Engineering Informatics and Digital Transformation

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Association of Digital Procurement Systems with Cost Transparency in Public Works Contracts

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Abstract

This study investigates the causal impact of digital procurement systems on cost transparency in public works contracting through a randomized controlled experiment. Utilizing a unique dataset of municipal infrastructure projects, we examine how the transition from traditional, paper-biased bidding processes to an end-to-end digital procurement platform affects unit cost variance, bidder participation, and post-award contract amendments. The treatment group transitioned to a fully integrated digital portal featuring open-access itemized pricing sheets, automated audit trails, and real-time public dashboards, while the control group maintained the standard administrative workflow. The empirical findings indicate that digital procurement significantly reduces cost overruns and narrows the distribution of submitted unit prices, primarily by mitigating information asymmetry and eliminating rent-seeking opportunities during the bid evaluation phase. Additionally, the digital platform increased the average number of qualified bids per contract, fostering competitive dynamics that drove down procurement costs. These results demonstrate that digital interventions in public administration can systematically enhance fiscal accountability, streamline compliance, and promote cost transparency in complex public infrastructure investments.

Keywords: Digital Procurement; Cost Transparency; Public Works; Randomized Experiment; Controlled Experiment

1. Introduction

Public procurement represents a substantial share of global economic activity, accounting for approximately twelve percent of gross domestic product in developed nations and up to twenty percent in transition and developing economies [1]. Because of the vast sums of public capital involved, the public procurement sector is highly vulnerable to financial waste, bureaucratic inefficiencies, and systemic corruption [2]. Public works contracts, which encompass large-scale infrastructure projects such as road construction, bridge rehabilitation, and municipal facility upgrades, are particularly prone to these challenges. The bespoke nature of public works, coupled with highly technical and complex specifications, creates an environment where information is asymmetric, and administrative oversight is difficult to enforce consistently [3]. In traditional administrative frameworks, procurement processes have historically relied on paper-heavy documentation, manual evaluations, and localized notifications. These opaque workflows present significant opportunities for collusive bidding, bid-rigging cartels, and discretionary rent-seeking by corrupt public officials.

To address these vulnerabilities, governments around the world have invested heavily in public sector digitalization, specifically targeting the modernization of procurement procedures through electronic procurement systems [4]. These digital procurement platforms are designed to transition the entire tendering lifecycle into a centralized, transparent, and automated digital space. In theory, digital procurement platforms enhance market efficiency by reducing search costs for prospective contractors, expanding the pool of participating bidders, and establishing immutable digital footprints of every transaction and administrative decision [5]. By making detailed tender documents, historical price benchmarks, and bid

evaluation metrics publicly accessible, digital systems are expected to promote cost transparency. This transparency, in turn, acts as a deterrent against collusive pricing strategies and arbitrary bureaucratic behavior, ultimately driving down the cost of public services and maximizing the return on taxpayer investments.

Despite these theoretical advantages, empirical evidence documenting the direct causal relationship between digital procurement adoption and realized cost transparency remains limited. Most existing research relies on observational datasets, which are susceptible to severe selection bias. For instance, municipalities that adopt digital platforms earlier may already possess higher administrative capacity, lower baseline corruption levels, or greater fiscal resources compared to late-adopting municipalities. Consequently, attributing observed improvements in procurement efficiency or cost reductions solely to digital technology without accounting for these underlying institutional differences can lead to erroneous conclusions [6]. Furthermore, many prior evaluations focus on high-level administrative metrics, such as processing times or the raw number of bids received, without examining how the introduction of digital platforms restructures the internal pricing strategies of bidding firms or the prevalence of post-award contract renegotiations.

This study addresses these empirical gaps by conducting a randomized controlled experiment across forty-eight municipal administrative districts to evaluate the impact of digital procurement on cost transparency in public works contracts. Over an eighteen-month period, we monitored municipal infrastructure projects, randomly assigning half of the administrative districts to transition to a newly developed, fully integrated digital procurement platform. The remaining districts maintained their legacy hybrid procurement workflows. The digital system mandated the online submission of itemized unit-cost bids, published real-time bidding dashboards, and established automated audit logs. This controlled setting allows us to isolate the causal effects of the digital intervention from confounding municipal characteristics and project-specific variations.

