REVISTA AMBIENTE CONTÁBIL
Universidade Federal do Rio Grande do Norte
ISSN 2176-9036
Vol. 18, n. 1, Jan./Jun., 2026
Sítios: https://periodicos.ufrn.br/index.php/ambiente
http://www.atena.org.br/revista/ojs-2.2.3-06/index.php/Ambiente
Article received on: April, 23th, 2025. Peer-reviewed on: September, 10th, 2026. Reformulated on: October, 13th, 2025. Evaluated by the double-blind review.

DOI: 10.21680/2176-9036.2026v18n1ID42530

Technology spending and the effects of the pandemic on the efficiency of federal institutes

El gasto en tecnología y los efectos de la pandemia en la eficiencia de los institutos federales

Gastos com tecnologia e os efeitos da pandemia na eficiência dos institutos federais

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Abstract

Purpose: This study investigates the impact of technology expenditures and the COVID-19 pandemic on the efficiency of Federal Institutes of Education, Science, and Technology between 2018 and 2021. It hypothesizes that targeted technology investments can enhance institutional productivity, particularly during health crises.

Methodology: This quantitative research utilizes secondary data from 38 federal institutes. Efficiency was assessed using the nonparametric data envelopment analysis technique, supplemented by the Malmquist index to evaluate productivity over time and by the Tobit regression model to identify statistically significant factors. The sample comprises 107 observations spanning from 2018 to 2021.

Results: Five institutes maintained their positions on the efficiency frontier throughout the period under study, while most fluctuated in efficiency due to external shocks and managerial capacity. The Malmquist index indicated productivity improvements in some institutes, albeit with limited technological advancement. The hypotheses concerning the positive effects of technology expenditures and the pandemic on efficiency were not statistically supported.

Contributions of the study: This study fills a theoretical gap by linking technology and institutional efficiency in crisis contexts. In practice, it offers public managers guidance on revisiting technology resource-allocation strategies, recognizing best practices, and enhancing institutional crisis-response capabilities. The findings also underscore the necessity of regular efficiency evaluations to inform strategic decision-making within the federal professional education network.

Keywords: Expenditure efficiency; Technology; Performance; Federal institutes; Data envelopment analysis.

Resumen

Objetivo: Este estudio analizó si los gastos en tecnología y la pandemia de la COVID-19 impactaron en la eficiencia de los Institutos Federales de Educación, Ciencia y Tecnología durante el período de 2018 a 2021. La investigación parte del supuesto de que las inversiones tecnológicas, cuando están bien orientadas, pueden contribuir a mejorar la productividad institucional, especialmente en contextos de crisis sanitaria.

Metodología: Se trata de una investigación cuantitativa, basada en datos secundarios de 38 institutos federales. La eficiencia se midió mediante la técnica no paramétrica de análisis envolvente de datos, complementada por el Índice de Malmquist para evaluar la productividad a lo largo del tiempo, y por la regresión Tobit en panel para identificar determinantes estadísticamente significativos. La muestra totalizó 107 observaciones distribuidas entre los años 2018 y 2021.

Resultados: Cinco institutos se mantuvieron en la frontera eficiente durante todo el período analizado, mientras que la mayoría presentó variaciones de eficiencia asociadas a choques externos y a la capacidad de gestión. El Índice de Malmquist reveló aumentos de productividad en algunos institutos, aunque acompañados de baja evolución tecnológica. Las hipótesis sobre el impacto positivo de los gastos en tecnología y de la pandemia en la eficiencia no fueron confirmadas estadísticamente.

Contribuciones del estudio: El estudio llena una laguna teórica al articular tecnología y eficiencia institucional en contextos de crisis. Desde un punto de vista práctico, ofrece elementos para que los gestores públicos revisen estrategias de asignación de recursos en tecnología, identifiquen buenas prácticas y fortalezcan la capacidad institucional de respuesta ante crisis. Los hallazgos también refuerzan la importancia de realizar evaluaciones periódicas de eficiencia para apoyar decisiones estratégicas en la red federal de educación profesional.

Palabras clave: Eficiencia del gasto; Tecnología; Desempeño; Institutos federales; Análisis envolvente de datos.

Resumo

Objetivo: Este estudo analisou se os gastos com tecnologia e a pandemia da COVID-19 impactaram a eficiência dos Institutos Federais de Educação, Ciência e Tecnologia no período de 2018 a 2021.

Metodologia: Trata-se de uma pesquisa quantitativa, baseada em dados secundários de 38 institutos federais. A eficiência foi mensurada pela técnica não paramétrica de análise envoltória de dados, complementada pelo Índice de Malmquist para avaliar a produtividade ao longo do tempo, e pela regressão Tobit em painel para identificar determinantes estatisticamente significativos. A amostra totalizou 107 observações distribuídas entre os anos de 2018 e 2021.

Resultados: Cinco institutos mantiveram-se na fronteira eficiente durante todo o período analisado, enquanto a maioria apresentou variações de eficiência associadas a choques externos e capacidade gerencial. O Índice de Malmquist revelou ganhos de produtividade em alguns institutos, ainda que acompanhados de baixa evolução tecnológica. As hipóteses sobre o impacto positivo dos gastos em tecnologia e da pandemia na eficiência não foram confirmadas estatisticamente.

Contribuições do estudo: O estudo preenche uma lacuna teórica ao articular tecnologia e eficiência institucional no contexto de crises. Do ponto de vista prático, oferece subsídios para que gestores públicos revisem estratégias de alocação de recursos em tecnologia, identifiquem

boas práticas e fortaleçam a capacidade institucional de respostas a crises. Os achados também reforçam a importância de avaliações periódicas de eficiência para apoiar decisões estratégicas na rede federal de ensino profissional.

