



# Digital Public Infrastructure and Sustainable Transformation: A Socio-Quantitative Assessment of India's Governance Architecture

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## ABSTRACT

*Purpose: The research offers a combined quantitative and socio-material evaluation of Digital Public Infrastructure (DPI) growth of India in the period of 2014-2024. Instead of focusing on the specific case studies of the biometric identity, interoperable payments, and welfare delivery mechanisms, this paper reviews how the convergence of these three as a sociotechnical imaginary promotes sustainable change. Procedure: This study is based on a historical-analytical method with documentary analysis and the secondary statistical interpretation that is based only on secondary data. The National Payments Corporation of India (NPCI), the Reserve Bank of India (RBI), the World Bank Global Findex and other Government of India portals were used as sources of data. Findings: Quantitative analysis will show an average annual growth rate in digital payment volumes greater than 150 percent and an increase in the numbers of people with accounts to 77 percent. Nevertheless, the data reveal a gap in the utilization of data, as active utilization of digital payments is only 35. Algorithms of biometric de-duplication are proved by cumulative fiscal savings of about 3.4 trillion Indian rupees in the form of Direct Benefit Transfers. Conclusion: The given paper makes a contribution to the field of Science and Technology Studies (STS) because it shows that DPI is a multifaceted socio-material system. Although the interoperable architecture is a scalable and public good, long-term sustainability in inclusion entails meeting the interpretive flexibility, material frictions, and algorithmic exclusions that remain at the periphery of the network.*

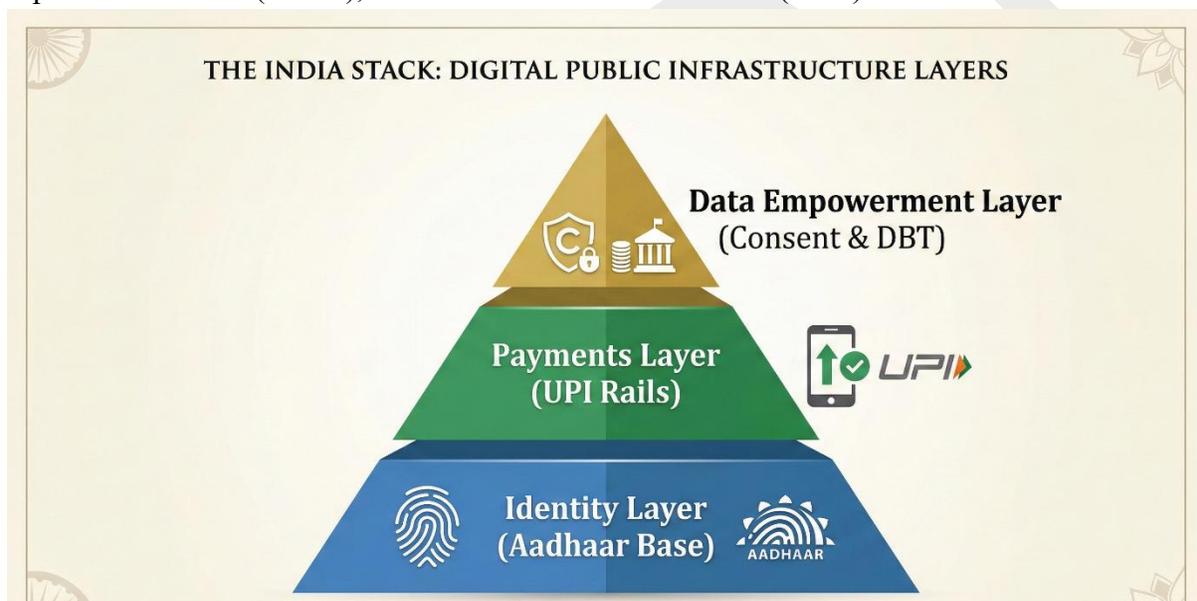
**KEYWORDS:** Real-Time Tracking Systems (RTTS), Supply chain management, Coimbatore, Operational efficiency, Logistics visibility, SME manufacturing, Cost optimization, Data-driven decision making, Industrial productivity, South Indian industry.