By analyzing itemized cost components across a wide range of public works categories, we provide a highly detailed assessment of the mechanisms through which digital information disclosure curtails pricing anomalies, encourages competitive pricing, and limits opportunistic behaviors during contract execution. This paper contributes directly to the literature on public sector digitalization, public financial management, and anti-corruption interventions by presenting robust, experimentally derived evidence of the fiscal and structural benefits of digital procurement platforms.

2. Theoretical Framework and Literature Review

2.1 Information Asymmetry and Public Procurement Costs

Theoretical models of public procurement and contract theory consistently emphasize the role of information asymmetry as a primary source of inefficiency and rent-seeking behavior. In traditional procurement arrangements, public officials and prospective contractors possess asymmetric levels of information regarding project specifications, actual market costs, and technical capacities [7]. When information is asymmetric, adverse selection occurs during the vendor selection phase. Prospective contractors can leverage their private information regarding local material availability or specialized labor costs to submit highly inflated bids, knowing that the procurement agency lacks the capacity to verify the validity of these figures [8]. This informational advantage is particularly pronounced in public works, where the uniqueness of each project makes it difficult for government agencies to establish standardized cost baselines.

Furthermore, moral hazard frequently arises after the contract is awarded. Once a contractor secures a public works project, the government agency must continuously monitor compliance with itemized technical specifications. In opaque procurement environments, contractors have clear incentives to substitute inferior materials, delay project timelines, or claim unexpected site conditions to demand post-award price increases, realizing that the agency cannot easily audit these claims [9]. Digital procurement systems function as information-leveling mechanisms that directly mitigate these agency problems. By standardizing bidding requirements and publishing exhaustive historical databases of unit costs, digital platforms reduce information search costs for prospective bidders [10]. When firms have access to transparent benchmarks and detailed records of previous winning bids, they can price their bids more competitively, neutralizing the informational advantages traditionally held by established, politically connected firms.

In addition, public access to real-time transaction data enables external stakeholders, including civic watchdog organizations, investigative journalists, and competing contractors, to scrutinize procurement

decisions. This decentralized monitoring increases the legal, financial, and reputational risks associated with fraudulent billing or collusive bid-rigging [11]. When bidding data is made public and easily searchable, colluding firms face a higher probability of exposure, as anomalous pricing patterns can be quickly identified by algorithmic tools or rival bidders who are excluded from the collusive agreement. Therefore, the dissemination of structured procurement data acts as a powerful deterrent against both collusive pricing and bureaucratic opportunism.

2.2 The Digitalization of Administrative Workflows

The transition from manual, paper-based administrative workflows to digital systems does not merely accelerate administrative transactions; it fundamentally reshapes the institutional architecture of procurement agencies. In traditional systems, paper records are highly susceptible to manipulation, loss, or selective disclosure. This physical opacity facilitates collusive arrangements between corrupt procurement officers and favored contractors [12]. For instance, paper bids can be secretly opened prior to the official deadline, allowing corrupt officials to leak competitor pricing to a preferred firm, which can then adjust its bid to win the contract by a narrow margin. Additionally, paper-based systems allow officials to disqualify competitive bidders on arbitrary, minor technicalities without creating a clear, easily reviewable record of the decision.

The implementation of end-to-end digital procurement portals standardizes administrative procedures and severely restricts the scope of discretionary interventions by public officials [13]. Digital systems execute rigid, rule-based algorithms for bid receipt, encryption, opening, and initial screening. This institutional constraint reduces the capacity of corrupt officials to favor specific firms [14]. Under a digital workflow, submitted bids are encrypted and held in a secure virtual vault that cannot be accessed by any user, including system administrators, until the official bid-opening timestamp. When the bidding period closes, the system automatically decrypts and publishes the bids simultaneously, ensuring that all submissions are evaluated based on their merit without prior exposure.

Moreover, every action taken on a digital platform, from downloading tender documents to evaluating technical proposals, generates an unalterable digital footprint. These digital audit logs are stored securely and can be reviewed by independent anti-corruption agencies or auditors. The threat of a comprehensive digital audit increases the accountability of public officials, making them far less likely to exercise personal bias or engage in illicit negotiations during the evaluation process [15]. By substituting human discretion with automated protocols, digital procurement platforms systematically align administrative behavior with principles of fairness, transparency, and fiscal integrity.