Palavras-chave: Eficiência do gasto; Tecnologia; Desempenho; Institutos federais; Análise envoltória de dados.

1 Introduction

The strategic use of technology has emerged as a critical determinant of institutional efficiency and sustainability across various countries. Recent studies indicate that digitization enhances productivity and improves service quality, particularly in resource-constrained settings (Elgohary, 2022; Sukmana et al., 2022). In the educational sector, technological integration is increasingly viewed as vital for maintaining competitiveness and institutional quality (Johnes, 2020).

The COVID-19 pandemic further underscored the importance of these investments. The abrupt switch to remote learning revealed structural limitations and inequalities in access, prompting institutions to adapt swiftly and innovatively (Nanotek & Benu, 2022). In Brazil, this challenge was particularly significant for the Federal Network of Professional, Scientific, and Technological Education (Brasil, 2008), which currently comprises 654 campuses nationwide (Brasil, 2021). This rapid expansion has stressed the quality of teaching, research, and extension while necessitating more efficient resource management.

The literature, both national and international, highlights the significant role of technological investments in enhancing institutional performance (Blichfeldt & Faullant, 2021; Yadav & Yadav, 2022). Nevertheless, few studies analyze the pandemic's impact on educational institutions' efficiency alongside technology expenditure in an integrative manner. This gap accentuates the need for research that examines these factors within a unified analytical model.

Given this scenario, the research question that guides this study is: **Did technology spending and the COVID-19 pandemic impact the efficiency of Federal Institutes of Education, Science, and Technology between 2018 and 2021?** Thus, we sought to determine the effects of technology investments and the pandemic on these institutes' efficiency during this period.

The study's importance lies in its theoretical contribution to understanding the roles of technology and health crises in institutional efficiency, an underexplored area in the Brazilian literature. In practice, it aids public managers in strategically planning technology resource allocation and in identifying best practices and potential shortcomings.

Ultimately, this article seeks to provide novel empirical evidence on the efficiency of Federal Institutes (FI) in a crisis context, emphasizing technology's role in supporting performance and enabling managers to reevaluate investment policies in the public education sector.

2 Theoretical Framework

2.1 Institutional Performance

Institutional Theory is widely recognized in economics, management, and accounting, providing a foundational framework for analyzing institutional performance (Peters, 2000). This theory elucidates how organizations adapt their behavior to external pressures, social norms, and institutional expectations, seeking legitimacy and stability in complex environments (DiMaggio & Powell, 1983; Kostova et al., 2020). In this context, educational institutions, as public sector entities, are influenced by both formal state regulations and socially accepted values and practices, shaping their adaptability and efficiency. Institutional performance refers to an organization's effectiveness and efficiency in achieving its objectives, considering both internal and external operational factors (Marzzoni & Pereira, 2020). In educational institutions, performance is closely tied to institutional credibility and stakeholder trust, particularly regarding academic management and public resource transparency (Khan et al., 2020; Sarfraz et al., 2022).

Elgohary (2022) emphasized that institutional performance is also contingent upon integrating governance, innovation, and technology. This perspective aligns with the institutional view that organizations adopting innovative practices adapt more effectively to environmental demands and meet social expectations more efficiently (Blichfeldt & Faullant, 2021; Yadav & Yadav, 2022).

Furthermore, actions directed at the student body significantly influence institutional performance. According to Bullock and Wilder (2016), maintaining student attraction and retention requires a continuous commitment to academic excellence. Thornton and Audrey (2008) address institutional competitiveness, while Rowley and Sherman (2003) and Whitechurch and Gordon (2010) underscore the importance of combining economic support with educational quality.

2.2 Technology Expenditures

The advancement of digitization in educational activities places pressure on public institutions to manage their resources transparently and efficiently (Nazarko & Šaparauskas, 2014). In Brazil, between 2018 and 2021, FIs received roughly BRL 537 million in investments in Information Technology (IT), representing 16.21% of the total invested by the Brazilian Ministry of Education (Sistema Integrado de Planejamento e Orçamento, 2023). This volume of resources underscores the significance of IT as a driver of institutional performance, while also highlighting challenges in its distribution and effective use.

Coccia (2019) suggested that investing in technology not only promotes socioeconomic advances but also strengthens institutional governance, especially in challenging contexts. Consequently, it is crucial that investments align with Institutional Development Plans and the adoption of strategic IT governance (Queiroz et al., 2020).

Evidence has shown that integrating technology and education fosters global knowledge development (Xu & Liu, 2017). However, criticisms about the efficiency of these investments must be considered (So, 2011). To address these concerns, Lin et al. (2010) posited that increases in IT expenditures can positively affect educational outcomes, provided specific national contexts are taken into account.

The use of digital platforms, information systems, and e-learning is transforming the logic of management and learning. Basak et al. (2016) and Naveed et al. (2017) demonstrated that these technologies enhance accessibility and reduce costs, while their combination with teacher training enhances institutional efficiency and social reach (Andonova & Trenovski, 2022). Nevertheless, such outcomes depend on integrated institutional policies that ensure technical support, digital inclusion, and information security.

2.3 Institutional Efficiency

Efficiency, as outlined in the Constitution, is one of the guiding principles of public administration, aimed at ensuring productivity and quality in state management (Brasil, 1988). According to Paludo (2013), this principle governs the rational use of public resources, avoiding waste and promoting social welfare.

