacy through recapitalisation and retention of earnings, ensuring banks possess the resilience to absorb shocks and maintain prudent lending standards.

Focused Asset Quality Resolution: While NPAs did not exhibit strong statistical influence in this model, their persistent economic impact necessitates continued vigilance, enhanced credit monitoring, and aggressive resolution measures to reduce stressed assets and improve risk-weighted asset quality.

Reform-oriented Consolidation: Mergers and consolidation should not be viewed merely as mechanisms for increasing bank size, but as instruments for strengthening capital positions, improving governance structures, and enhancing operational discipline across public sector banks.

Managerial Capacity Building: Improvement in pure technical efficiency underscores the importance of continuous managerial training, performance benchmarking, and adoption of best practices in risk and cost management across all PSBs.

Regulatory Oversight and Incentive Alignment: Regulators should develop incentive structures that encourage efficiency-driven behavior, while maintaining public policy

objectives, to balance social and commercial priorities effectively.

In conclusion, the trajectory of India's public sector banks reflects a substantial transformation, with improved operational efficiency and financial resilience shaped by policy reforms and structural consolidation. However, balancing developmental credit imperatives with efficiency remains an ongoing challenge. This study contributes empirical evidence to inform policy formulation and strategic management aimed at fostering a more productive, stable, and inclusive public banking sector capable of supporting India's sustained economic growth.

Future research may extend this analysis by incorporating non-parametric bootstrap methods to assess the robustness of efficiency scores, explore dynamic panel data models for efficiency evolution, and examine the interplay of digitalization and financial inclusion on PSB performance.

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