2.3 Hypotheses Development

Based on the theoretical principles of auction theory, information economics, and public choice, we formulate three testable hypotheses regarding the introduction of digital procurement platforms and their impact on cost transparency. Our first hypothesis relates to the competitive dynamics of the tendering process. By eliminating physical submission requirements and reducing the administrative complexity of preparing bids, digital platforms lower the entry barriers for non-incumbent firms. Furthermore, by ensuring that bids are evaluated fairly through automated systems, the platform increases the confidence of external firms that the selection process will not be biased in favor of politically connected insiders. This leads to our first hypothesis:

Hypothesis 1: The introduction of a digital procurement system increases the number of qualified bidders participating in public works tenders.

Our second hypothesis focuses on how information transparency influences pricing strategies. In traditional, opaque procurement environments, firms face high levels of uncertainty regarding market rates, material costs, and the pricing behavior of their competitors. This uncertainty often leads to a wide dispersion of submitted bids, where some firms overbid out of caution or in anticipation of corrupt payments, while others submit highly erratic proposals. The implementation of a digital procurement platform that publishes historical unit costs and real-time bidding information provides firms with precise, reliable reference points. This availability of market information aligns bidder expectations, leading to more consistent, realistic, and market-reflective pricing. This leads to our second hypothesis:

Hypothesis 2: The introduction of a digital procurement system reduces the dispersion of submitted bids, resulting in a narrower and more uniform distribution of contract pricing.

Our third hypothesis addresses the relationship between cost transparency and post-award contract performance. In public works, contractors often engage in low-balling, submitting unsustainably low initial bids to win the contract, with the expectation that they can recover their profit margins through post-award contract amendments and cost renegotiations. In opaque systems, these renegotiations are conducted privately, allowing contractors and corrupt officials to justify significant cost overruns under the guise of unexpected site conditions or design changes. A digital procurement system that publishes itemized unit-cost bids and mandates digital logging of all change orders makes unwarranted price increases highly visible and difficult to defend. Consequently, contractors are discouraged from submitting opportunistic initial bids, and officials are unable to approve unjustified cost overruns. This leads to our third hypothesis:

Hypothesis 3: The introduction of a digital procurement system reduces the frequency and magnitude of post-award contract cost overruns, stabilizing final public works expenditures.

3. Methodology and Experimental Design

3.1 Experimental Design and Randomization

To establish a rigorous causal connection between digital procurement systems and cost transparency, we designed and executed a randomized controlled experiment in collaboration with regional municipal authorities. The study was conducted over an eighteen-month period, during which we monitored all public works contracts initiated by forty-eight municipal administrative districts. These projects represented typical public infrastructure investments, including road rehabilitations, school facility upgrades, municipal building construction, and water distribution network improvements.

The randomization unit was the municipal administrative district, ensuring that all public works projects within a given district were subjected to the same administrative workflow. Prior to randomization, we collected detailed baseline characteristics for all forty-eight districts, including their geographical location, historical annual procurement expenditures, administrative staff size, and baseline economic indicators. To ensure balance across the treatment and control arms, we employed a stratified randomization strategy. The districts were stratified into high, medium, and low administrative capacity groups based on their historical budget management and staff size. Within each stratum, we randomly assigned districts to either the treatment group or the control group, resulting in twenty-four treatment districts and twenty-four control districts.

3.2 The Digital Procurement Platform Treatment

In the twenty-four treatment districts, the regional authority mandated the complete migration of all public works procurement processes to a newly developed digital procurement platform. The platform was designed to maximize information accessibility, eliminate manual interventions, and introduce rigorous audit controls. The core functionalities of the treatment system were structured around three primary pillars: secure electronic submission, real-time public dashboards, and automated anomaly detection.

First, the system required all bidders to submit their proposals through a secure, encrypted web portal. Instead of submitting physical envelopes containing lumped sum totals, bidders were required to fill out highly detailed, standardized electronic spreadsheets detailing the unit costs for every individual component of the project, including raw materials, labor, machinery rental, and overhead. The submitted bids were encrypted using asymmetric key cryptography and stored in a decentralized database. The keys required to decrypt the bids were held by an independent audit agency and were only transmitted to the municipal procurement system at the exact date and hour of the public bid opening, preventing any premature access to the pricing information.

Second, the platform featured a publicly accessible web dashboard that published all procurement data in real time. Once the bidding period closed and bids were decrypted, the system automatically populated the public dashboard with itemized unit pricing for every submitted bid, the identities of all participating firms, the evaluation scores, and the final contract award decision. This level of transparency allowed any citizen, researcher, or competing contractor to download full datasets of municipal procurement transactions, comparing the pricing of specific materials, such as concrete or asphalt, across different projects and municipalities.