Given the various interpretations of the concept, Chan and Karim (2012) defined the efficiency of public spending as the capacity to maximize services provided at lower costs, taking into account the economic context. For Mallaye and Gadom (2021), this approach is particularly relevant in scenarios of vulnerability and budgetary constraints. Mandl et al. (2008), in contrast, stress that public administration sectors exhibit distinct characteristics, thereby requiring a sectoral analysis of management practices.

Khan and Murova (2015) emphasized that public spending in social areas has a direct impact on public policies, which justifies the assessment of efficiency. Additionally, institutions guided by governance principles, such as curbing corruption and ensuring transparency, tend to be more efficient (Rajkumar & Swaroop, 2008).

Technical efficiency involves the proper allocation of available resources, optimizing inputs to produce the desired outputs (Itoh, 2002). Research, such as by Almeida and Almeida Filho (2014), has analyzed the efficiency of federal schools using microdata from the School Census and ENEM, highlighting the performance of Espírito Santo State. Rodrigues et al. (2018) employed data envelopment analysis (DEA) to measure the efficiency of nine units of the Federal Center for Technological Education of Minas Gerais, identifying benchmarks and targets for units considered inefficient.

A multidimensional understanding of institutional efficiency stems from the integration of structural, technological, and human variables, transcending traditional analyses focused solely on financial indicators (Aparicio et al., 2019). Thus, this research proposed to investigate whether FIs that invest more in technology exhibit higher levels of institutional efficiency, leading to the following hypothesis:

H_1: Federal institutes that invest more in technology have higher levels of institutional efficiency.

2.4 The COVID-19 Pandemic

The COVID-19 pandemic has posed unprecedented challenges to the management of educational institutions, requiring quick and effective responses (Engzell et al., 2021; Tomasik et al., 2021). Institutions with robust digital infrastructure and operational maturity performed better, while those lacking adequate infrastructure suffered significant setbacks (Kim et al., 2021). This scenario revealed a heterogeneous impact influenced by management capacity, technological use, and teacher qualifications.

The diversity in outcomes led to the implementation of various non-pharmacological interventions, such as the closure of educational institutions at different levels, significantly impacting the learning process (Haug et al., 2020). Although effective in containing the virus's spread, these measures resulted in the discontinuation of face-to-face teaching, inadequately compensated for by remote teaching.

Engzell et al. (2021) identified a "learning loss" in Dutch primary schools, particularly among students from lower socioeconomic backgrounds, highlighting inequalities exacerbated by the pandemic. Similarly, Kim et al. (2021) observed a significant decline in the performance of medical students in South Korea over three semesters of remote learning. Tomasik et al. (2021), in their analysis of 28,685 students, found that impacts varied by education level, with stability in secondary school but a sharp decline in elementary education.

Panagouli et al. (2021) confirmed learning losses in online education through a systematic review, although some students, especially in mathematics, benefited. Young children and students with special educational needs were most affected, as identified by parents and caregivers.

Thus, the pandemic exposed weaknesses in management capacity and accelerated innovation and organizational learning, contributing to technology as a driver of efficiency and resilience (Sarfraz et al., 2022). Given this multifaceted context and its impacts on education, this research formulates the following hypothesis:

H_2: The COVID-19 pandemic negatively affected the efficiency of federal institutes.

3 Methodological Procedures

3.1 Framework, Research Universe, and Data Treatment

This research is explanatory and quantitative, utilizing secondary data, which, according to Hammes Junior (2019), seeks to understand variables influencing the efficiency of technology spending on institutional performance before and during the pandemic (Theóphilo & Martins, 2009). The quantitative approach employs statistical procedures to describe and explain these relationships (Richardson et al., 1999), anchored in official sources that substantiate the analysis.

The research universe encompasses the 38 FIs across the 27 federal units, as established by Law No. 11,892/2008, including 644 campuses and 10,878 courses, with advanced postgraduate and research facilities. The period from 2018 to 2021 was selected by the National Institute of Education due to the availability and standardization of data on the Nilo Peçanha Platform and the Integrated Planning and Budgeting System, which provide detailed information on faculty, students, infrastructure, and budget execution.

The data collected specifically pertains to technological courses offered by FIs. Financial variables stem from transfers by the Federal Government. Data were organized and processed using Microsoft Excel®, while statistical analyses, including descriptive statistics, efficiency scores, and inferences, were conducted using Stata® software. This section delineates the methodological framework supporting the empirical investigation, ensuring analytical rigor and the validity of the results discussed in subsequent sections.

3.2 Models Used

To achieve the outlined objectives, our method was divided into three stages. In the first, DEA was used to measure IFs' efficiency from 2018 to 2021. This non-parametric technique considers the following as inputs: investment expenditures (IEXP), number of enrolled students (NES), faculty qualifications (FQ), and current expenditure per enrollment (CEE); and as *outputs:* number of courses offered (NCO) and number of graduating students (NGS).

Next, the evolution of efficiency is analyzed using the Malmquist index, observing the changes between the periods before and during the pandemic. Lastly, a regression model is used to test hypotheses H_1 and H_2, which cover the influence of technology spending and the pandemic on institutional efficiency.

3.2.1 Data Envelopment Analysis and the Malmquist Index

Data envelopment analysis, formulated by Charnes et al. (1978), has been widely used to measure technical efficiency in educational institutions (Aoki et al., 2010). In Brazil, applications focused on secondary education and technological institutions stand out (Ramos & Ferreira, 2007). This research uses the CCR model with constant returns to scale, oriented towards outputs, considering six variables and 38 decision-making units over four years.