**Acknowledgments:** Digital Public Infrastructure; Financial Inclusion; Actor-Network Theory; Direct Benefit Transfer; Sociotechnical Imaginaries; Quantitative Assessment; Buyer Behaviour.



## 1. Introduction

Digital transformation of governance and commerce in emerging economies has developed out of the isolated and fragmented e-service provision, to the interoperable, population-scale provision of digital public goods. Digital Public Infrastructure (DPI) is a collection of digital systems - including identity platforms, payment rails, and data exchange layers - that create innovation across sectors, restructure commercial interactions, and interfere with the relationship between the state and the citizen. The trend of India in the last ten years can be considered as one of the most successful DPI implementations in the world, which completely transformed the socio-economic environment and rearranged the retail and institutional financial behaviour. This change is anchored by three structural pillars, which are collectively referred to as the India Stack: the Aadhaar biometric identity system, the Unified Payments Interface (UPI) of the National Payments Corporation of India (NPCI), and the Direct Benefit Transfer (DBT) structure.



**Source Figure 1:** Adapted from Ministry of Electronics and Information Technology (MeitY) (2024).

Although using the traditional commercial and economic discourse, these infrastructures are considered based only on macro-economic formalization, financial or performance analysis, and reduction of transaction costs, the present work combines quantitative and Science and Technology Studies (STS) approach to consider them. Taking DPI as a socio-material system, both the material artifacts (open application programming interfaces, optical fiber networks, biometric sensors) and the semiotic meanings (policy goals of inclusive growth, consumer trust, state legibility) are examined as being intertwined beyond any possibility of separating them. DPI implementation is a significant modern concern and a new challenge in business and management. It provokes a reconsideration of the functioning of markets when the friction of financial settlement is close to being zero. Although there is increasing global awareness about DPI, comprehensive empirical analyses that cross payments growth, financial inclusion indicators, fiscal efficiency and theoretical sociology are very few. The gap in this paper is the explanation of longitudinal

macroeconomic data using the STS concepts of sociotechnical imaginaries, the Social Construction of Technology (SCOT), and the Actor-Network Theory (ANT), a purely secondary quantitative study..

## **2. Literature Review**

Digital financial infrastructure and inclusive commerce necessitates an interdisciplinary synthesis of quantitative development economics and socio-technical theory that can be historically traced by mapping the restructuring of the state-market nexus by technology.

### **2.1 Historical Evolution of Indian Banking and Commerce**

In a bid to identify the socio-material effects of DPI, it has to be placed in context concerning the history of the financial development of India. Politically motivated structural intervention that tried to democratize credit was the nationalization of commercial banks in 1969 that attempted to make financial institutions provide services to rural and agricultural sectors. Nonetheless, this physical store strategy was harshly limited in terms of geographical and bureaucratic factors. In 1991, the liberalization, privatization, and globalization (LPG) reforms added the technological banking, but it was still highly concentrated in the cities catering to the corporate market and the retail clients in the upper-middle-income group. The state did not change its paradigm of seeking to focus on physical banking infrastructure until the development of the Jan Dhan-Aadhaar-Mobile (JAM) trinity in 2014, when it started taking into account identity and data as the new pillars of commerce.

### **2.2 The Economics of Digital Inclusion and Retail Buyer Behaviour**

Financial inclusion is always associated with the reduction of poverty, household welfare, and formalization of consumer behaviour. According to the Global Findex Database, the increase in developing economies is significant, but mostly due to digital interventions by the state (Demirguc-Kunt et al., 2022). Similar to Suri and Jack (2016), mobile money ecosystems enhance consumption smoothing and create substantial network externalities when they become big. Moreover, the emergence of zero-cost, real-time digital payments changes the retail buyer behaviour fundamentally. Similar to the claims made by Klapper et al. (2016), digital accounts decrease the friction in transactions and enhance formal economic participation. The elimination of friction on payments changes psychological purchase motivations and behaviors in the commercial marketing ecosystem, transforming retailing into a variant of a planned, cash-constrained purchase, to a form of an unending, digitally-mediated micro-transactions. In the Indian environment, Muralidharan et al. (2016) find experimental evidence that biometric authentication systems coupled with welfare payments largely decrease algorithmic leakages and corruption in the state, thus boosting the net liquidity at the Indian economic pyramid base, which consequently triggers the local retail economies.