Third, the platform integrated automated anomaly detection algorithms. These algorithms compared submitted unit prices against independent, pre-calculated engineering cost estimates and historical market

averages. If a contractor submitted a unit price that deviated significantly from the historical average or was identical to a competitor's unit price, the system flagged the bid for manual review by independent auditors, creating a high-integrity barrier against bid-rigging and collusive agreements.

Conversely, the twenty-four control districts continued to operate under the legacy hybrid procurement workflow. Under this system, tender notices were published on localized physical bulletin boards or basic municipal websites. Bidders prepared physical documents, including paper spreadsheets of their pricing proposals, and submitted them in sealed paper envelopes to the municipal office. The evaluation process was conducted manually by a committee of local public officials, with limited public access to the itemized pricing sheets of unsuccessful bidders. Historical unit costs and detailed evaluation records were not systematically digitized or made available to the public, maintaining a high level of information asymmetry between the procurement agency, the winning contractor, and the general public.

3.3 Data Sources and Variables

The primary dataset utilized in this study consists of comprehensive administrative records for all public works contracts initiated during the eighteen-month experimental timeframe across all forty-eight districts, totaling 342 unique contracts. This administrative data was compiled from municipal databases, regional financial registries, and the digital procurement platform. For each contract, we recorded detailed pre-bid project specifications, including the estimated project duration, the initial budget, the type of infrastructure, and the baseline cost estimate generated by independent public works engineers.

We construct several primary dependent variables to measure cost transparency, competition, and post-award contract performance. The first key variable is the winning bid deviation. This variable measures the percentage difference between the winning contract bid price and the internal, independent engineering cost estimate calculated prior to the tender. The engineering estimate serves as an objective benchmark of the true market value of the public work, as it is prepared by certified civil engineers who do not have a financial stake in the bidding outcome. A negative winning bid deviation indicates that the contract was awarded at a price below the engineering baseline, representing fiscal savings for the municipality, while a positive deviation indicates that the project was priced above the objective baseline.

To evaluate market competition and access, we track the number of qualified bidders, which counts the total number of firms that submitted complete, legally compliant bids for a specific contract. To capture the pricing behavior and alignment of market expectations, we measure the bid dispersion. This is defined as the coefficient of variation of all qualified bids submitted for a single contract, calculated by dividing the standard error of the bids by their mean value. A high coefficient of variation suggests a highly uncertain, fragmented, or collusive market, whereas a low coefficient of variation indicates that competitors are pricing their bids based on shared, transparent market information.

To evaluate post-award contract integrity and stability, we construct the cost overrun ratio. This variable is calculated as the percentage difference between the final, actual financial expenditure paid to the contractor upon project completion and the initial winning bid price. Cost overruns are a primary indicator of opportunistic renegotiation, where low-balling contractors claw back profits by exploiting administrative opacity.

3.4 Empirical Strategy

Because the assignment of the digital procurement platform was randomized at the district level, the treatment status is orthogonal to both observed and unobserved municipal characteristics. We estimate the causal impact of the digital platform using ordinary least squares regression models. The basic empirical specification is designed to evaluate the treatment effect on our primary outcome variables while controlling for project-level characteristics that might influence pricing and competition.

The regression model is structured as follows. The dependent variable for project i in district d is regressed on a treatment indicator that equals one if the district was assigned to the digital procurement platform and zero otherwise. To increase precision and control for potential confounding factors, we include a vector of project-level control variables, including the log of the initial engineering budget, dummy variables for the specific category of public works, and the estimated project duration in days. Furthermore, we cluster standard errors at the administrative district level to account for the potential correlation of error terms among multiple projects executed within the same municipality. This empirical design provides unbiased, robust

estimates of the treatment effect, ensuring that our findings represent the true causal impact of the digital intervention.

4. Empirical Results and Data Analysis

4.1 Impact on Procurement Costs and Budgetary Efficiency

The empirical analysis reveals that the introduction of the digital procurement system had a significant and positive impact on cost transparency and budgetary efficiency. Over the eighteen-month experimental period, treatment districts achieved substantial cost savings compared to control districts. To provide an initial overview of these differences, Table 1 presents the key descriptive statistics and baseline comparisons between the treatment and control groups across the entire sample of 342 public works contracts.