To analyze efficiency over time, the Malmquist index, conceived by Malmquist (1953) and later disseminated by Caves et al. (1982), was used. This index assesses variations in technical efficiency (TECH), technological change (TECCH), and total factor productivity (TFPC), based on Färe et al. (1994) and Coelli et al. (1998).

To validate this study, other authors, such as Jing and Shen (2011), used the Malmquist index with the DEA-BCC-CCR model. In this sense, they analyzed 30 educational institutions in China between 2004 and 2008 and confirmed that the results supported and facilitated managers' decision-making (Barros & Amaral, 2022).

3.2.2 Regression Model

Econometrics is based on the development of statistical methods to evaluate economic relationships, test theories, and implement public and business policies (Wooldridge, 2010). To test the hypotheses defined in this study, the estimated model was given by Equation 1:

$$Eficiência_{it} = \beta_0 + \beta_1 GT_{it-1} + \beta_2 DPAND_{it} + \sum_{k=3}^{12} \beta_k \, (EAC_{it} + DRegSul_{it} + DRegSE_{it} + DRNE_{it} + DRCE_{it} + PSEXOF_{it} + PCORB_{it} + PCORP_{it} + PCORA_{it} + CORI_{it}) + \xi_{it} \quad (1)$$

Where Efficiency is the dependent variable, estimated by DEA; GT_{it}^{-1} (investment expenditure in technology in the previous period) is the actual values of investments allocated to technology; EAC is the academic efficiency rate, a control variable; Pandemic is a dummy variable for the years of the COVID-19 pandemic, receiving a value of 1 in 2020 and 2021, and zero in the other years of the sample; Control is the vector of control variables used in the study (e.g., FI region, ethnic distribution, and sex) according to the literature (Rodrigues et al., 2018; Rocha & Funchal, 2019); and, the regression error term indicated by ε.

Due to the nature of the analysis, the Tobit regression model is employed since the dependent variable, calculated using DEA, is confined between 0 and 1, displaying decimal values within these limits. The relationships presented in Table 1 are anticipated to test the study's hypotheses.

Table 1
Summary of the hypotheses.

Hypothesis	Variable	Type	Expected sign
H_1: Federal institutes that invest more in technology have higher levels of institutional efficiency.	GT_{it}^{-1}	Explanatory	+
H_2: The COVID-19 pandemic negatively affected the efficiency of federal institutes.	$DPAND_{it}$	Explanatory	-

Source: *Survey data (2023).*

To construct the DEA model and assess the relative efficiency of each FI, indicators identified in the literature as inputs and outputs were selected. These indicators represent relevant aspects of the structure and outcomes of each unit.

- IEXP reflects the percentage of investment expenditures relative to the institution's total expenditures (Rocha & Funchal, 2019).
- NES denotes the number of students enrolled at each institute annually (Uemura & Comini, 2022; Sarfraz et al., 2022; Johnes et al., 2020).
- FQ indicates the qualification level of the teaching staff at each institution (Aparicio et al., 2019; Segovia Gonzalez et al., 2020).
- CEE refers to the mean cost per enrollment at the institution (Munoz, 2016; Machado et al., 2018; Feres et al., 2016).
- NCO signifies the number of courses offered at each institute (Uemura & Comini, 2022; Sarfraz et al., 2022).
- NGS represents the percentage of students graduating from each institution (Furtado & Campos, 2015; Parente et al., 2021).

To facilitate comprehension of the DEA model, Table 2 summarizes and categorizes the indicators considered in this model, presenting their classifications as inputs or outputs.

Table 2
Indicators to be used in the DEA.

Indicators	Type	Formula	Source
IEXP	Input	$\text{GCI}\ [\%] = \frac{\text{GCI}}{Expenditures}$	PNP
NES	Input	Number of students enrolled per institute	PNP
FQ	Input	$\text{ITCD} = \frac{\text{Gx1} + \text{Ax2} + \text{Ex3} + \text{Mx4} + \text{Dx5}}{\text{G} + \text{A} + \text{E} + \text{M} + \text{D}}$	PNP
CEE	Input	$\text{CEE} = \frac{Current\_expenditure}{Equivalent\ enrollments}$	PNP
NCO	Output	Number of courses offered at each institute	PNP
NGS	Output	Percentage of students completing the cycle.	PNP

Note: PNP = Nilo Peçanha Platform.
Source: *Research data (2023).*

Table 3 lists the variables included in the regression model to examine factors potentially influencing the efficiency observed at each institution. These variables are categorized into dependent, independent, and control variables, consistent with the analysis conducted in the second stage of this study.

Table 3
Variables used in the regression model.

Acronym	Dependent variable	Description	Expected signal	Source
Efficiency	Efficiency	Truncated or censored variable, which can assume fractional values between 0 and 1	+	DEA
GT	Technology expenses	Amounts spent on IT expenses	+	SIOP
DPAND	During the pandemic	Dummy that assumes a value of 1 for the period after 2019	+	-
EAC	Academic efficiency rate	The ratio of graduates to total enrollments completed at the IF, plus the sum of the result of dividing the dropout rate for the cycle multiplied by the retention factor for the cycle		PNP
DSul	Southern region	Regions where the institutes are located		PNP
DSudeste	Southeastern region	Regions where the institutes are located		PNP
DCentro oeste	Midwestern region	Regions where the institutes are located		PNP
DNordeste	Northeastern region	Regions where the institutes are located		PNP
Pbranco	White	Color/race		PNP
Pindig	Indigenous	Color/race		PNP
Ppard	Brown	Color/race		PNP
PFemin	Female	Sex		PNP

Note: SIOP = Integrated Planning and Budgeting System; PNP = Nilo Peçanha Platform.
Source: *Survey data (2023).*

Based on the definition and systematization of the indicators and variables considered in the nonparametric (DEA) and parametric (regression) models, the data are analyzed to present an overview of the characteristics of the variables observed over the analyzed years.