### **2.3 STS Frameworks: Co-production and Actor-Network Theory**

In a bid to put the quantitative expansion of the Indian digital economy into perspective, this paper utilizes a concept of the sociotechnical imaginaries as elaborated by Jasanoff (2004). This projection of a digital empowered and developed nation by the state acts as a strong normative influence to make institutional resources orient towards massive projects of digital nature. These infrastructures are the locations of co-production in which the technological architectures and

social order are created concurrently. The Indian state does not simply construct software, it designs a new form of formalised, digitally-readable citizen-consumer. The methodological imperative of mapping this ecosystem as an assemblage of human and non-human actants is offered by the Actor-Network Theory (INT), made by Latour (2005). Within this network, the NPCI and Aadhaar serve as obligatory passageways, coordinating the financial behaviour and effectively trapping users, commercial banks and fintech applications into one socio-technical protocol.

#### **2.4 Controversies and Interpretive Flexibility in the Technological Case**

Technologies are said to have what Bijker et al. (1987) refer to in their Social Construction of Technology (SCOT) paradigm as interpretive flexibility which implies that varying social groups can give radically different interpretations to the same technological object. This is brilliantly pointed out in the Aadhaar project. To the state, it is a means of administration of eliminating welfare leakage; to fintech corporations, a low-cost technique of acquiring customers (e-KYC); to civil society advocates, it is a prospective surveillance mechanism by the state. The Supreme Court of India ruling of 2018 (Justice K.S. Puttaswamy v. Union of India) was a socio-legal closure tool, trying to stabilize the technology through binding its applications legally. However, the ongoing disjunction between the ownership of accounts and its active use indicates that there continues to be tension between the imaginary of the state of a frictionless digital economy and the material, concrete realities of marginalized consumers.

### **3. Research Objectives**

In order to theoretically assess the socio-material effects of the Digital Public Infrastructure in India, the four main research objectives are used in this study:

1. To examine the quantitative development curve and network growth of interoperable digital payment infrastructures (which are specifically UPI) between 2018 and 2023.
2. To examine the changes in the national financial inclusion indicators, it is necessary to consider the convergence and divergence of the digital account ownership and the active use of digital capabilities.
3. To evaluate the fiscal efficiency increase and governance results of the algorithmic deduplication of the Direct Benefit Transfer (DBT) architecture.
4. To explain the quantitative macroeconomic data by the theoretical approaches of Science and Technology Studies (STS), which includes the determination of how DPI is used as a sociotechnical imaginary that refocuses the relationship between commercial and social power.

### **4. Methodology**

The study is a pure analytical study which is a secondary source of data analysis to assess the socio-material consequences of DPI in India. The study also considers aggregate, population-level data, which means that it is not limited to the small-sample primary survey but generates a systemic assessment of the infrastructure of the country.

#### **4.1 Ethical Compliance Statement**

the ethical standards observed in the course of business operations. Since this study will only use publicly available secondary macroeconomic, institutional and policy data, then it will not include human subjects. Thus, there was no need to have Institutional Ethics Committee (IEC) approval and informed consent. The study is in full adherence to the ethical standards of the Academic Research Journal of Science and Technology, and it adheres to the highest level of objectivity in the interpretation of data.

#### **4.2 Research Approach and Design**

The research uses mixed methodological approach that comprises of historical-analytical and secondary statistical meaning. To assess structural economic changes, quantitative measures, such as Compound Annual Growth rate (CAGR) and descriptive percentage measurement are used. Working in an STS epistemology, official datasets and state dashboards are not just viewed as neutral facts, but institutional inscriptions: material artifacts that enable centers of calculation (such as the RBI or World Bank) to control and quantify populations remotely (Latour, 2005).