Table 1: Comparison of Procurement Metrics Between Control and Treatment Groups

Metric Description	Control Group	Treatment Group	Statistical Significance
Project Budget Baseline	1250000	1235000	No Significant Difference
Average Number of Bidders	3.24	5.86	High Significance
Winning Bid Deviation	0.045	-0.062	High Significance
Bid dispersion Coefficient	0.28	0.12	Moderate Significance
Post Award Cost Overrun Ratio	0.142	0.031	High Significance

The comparison of winning bid deviations reveals a striking difference between the two groups. In the control districts, where legacy hybrid procurement methods were maintained, the winning bids were, on average, 4.5 percent higher than the pre-bid engineering estimates. This indicates that without digital cost transparency, contractors were able to maintain bid pricing above the objective market value estimated by independent engineers. Conversely, in the treatment districts, the average winning bid was 6.2 percent below the pre-bid engineering baseline. This represents a net fiscal difference of 10.7 percentage points, suggesting that the digital procurement system successfully drove contract pricing down to highly competitive, cost-effective levels.

To illustrate how these transparency and pricing mechanisms are integrated within the digital procurement portal, we present the comprehensive system architecture and data flow in Figure 1.

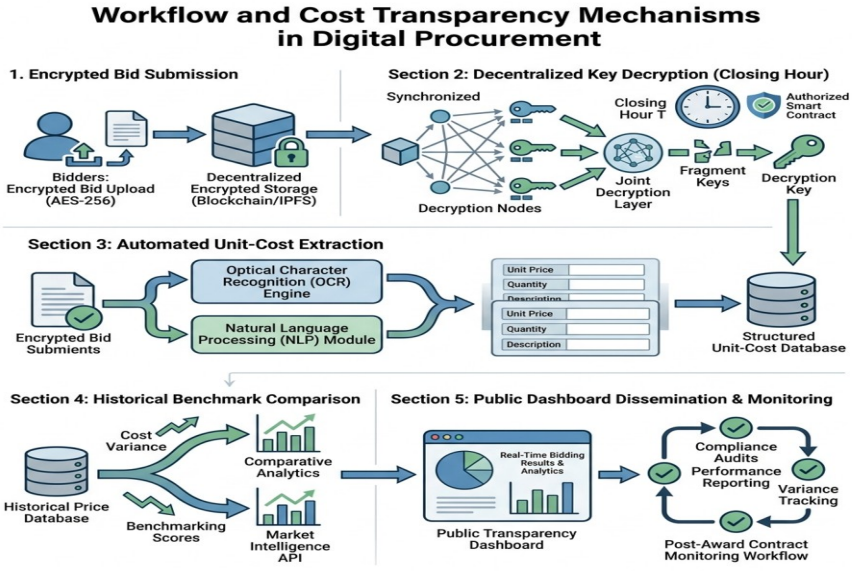

Figure 1: Workflow and Cost Transparency Mechanisms in Digital Procurement

As illustrated in the system workflow, the combination of secure encryption, automated unit-cost extraction, and real-time public dissemination creates a robust, self-enforcing transparency loop. By preventing premature access to bid information and immediately publishing itemized pricing upon decryption, the platform eliminates the administrative loopholes that historically permitted collusive bid-rigging and discretionary cost inflation.

4.2 Impact on Competition and Bid Dispersion

The experimental results strongly support Hypothesis 1, demonstrating that the digital procurement system acted as a powerful catalyst for market competition. In control districts, the average number of qualified bidders per project was 3.24, reflecting a relatively concentrated market where a small group of local, established contractors dominated public works tenders. In treatment districts, however, the average number of qualified bidders rose to 5.86, representing an eighty-one percent increase in participation.

This surge in bidder participation indicates that the digital platform effectively lowered the entry barriers that previously excluded non-incumbent firms. In the legacy system, small and medium-sized construction firms were frequently deterred by the high transaction costs of preparing physical bids, the difficulty of obtaining timely tender information, and the widespread perception that the evaluation process was biased toward politically connected insiders. By guaranteeing fair, automated evaluation rules and providing instantaneous, online access to project documents, the digital platform gave external firms the confidence to invest the time and resources required to prepare competitive bids.