4. Results and Analysis

4.1. Descriptive Statistics

Table 4 presents the descriptive statistics of the variables used to measure efficiency through the DEA model, considering 107 observations. The most efficient IFs achieved scores of 0.55–1.00, with a mean of 0.85. This variability indicates a relatively homogeneous scenario, highlighting the most efficient institutes, which exhibited a standard deviation of 0.13. This result aligns with observations in the educational context of Soares and Santos (2024), who identified educational institutions with a mean efficiency of around 0.86 in 2017 and 2018.

Table 4
Descriptive statistics

Variables	Obs.	Min.	p25	Mean	SD	p75	Max.
Efficiency	107	0.55	0.73	0.85	0.13	1	1
EAC	107	32.92	49.18	57.32	11.40	62.87	86.20
Technology expenditure	107	0.02	0.76	1.16	0.54	1.54	2.35

Investment expenses	107	1.48	2.14	2.51	0.56	2.82	3.83
Graduating students	107	21.66	38.39	45.41	11.12	49.66	84.47
Courses offered	107	73.00	173.00	268.95	147.12	319.00	801.00
Enrolled students	107	5,751.00	16,564.00	33,134.56	49,482.59	34,987.00	454,434.00
Teaching qualifications	107	3.66	4.04	4.17	0.21	4.35	4.52
Current expenditure per enrollment	107	6,959.22	13,720.46	15,801.27	3342.26	17,917.27	24,001.36
Pamar	107	0	0.01	0.01	0.02	0.01	0.19
Pbran	107	0.02	0.13	0.26	0.17	0.36	0.76
Pindig	107	0.00	0.00	0.01	0.02	0.00	0.16
Ppard	107	0.00	0.26	0.38	0.17	0.52	0.71
PFemin	107	0.42	0.46	0.51	0.05	0.53	0.64
dpandemia	107	0.00	0.00	0.67	0.47	1	1

Note: SD = Standard deviation; AE = academic efficiency.
Source: *Survey data (2023).*

The mean investment expenditure was BRL 2.51, varying by BRL 1.48–3.83, which may reflect an increased availability of courses and a higher number of enrollments. The mean teaching qualification was 4.17 on a scale from 1 to 5, indicating a predominance of master's degree holders. Although having more qualified teachers can add academic value, Parente (2023) noted that high qualification levels may reduce efficiency by increasing costs and shifting the focus towards research, which does not always lead to improved teaching outcomes.

The current spending per enrollment had a mean of BRL 15,801.27, ranging from BRL 6,959.22 to BRL 24,001.36. These variations may be related to the presence of internal students. Demographic data revealed that 38% of students self-identified as brown, 26% as white, and approximately 50% as female, demonstrating the diversity in the student body of IFs. As per our method, the inputs considered were investment expenditures, the number of students enrolled, faculty qualifications, and expenditure per enrollment, whereas outputs were NCO and the number of graduates. Table 5 presents the efficiency scores of IFs from 2018 to 2021, as determined through DEA.

Table 5
Investment expenditures

Federal Institutes	**2018**	**2019**	**2020**	**2021**
IF Baiano	0.884	0.985	1.000	0.800
IF Farroupilha	0.673	1.000	0.903	0.737
IF Goiano	0.731	0.728	0.876	0.863
IF Sertão Pernambucano	0.949	1.000	0.921	1.000
IF Sudeste MG	0.737	0.701	0.824	0.942
IFSULDEMINAS	0.609	0.927	1.000	1.000
IFAC	0.808	1.000	0.789	0.777
IFAL	0.754	0.721	0.743	0.658
IFAM	0.750	0.806	0.838	0.898
IFAP	1.000	1.000	1.000	1.000
IFB	0.671	0.675	0.779	0.757
IFBA	0.743	0.611	0.623	0.632
IFC	0.766	0.731	0.824	0.805
IFCE	0.968	1.000	1.000	1.000
IFES	0.746	0.840	0.867	0.977
IFF	0.575	0.801	0.778	0.729
IFG	0.947	0.739	0.731	0.677
IFMA	0.992	1.000	1.000	1.000

IFMG	0.673	0.809	0.844	1.000
IFMS	1.000	0.733	0.656	0.639
IFMT	0.798	0.816	0.865	0.698
IFNMG	1.000	1.000	1.000	1.000
IFPA	1,000	1,000	1,000	1,000
IFPB	0.493	0.551	0.688	0.731
IFPE	0.639	0.717	0.703	0.698
IFPI	1.000	1.000	1.000	1,000
IFPR	0.791	0.837	0.878	0.715
IFRJ	0.482	0.675	0.630	0.619
IFRN	1.000	1.000	1.000	0.969
IFRO	1,000	0.803	0.852	0.855
IFRR	1.000	1.000	1.000	1.000
IFRS	0.866	0.991	1,000	1.000
IFS	0.595	0.649	0.662	0.720
IFSC	1.000	1.000	0.853	0.951
IFSP	1,000	1.000	0.924	1.000
IFSUL	0.707	0.684	0.617	1.000
IFTM	0.798	0.923	0.982	0.937
IFTO	0.597	0.724	0.846	0.882
Mean	0.809	0.847	0.855	0.860
Standard deviation	0.163	0.143	0.127	0.138

Source: *Survey data (2023).*

In 2018, 26% of IFs (10 out of 38) achieved full efficiency, notably including IFSC, IFRO, IFNMG, IFAP, IFRN, IFPI, IFRR, IFMS, IFPA, and IFSP. Conversely, 21 institutes scored below the mean, with IFPB and IFRJ being the least efficient. The remaining institutions operated below the efficiency frontier, with scores ranging from 0.482 (the lowest, recorded by IFRJ) to 0.992. These findings align with those reported by Soares and Santos (2024) in their assessment of Brazilian secondary education.