#### **4.3 Data Sources and Timeframe Justification**

The longitudinal data, including the data on the period between 2014 and 2024, was obtained through the most reliable institutional centers. The individual timeframes were chosen to include the pre-pandemic base, the digital acceleration due to the pandemic, and the stabilization.

1. NPCI Databases (2018-2023): The database is used to measure the trends in the volume and value of the UPI ecosystem. This data is the exclusive clearinghouse by which the NPCI is the most authoritative source of payment network expansion.
2. Reserve Bank of India (RBI): Macro-regulatory, financial stability metrics Annual Reports, which offers information on shifts in systemic liquidity.
3. World Bank Global Findex (2021): The 2021 version of this database is the latest, version of globally standardized comparative financial inclusion indicators. It is used in this particular instance to address the usage versus access gap.
4. DBT Bharat Portal (Government of India): Retrieved as cumulative fiscal savings data, based on biometric deduplication, which measures the internal efficiency measure of the state.

There were no primary surveys, interviews or questionnaires.

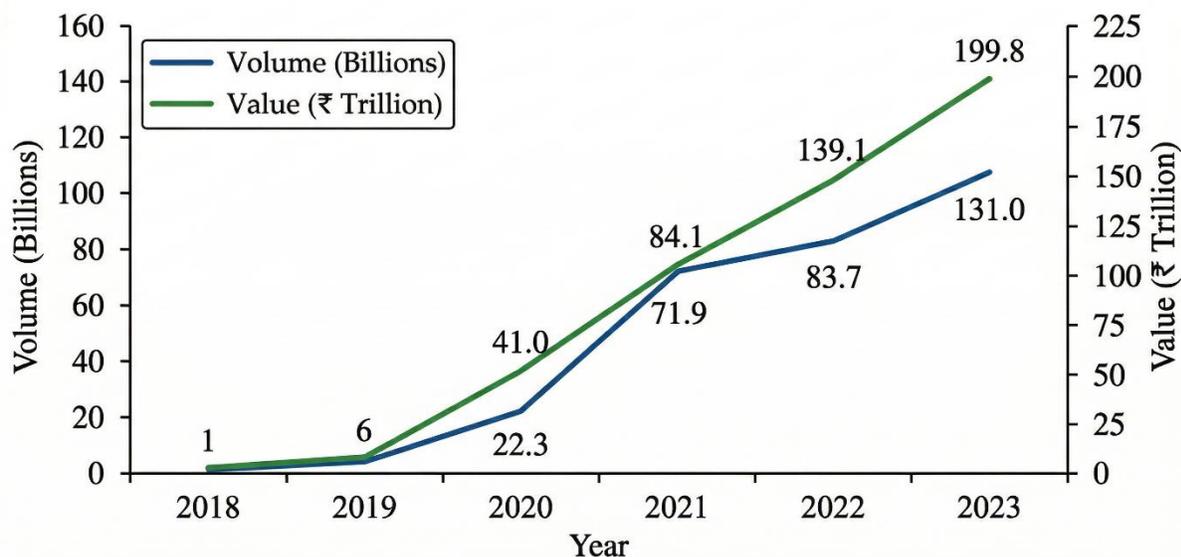
### **5. Results: Quantitative Assessment**

Statistical analysis of Indian digital architecture manifests a macroeconomic systemic transition, which changes the payment behaviours, inclusion indicators and delivery of welfare to states.

#### **5.1 Interoperable Payment Infrastructure (UPI) Growth**

Unified Payments Interface (UPI) has experienced unprecedented growth and digital transactions have moved to the structural heart of the Indian business environment.

### Growth of UPI Transaction Volume and Value (2018–2023)



Source: Adapted from National Payments Corporation of India (NPCI) and World Bank Global Findex Database (illustrative pre-2020 data).