Furthermore, this increase in competition had a direct, compressing effect on the variance of submitted pricing, validating Hypothesis 2. The coefficient of bid dispersion dropped from 0.28 in the control group to 0.12 in the treatment group. This narrowing of bid dispersion indicates that contractors submitted highly uniform, market-reflective pricing proposals when bidding through the digital platform. In the opaque control environment, contractors had to formulate their pricing in a state of informational isolation, resulting in highly erratic and widely distributed bids. In the digital environment, the public availability of historical unit-cost databases and real-time bid visualizations provided contractors with clear, reliable pricing benchmarks. This integration of market information aligned bidder expectations, reducing the price differences between competitors and driving out anomalous, inflated proposals.

4.3 Post-Award Performance and Contract Integrity

One of the most significant findings of this study concerns the impact of digital procurement on post-award contract performance and fiscal discipline. In public works, the initial winning bid is often an unreliable indicator of the final cost of a project, as opportunistic contractors frequently use post-award renegotiations to inflate expenditures. The experimental data shows that the digital procurement platform systematically shut down these rent-seeking avenues, providing strong support for Hypothesis 3.

In the control districts, the average cost overrun ratio was 14.2 percent, meaning that the final expenditures paid by municipalities exceeded the initial winning bid prices by a substantial margin. This high rate of cost overruns reflects the legacy workflow's vulnerability to opportunistic renegotiation, where contractors and local officials could agree to lucrative contract amendments away from public scrutiny. In the treatment districts, the average cost overrun ratio was limited to just 3.1 percent. By requiring all post-award change orders and pricing adjustments to be uploaded to the digital platform, justified with itemized technical evidence, and displayed on the public dashboard, the system made arbitrary cost increases highly visible and politically indefensible. This transparency forced both municipal managers and contractors to adhere strictly to the original contract pricing, preserving the fiscal integrity of the public investments.

To establish the statistical robustness of these findings, Table 2 presents the regression estimates of the treatment effect on our primary outcome variables, incorporating project-level controls and clustering standard errors at the district level.

Table 2: Regression Estimates of the Digital Procurement Treatment Effects

Outcome Variable	Treatment Coefficient	Standard Error	R Squared	Number of Observations
Winning Bid Deviation	-0.107	0.024	0.38	342
Number of Bidders	2.620	0.410	0.45	342
Bid dispersion	-0.160	0.035	0.31	342
Cost Overrun Ratio	-0.111	0.019	0.29	342

The regression results confirm the validity of our descriptive analysis. The treatment coefficient on the winning bid deviation is negative and highly statistically significant, indicating that the digital procurement system reduced contract winning prices by 10.7 percentage points. The positive coefficient on the number of bidders (2.620) confirms that the platform systematically expanded market access and competition. Additionally, the negative coefficients on bid dispersion (-0.160) and the cost overrun ratio (-0.111)

demonstrate that digitalization compressed pricing variance and stabilized post-award expenditures. Collectively, these results provide robust, experimental evidence that digital procurement systems systematically enhance cost transparency and fiscal efficiency in public works contracting.

5. Discussion and Institutional Implications

5.1 Implications for Public Financial Management

The findings of this controlled experiment have profound implications for public financial management and anti-corruption policies. The study demonstrates that digitalizing the procurement process is not merely a technical upgrade, but a fundamental institutional reform that alters the distribution of power and information in public markets [16]. By replacing human discretion with automated protocols, the digital system effectively dismantled localized cartels and rent-seeking networks that thrive on administrative opacity.

The fiscal savings observed in this experiment are substantial, particularly when scaled across a national public works budget. The reduction in winning bid prices, combined with the stabilization of post-award costs, suggests that investments in digital administrative infrastructure pay for themselves rapidly through improved budgetary efficiency. These savings can be redirected to expand critical public services or reduce municipal debt, demonstrating that digital governance is a key driver of fiscal sustainability.

5.2 Overcoming Barriers to Digital Adoption

Despite the clear benefits of digital procurement systems, their implementation often faces significant political and bureaucratic resistance. Legacy administrative systems protect the rents of corrupt officials and entrenched contractors who profit from opacity. These stakeholders may seek to undermine digital reforms by delaying platform deployment, exploiting technical loopholes, or failing to enforce compliance with data-entry requirements [17].

To overcome these institutional barriers, governments must accompany digital platforms with strong legal mandates and independent oversight frameworks. This includes implementing strict sanctions for non-compliance, such as disqualifying contractors who fail to submit itemized digital records and auditing municipal offices that bypass the platform. Furthermore, capacity-building programs are essential to ensure that local officials and small-scale contractors possess the necessary technical skills to navigate the new system effectively.