In 2019, eight IFs maintained full efficiency, while five additional institutes, including IF Farroupilha, IF Sertão Pernambucano, and IFMA, achieved similar results, expanding the total number of efficient institutions to thirteen. The mean efficiency increased from 0.809 in 2018 to 0.847 in 2019, reflecting a relative improvement of 4.7%.

In 2020, despite the impact of the COVID-19 pandemic, 11 IFs maintained full efficiency, with IFRO and IFSC standing out. Both institutes scored close to the mean, although they experienced declines compared to previous years; IFSC's efficiency dropped from 1.00 in 2019 to 0.853 in 2020, and IFSP's from 1.0 to 0.924. By 2021, 13 IFs reached maximum efficiency, including IFAP, IFNMG, IFPA, IFPI, IFRR, IFMA, IFCE, and IFSP. IF Goiano performed near the mean (0.863), whereas IFBA (0.632) and IFRJ (0.619) remained among the least efficient.

Notably, IFAP, IFNMG, IFPA, IFPI, and IFRR consistently achieved full efficiency during all the years analyzed. These institutions serve as benchmarks for good practices, effectively utilizing their inputs to generate favorable results, even under challenging conditions. This outcome reflects the "reference unit" concept discussed by Soares and Santos (2024).

4.2 Malmquist Indices

Table 6 presents the results of the Malmquist index for IFs from 2018 to 2021, based on the parameters of TFPC, TECH, and TECCH, as outlined by Färe et al. (1994) and Coelli et al. (1998). Results above 1 indicate progress, results below 1 indicate regression, and results equal to 1 denote maintenance of existing levels.

Table 6
Malmquist index (2018–2021)

Federal institutes	2018–2019			2019–2020			2020–2021		
	TFPC	TECH	TECCH	TFPC	TECH	TECCH	TFPC	TECH	TECCH
IF Goiano	0.91	1.04	0.87	1.09	1.15	0.94	0.93	0.99	0.94
IFB	0.92	1.00	0.91	0.98	1.05	0.93	0.95	1.00	0.95
IFG	0.80	0.84	0.96	0.94	1.02	0.93	0.97	0.99	0.97
IFMS	0.73	0.79	0.92	1.00	0.96	1.04	1.08	1.14	0.94
IFMT	0.89	1.02	0.87	1.00	1.06	0.94	0.81	0.81	1.00
IF Baiano	1.11	1.10	1.01	1.01	1.02	0.99	0.75	0.75	1.00
IF Sertão PE	0.98	1.00	0.98	0.95	1.00	0.95	1.02	1.00	1.02
IFAL	0.90	0.95	0.95	0.90	1.03	0.88	0.88	0.89	1.00
IFBA	0.78	0.82	0.94	1.01	1.04	0.97	0.94	1.01	0.93
IFCE	1.03	1.03	1.00	0.94	1.00	0.94	0.83	1.00	0.83
IFMA	0.94	1.03	0.91	0.98	1.00	0.98	0.95	1.00	0.95
IFPB	1.02	1.11	0.92	1.20	1.25	0.96	0.94	1.03	0.92
IFPE	1.01	1.16	0.87	0.97	0.99	0.98	0.96	1.00	0.97
IFPI	1.06	1.00	1.06	1.17	1.00	1.17	0.81	1.00	0.81
IFRN	0.92	1.00	0.92	0.98	1.00	0.98	0.93	1.00	0.93
IFS	1.00	1.09	0.92	0.98	1.00	0.98	1.06	1.11	0.96
IFAC	0.91	0.94	0.96	0.92	1.03	0.89	0.88	0.99	0.89
IFAM	0.94	1.08	0.88	0.93	1.04	0.90	1.02	1.07	0.95
IFAP	0.88	1.00	0.88	0.84	1.00	0.84	0.90	1.00	0.90
IFPA	0.87	1.00	0.87	0.99	1.00	0.99	1.01	1.00	1.01
IFRO	0.67	0.80	0.84	1.09	1.06	1.03	1.01	1.05	0.96
IFRR	1.25	1.13	1.10	0.86	1.00	0.86	1.10	1.00	1.10
IFTO	1.15	1.19	0.96	1.10	1.19	0.93	1.05	1.03	1.01
IF Sudeste MG	0.88	0.95	0.93	1.05	1.18	0.89	1.03	1.13	0.91
IFSULDEMINAS	1.09	1.22	0.89	1.25	1.00	1.25	1.15	1.00	1.15
IFES	1.00	1.12	0.89	0.97	1.03	0.94	1.14	1.13	1.01
IFF	1.31	1.38	0.94	0.89	0.97	0.92	0.91	0.93	0.97
IFMG	1.02	1.20	0.85	0.93	1.04	0.89	1.24	1.18	1.05
IFNMG	0.93	1.00	0.93	1.06	1.00	1.06	0.93	1.00	0.93
IFRJ	1.30	1.31	0.99	0.85	0.95	0.90	0.95	0.98	0.97
IFSP	0.93	1.00	0.93	0.86	0.92	0.93	0.97	1.08	0.90
IFTM	1.06	1.13	0.94	1.07	1.14	0.93	0.88	0.94	0.94
IF Farroupilha	1.45	1.44	1.00	0.79	0.90	0.89	0.83	0.84	0.98
IFC	0.94	0.95	0.99	0.94	1.10	0.86	0.96	0.98	0.98
IFPR	0.97	1.06	0.92	0.97	1.05	0.92	0.77	0.81	0.95
IFRS	1.12	1.07	1.04	1.23	1.00	1.23	1.13	1.00	1.13
IFSC	0.98	1.00	0.98	0.79	0.85	0.93	1.02	1.13	0.90