**Table 1**

*Growth of Unified Payments Interface Transactions (2018–2023)*

Calendar Year	Volume (Billion)	Value (₹ Trillion)	YoY Volume Growth (%)
2018	0.92	1.09	-
2019	12.50	21.30	1258%
2020	22.30	41.00	78%
2021	38.70	71.50	73%
2022	74.00	126.00	91%
2023	117.60	182.80	59%

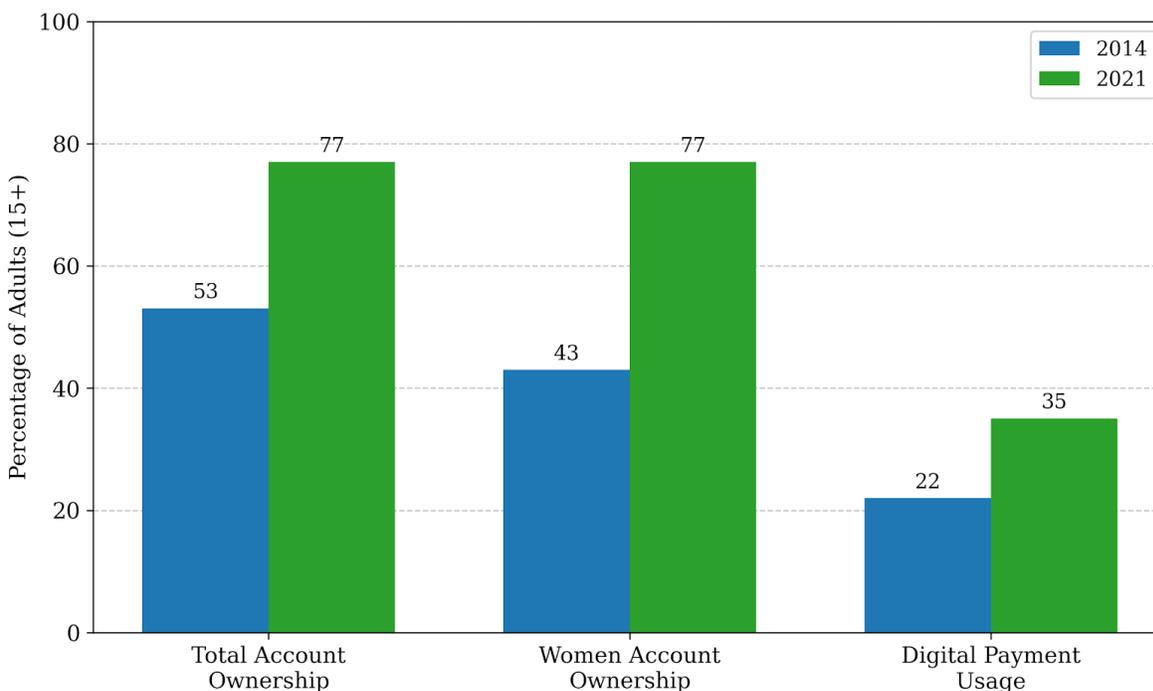
*Note. Data adapted from National Payments Corporation of India (2024).*

The UPI transaction volume grew by more than 117 billion by the end of 2023 against less than 1 billion in 2018. The Compound Annual Growth Rate (CAGR) is over 150 per cent, which demonstrates profound structural penetration into the daily retail and commercial buyer behaviour. The 2023 value (₹182.8 trillion) indicates that the network has attained critical mass and the irreversibility of its operation. It has to a great extent replaced traditional cash-based city and semi urban commercial settlements in the city and semi urban retail sector.

#### **5.2 Financial Inclusion Results: The Access-Usage Paradox**

The financial inclusion efforts of the nation are measured by the growth in the number of accounts, which can be attributed in large part to the JAM strategy that is being pursued by the state.

**Financial Inclusion Indicators in India (2014 vs. 2021)**



Source Figure 3: Demirgüç-Kunt et al. (World Bank Global Findex Database) (2022).