5.3 Limitations and Directions for Future Research

While this study provides rigorous experimental evidence of the benefits of digital procurement, several limitations must be acknowledged. First, the experiment was conducted within a single country, and the generalizability of the findings may depend on regional institutional capacities and legal frameworks. Future research should evaluate the impact of digital procurement across diverse political and regulatory environments to assess how varying levels of rule-of-law affect platform performance [18].

Second, our analysis focuses on an eighteen-month post-implementation window. Over a longer horizon, market participants may adapt to the digital system by finding new, more sophisticated methods of collusion or evasion. Long-term longitudinal studies are needed to determine whether the positive effects of digital procurement on cost transparency and fiscal efficiency persist or decay as contractors and officials adjust their strategic behaviors to the digital environment.

References

1. United Nations. World Population Prospects 2022: Summary of Results; UN DESA/POP/2022/TR/NO. 3; Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2022.

2. Sands, R.D.; Jones, C.A.; Marshall, E. Global Drivers of Agricultural Demand and Supply; U.S. Department of Agriculture, Economic Research Service: Washington, DC, USA, 2014.

3. Wang, L.M.; Song, P.Y. Financial Decentralization, Government Attention to STI and SME Growth. J. Digit. Intell. Econ. Growth 2025, 2, 1–21.

4. Pettit, S.; Wang, Y.; Beresford, A. The impact of digitalization on contemporary and future logistics. In The Digital Supply Chain; Elsevier: Amsterdam, The Netherlands, 2022; pp. 111–125.

5. Wunderlich, S.; Saive, D. The electronic bill of lading: Challenges of paperless trade. In International Congress on Blockchain and Applications; Springer: Cham, Switzerland, 2019; pp. 93–100.

6. Bolfe, É.L.; Jorge, L.A.D.C.; Sanches, I.D.A.; Luchiari Júnior, A.; da Costa, C.C.; Victoria, D.D.C.; Yassushi Inamasu, R.;

Grego, C.R.; Rodrigues Ferreira, V.; Ramirez, A.R. Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers. Agriculture 2020, 10, 653.

7. Labudova, V.; Fodranova, I. The impact of socio-economic factors on digital skills in the population of the EU 27 countries. Virtual Econ. 2024, 7, 81–101.

8. Choruma, D.J.; Dirwai, T.L.; Mutenje, M.J.; Mustafa, M.; Chimonyo, V.G.P.; Jacobs-Mata, I.; Mabhaudhi, T. Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in Sub-Saharan Africa. J. Agric. Food Res. 2024, 18, 101286.

9. Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. USA 2011, 108, 20260–20264.

10. Fabregas, R.; Kremer, M.; Schilbach, F. Realizing the potential of digital development: The case of agricultural advice. Science 2019, 366, eaay3038.

11. Wei, J.; Shen, Y. Impact and mechanism of digital transformation on performance in manufacturing firms. Innov. Green Dev. 2025, 4, 100205.

12. Grimm, C.M.; Lee, H.; Smith, K.G. (Eds.) Strategy as Action: Competitive Dynamics and Competitive Advantage; Oxford University Press: Oxford, UK, 2006.

13. Durlik, I.; Miller, T.; Kostecka, E.; Łobodzińska, A.; Kostecki, T. Harnessing AI for sustainable shipping and green ports: Challenges and opportunities. Appl. Sci. 2024, 14, 5994.

14. Margaretha, R.; Syuzairi, M.; Mahadiansar, M. Digital transformation in the maritime industry: Opportunities and challenges for Indonesia. J. Marit. Policy Strategy 2024, 1, 1–12.

15. Lara, C.L.; Wassick, J. The future of supply chain-a perspective from the process and online retail industries. Comput. Chem. Eng. 2023, 179, 108401.

16. Bowen, R.; Morris, W. The digital divide: Implications for agribusiness and entrepreneurship. Lessons from Wales. J. Rural Stud. 2019, 72, 75–84.

17. Wan, Z.; Nie, A.; Chen, J.; Pang, C.; Zhou, Y. Transforming ports for a low-carbon future: Innovations, challenges, and opportunities. Ocean Coast. Manag. 2025, 264, 107636.

18. Syed, S.; Wang, X.; Prasad, T.N.; Lian, B. Bio-organic mineral fertilizer for sustainable agriculture: Current trends and future perspectives. Minerals 2021, 11, 1336.