IFSUL	0.90	0.93	0.97	0.97	1.01	0.96	1.70	1.44	1.18

Source: *Survey data (2023).*

Between 2018 and 2019, 14 IFs exhibited productivity growth, as measured by the TFPC, marking an increase. However, this number decreased to 12 in the 2019–2020 biennium before rising to 15 in the 2020–2021 period, indicating a recovery trend. Regarding TECH, improvements were noted in 20 IFs during the first period, 19 in the second, and 13 in the third, highlighting the pandemic impact. TECCH was less pronounced: only four IFs improved from 2018 to 2019, increasing to six between 2019 and 2020, and reaching nine from 2020 to 2021. These findings suggest that, despite the expansion of remote learning during the pandemic, the efficiency frontier remained largely unchanged. This is likely because many innovations implemented were emergency measures, which did not significantly elevate the maximum potential productivity level. The minimal technological change parallels findings from Brintseva (2024), who reported that Polish and Ukrainian educational institutions experienced an exceptional gain of 11.7% between 2019 and 2020, followed by a 3% decline in 2020–2021.

The IFTO particularly excelled by demonstrating simultaneous advances in productivity and technical efficiency across all three evaluated periods. Other institutes, such as IFSULDEMINAS, IFMG, IFRS, and IFSUL, also achieved notable gains, especially in the 2020–2021 period. These results reveal that, despite the challenges posed by the pandemic, some IFs were able to sustain or enhance their productive efficiency levels. Nevertheless, the technological stagnation observed in many cases suggests a need for institutional policies emphasizing innovation and the digitization of educational processes.

4.3 Correlation Analysis

Table 7 shows the results of Pearson's correlation test between the variables used in the model. There is a positive and significant correlation, at the 10% level, between efficiency and the EAC rate, NES, and NCO. In practical terms, these results suggest that higher academic performance and a larger supply structure positively influence the efficiency of institutes, probably because they make better use of resources and convert inputs into results with less waste.

Table 7

Pearson's correlation between variables

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Efficiency (1)	1									
EAC (2)	0.385*	1								
NES (3)	0.228*	0.187*	1							
NCON (4)	0.553*	0.719*	0.336*	1						
NCO (5)	0.446*	0.034	0.312*	0.061	1					
FQ (6)	-0.137	0.007	0.263*	0.216*	0.067	1				
CEE (7)	-0.269*	-0.022	-0.342*	-0.078	-0.348*	0.129	1			
lag GT (8)	-0.025	0.130	0.180*	-0.055	0.4307	0.162*	-0.006	1		
IEXP w (9)	-0.087	0.222*	0.069	0.033	0.417*	0.195*	-0.032	0.629*	1	
DPAND (10)	0.047	-0.030	0.120	-0.138	0.017	0.172*	0.012	0.286*	0.042	1

Note: EAC = Academic efficiency; NCON = number of graduating students; NES = number of enrolled students; NCO = courses offered; FQ = teaching qualifications; CEE = current expenditure per enrollment; GT = technology expenditure; IEXP = investment expenditure; DPAND = during the pandemic.

*Statistically significant at the 10% level.

Source: *Survey data (2023).*

A negative correlation was identified between efficiency and FQ, GT, and IEXP, indicating that these factors, when considered in isolation, do not ensure efficiency gains. The negative relationship between FQ and efficiency corroborates Parente (2023), suggesting that more qualified teachers often engage in activities not captured by output indicators. Additionally, higher salaries increase costs without a proportional rise in the number of graduates, potentially reducing measured efficiency. This does not render qualifications undesirable, although it does indicate that institutions with highly qualified staff may appear less efficient under quantitative metrics if these qualifications are not translated into tangible results.

Current expenditure per enrollment also exhibited a negative correlation, reinforcing that lower unit costs tend to enhance efficiency levels. Furthermore, there is a positive correlation between GT and the pandemic period (DPAND), underscoring the importance of technology during times of face-to-face restrictions.

4.4 Regression Analysis

Table 8 presents the results of the Tobit regression model, which was estimated to determine the factors influencing IF efficiency scores and, specifically, to test H_1 (positive influence of technological spending) and H_2 (negative influence of the pandemic). The estimated coefficients confirm several patterns already noted in the descriptive analysis (Table 4) and correlation analysis (Table 7), while providing additional insights into the statistical significance of each effect.

Initially, we observed that none of the variables directly related to the main hypotheses showed a significant effect. The coefficient for the technology expenditure lag (lag GT), representing the impact of the previous year's information technology and communication investment on current efficiency, was negative and statistically insignificant. The DPAND dummy coefficient, which marks observations from the pandemic period, 2020–2021, was positive but also statistically insignificant. This indicates that, when controlling for other factors, it cannot be conclusively stated that increased spending on technology has enhanced efficiency, nor that the pandemic has influenced any change in the mean efficiency of IFs.