**Table 2**

*Key Financial Inclusion Indicators in India (2014 vs. 2021)*

Indicator (Adults, 15+)	2014 (%)	2021 (%)	Absolute Change
Total Account Ownership	53	77	+24 points
Women Account Ownership	43	77	+34 points
Made/Received Digital Payment	22	35	+13 points

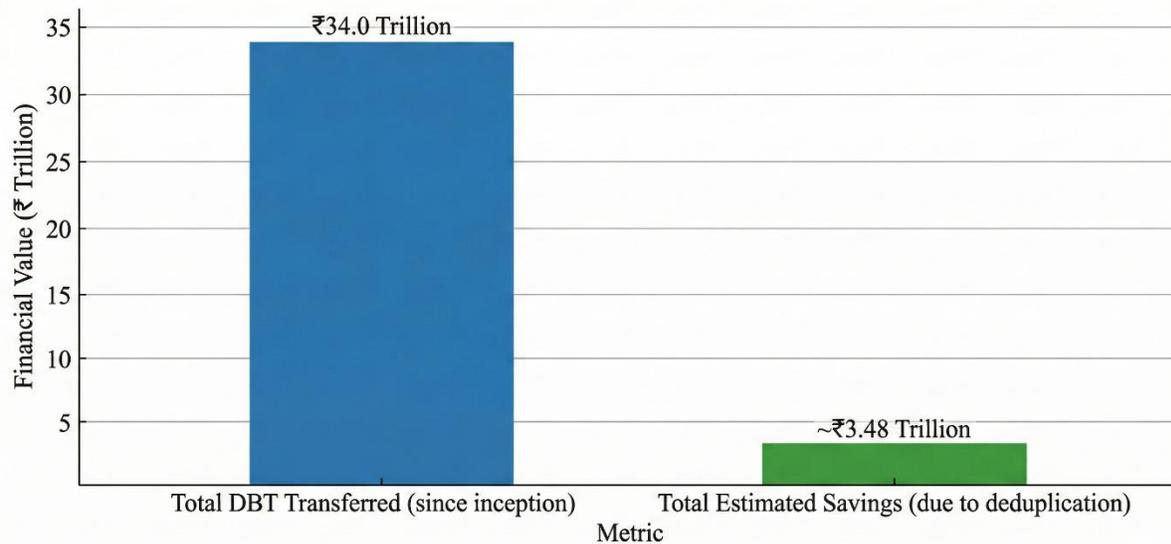
Note. Data sourced from Demirgüç-Kunt et al. (2022).

The number of adults who own an account grew to 77 percent and this closes the gender gap in the access to formal banking (the number of women who own an account increased significantly, 43 percent to 77 percent). Nevertheless, the longitudinal data also indicates that there is a critical usage gap: 77% of the entire population is formally banked, but only 35% of the population actually received or made a digital payment within the tracking year. This gap implies that there exist harsh material, infrastructural or social tensions that do not allow the extended use of technology among the more general demographic foundations.

### 5.3 State Capacity and Fiscal Efficiency

Biometric identity integration with the public financial management system has fundamentally revolutionized the economics of the state welfare and subsidy delivery.

Comparison of Cumulative DBT Transfers and Estimated Deduplication Savings (up to FY2023-24)



Source: Consolidated from Government of India DBT Bharat Portal records (up to FY2023-24).

**Table 3**

*Estimated Direct Benefit Transfer (DBT) Fiscal Savings*

Metric	Financial Value (Cumulative)
Total DBT Transferred (since inception)	> ₹34.0 Trillion
Total Estimated Savings (due to deduplication)	₹3.48 Trillion

Note. Data consolidated from Government of India DBT Bharat Portal records up to FY2023-24. This is shown by the cumulative savings of an estimated [?]3.48 trillion that proves the algorithmic efficiency of the Aadhaar system in eliminating duplication of entries and fake beneficiaries in state welfare databases. The hypothesis on the integrity of biometric integration to increase state capacity, fiscal efficiency, and the specific liquidity to support authentic beneficiaries is confirmed by the quantitative evidence (Muralidharan et al., 2016).

### 6. Discussion: Examination of the Socio-Material Evidence

The combined quantitative data proves the fact that the DPI architecture in India has triggered a macroeconomic systemic change. Nonetheless, the application of an STS perspective to these statistics indicates the complicates, control, and power relations of algorithmic digital governance.