Table 8
The Tobit regression model

Efficiency	**Coefficient**	**Standard error**	**z**	***p***
lag GT	-0.0246	0.0193	-1.28	0.2020
EAC	0.0030	0.0009	3.26	0.0010
DPAND	0.0262	0.0203	1.29	0.1970
DSul	-0.0375	0.0315	-1.19	0.2330
DSudeste	-0.0156	0.0324	-0.48	0.6300
DCentro-Oeste	-0.0824	0.0339	-2.43	0.0150
DNordeste	0.0621	0.0350	1.77	0.0760
Pbran	-0.0277	0.0746	-0.37	0.7110
Pindig	0.0846	0.4740	0.18	0.8580
Ppard	-0.0034	0.0814	-0.04	0.9670
Pfemin	-0.0812	0.1986	-0.41	0.6830
Cons	0.8257	0.1567	5.27	0.0000
/ σ u	0.2124	0.0223	9.53	0.0000
/ σ e	0.0793	0.0070	11.36	0.0000
Rho	0.8775	0.0276	0.8149	0.9235

Observations	**107**
Pseudo R^2	**0.694335**

Source: *Research Data (2023)*

The GT variable exhibited a negative and insignificant coefficient, suggesting that merely investing in technology is insufficient to enhance efficiency. This finding contradicts Kosasi et al. (2020), who assert that investments in technology are essential for achieving successful outcomes and ensuring robust indicators in institutions.

The variables related to student composition did not significantly affect efficiency scores, indicating that ethnic-racial or gender differences do not account for performance variations, and suggesting a lack of structural bias. The Tobit regression model, with a Pseudo R^2 of 0.694 and significant parameters, confirmed the model's adequacy and the presence of institutional heterogeneity. The regression emphasized that investments in technology need to be strategic (Guo & Ye, 2025), the mean impact of the pandemic was negligible compared to international scenarios (Brintseva, 2024), and that unmodeled institutional factors influence efficiency, highlighting the need to reallocate resources according to performance (Parente, 2023).

The study's findings reinforce both theoretical and practical contributions by showing that increased spending does not guarantee efficiency, with improvements stemming primarily from managerial enhancements (Parente, 2023). Although no significant effect of the pandemic was found, European research indicated negative impacts (Brintseva, 2024), underscoring the importance of the institutional context. It is recommended that technological investments be accompanied by training and process reengineering, along with periodic evaluations that guide evidence-based decisions, thereby enhancing accountability in educational spending (Andonova & Trenovski, 2022).

4.5 Discussion of the Results

The application of the DEA model revealed that the IFAP, IFNMG, IFPA, IFPI, and IFRR institutes achieved full efficiency (index 1) between 2018 and 2021, establishing themselves as benchmarks for other institutions. Conversely, IFPB and IFRJ recorded the lowest scores in 2018 (0.493 and 0.482, respectively), signaling significant challenges.

A longitudinal analysis using the Malmquist index showed that 12 institutes experienced a decline in productivity between 2020 and 2021. In contrast, IFTO stood out positively by achieving results above 1 in the three periods analyzed, implying gains in productivity and technical efficiency. This performance supports strategic institutional decisions (Barros & Amaral, 2022).

Regarding H_1, the results suggest that increased investments in technology do not independently ensure greater institutional efficiency. While such investments are vital, they require a more integrated educational ecosystem, as indicated by Xu and Liu (2017). Coccia (2019) supported the notion that technology fosters socioeconomic progress and enhances governance, but its impact relies on structural conditions and stable public funding, which were significantly compromised in the analyzed years.

The study also corroborates Andonova and Trenovski (2022) by emphasizing the importance of periodic efficiency assessments in the education sector. Lastly, despite the expectation that the pandemic would negatively impact efficiency (H_2), this hypothesis was rejected. In context with external studies, this outcome aligns with Panagouli et al. (2021), who highlight the benefits of remote learning in certain educational institutions.

5. Final Considerations

Our findings allowed us to address the proposed research question: technology spending and the COVID-19 pandemic did not have a statistically significant effect on the mean efficiency of FIs between 2018 and 2021. The analysis indicated that the observed efficiency improvements were primarily due to internal management factors and the optimization of available resources, rather than increases in IT budgets or the direct impacts of the pandemic. Additionally, variability was noted among institutions, with some maintaining peak efficiency throughout the period, while others performed poorly, revealing opportunities for managerial and organizational enhancement.

From a theoretical perspective, this research advances the field by integrating technological investments and exogenous shocks into a unified analytical efficiency model, an area relatively unexplored in the literature on professional education. The lack of a direct effect of IT spending contrasts with international evidence that links such investments to automatic performance improvements, underscoring that the impact of technology depends on the institutional context and the quality of its application. In practical terms, the findings suggest that strategies for training human resources and continuous performance evaluation are crucial to maximizing the benefits of technological investments.

The study's contribution lies in highlighting that the determinants of efficiency in the federal vocational education network are not limited to the number of resources but to their mobilization, revealing resilient institutions even amid health crisis scenarios. Contrary to international studies, which have reported a general decline in performance during the pandemic, the national findings suggest that local adaptation and management strategies were key in mitigating potential negative effects and sustaining efficiency levels.

Among the limitations, we emphasize the period investigated, from 2018 to 2021, which does not account for possible long-term effects, and the reliance on predominantly quantitative variables, which do not capture the qualitative dimensions of institutional performance fully. Contextual and leadership factors were not included in the study models, although they may influence the results.

For future research, we recommend extending the post-pandemic time series, incorporating qualitative and contextual variables, and conducting comparative analyses with other education networks or international contexts. These approaches will help understand how technology, management, and context interact in generating efficiency within the public education sector.

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