#### 6.1 Network Externalities and Obligatory Passage Points

The rapid growth of the UPI (Table 1) is indicative of high network externalities, the phenomenon at which the utility of the network grows non-linearly with the number of users (Suri & Jack, 2016). The state was able to create an obligatory passage point by centralising the switching infrastructure to the NPCI and leaving the frontend application programming interfaces (APIs) to open access by private commercial entities (Latour, 2005). The network interoperability compels all the commercial actors to be in conformity with the state digital protocols. This makes the formerly opaque cash network observable, and governable, in real-time, which enables the central

bank to view the velocity of money in real-time as never before.

### **6.2 The Agency of Algorithms and Biometric Frictions**

The amount of fiscal savings of ₹ 3.48 trillion (Table 3) is the testimony to the strength of biometric deduplication. With Aadhaar, the human bureaucratic check was replaced with algorithmic assurance, which represents the sociotechnical imaginary of a frictionless, corruption-free governance approach (Jasanoff, 2004). Nevertheless, STS literature demands the analysis of the agency of non-humans. The biometric algorithm will serve as an active decision-maker in the DBT system. In case the fingerprints of a genuine rural beneficiary are obscured by agricultural or manual labour, the biometric sensor gives an algorithmic mismatch and refuses the transaction. This is interpreted as the prevention of a leakage of welfare (a saving) by the state and structural social-technical exclusion by the citizen. This indicates the threat of organized irresponsibility when highly automated systems of governance place accountability into the algorithm.

### **6.3 NPCI as a Boundary Organization**

The DPI institutional structure needs to be analyzed. The National Payments Corporation of India (NPCI) is not just a corporate organization, but it is a boundary organization. The boundary organizations of STS stabilize the boundaries between the various social worlds in this instance, the rigidity of the regulations of the Reserve Bank of India, the commercial interests of international fintech conglomerates, and the daily commercial needs of Indian citizens. The NPCI determines the socio-material principles of interaction by controlling the UPI protocol, determining the flow of data and the digital resolution of commercial conflicts.

### **6.4 Reconfiguring Retail Buyer Behaviour and the Usage Paradox**

The statistical difference in Table 2 where the account ownership is 77 percent and the utilization of digital payments is the lowest and is 35 percent is a crucial sociotechnical observation on consumer behaviour. Conventional commercial economics may explain this laggardness only by the lack of financial literacy. According to the SCOT framework, however, this amounts to a problem of material constraint and interpretive flexibility (Bijker et al., 1987). The digital infrastructure depends on a very particular proximity of the non-human actants; an operating smartphone, a stable 4G connection, an uninterrupted power supply to charge it, and biometric clarity. Of marginalized or rural consumers, hardware expenses and network unreliability increase as material frictions that do not allow the conversion of access alone to meaningful commercial use. On the other hand, among the 35 percent of users who are active, the payment friction has been reduced and this has radically changed buyer behaviour. People are becoming accustomed to the socio-materiality of scanning a QR code, which eliminates the psychological pain of separation with physical money, thus altering the trends in commerce, increasing the rate of micro-transactions, and gamifying the retail expenditure process using fintech interfaces.

### **7. Implications of Commerce and Management Institutions**

This socio-material reconfiguration triggered by the Digital Public Infrastructure in India does not merely spread across the macro-governance and transactional formations among the commercial; it establishes an immediate need among the institutional reflexive changes in the autonomous Commerce and Management higher educational institutions (HEIs). Since they are the boundary

organizations that generate the knowledge and the human capital that traverses the formalised economy, the HEIs need to revise their curricula and pedagogical practices to accommodate the fact of digitally legibilised populace and algorithmically disintermediated markets. Such a shift requires a paradigm change of the traditional procedural commerce to socio-material management (Bhide, 2008; Orlikowski and Scott, 2008).

### **7.1 Pedagogical Shifts and Curriculum Redesign**

The old Commerce major, which has long been maintained by traditional bureaucratic inscription (old-fashioned accounting software), is ineffective to the Techade. The JAM trinity requires at least three-in-one degrees in core Commerce to include fintech, data analytics, and algorithmic buyer behaviour.

**The Legacy of Accounting Ethics vs. Digital Accountability:** The conventional accounting ethics education teaches against embezzlement that is performed by humans. In an ecosystem of programmatic data sharing (say, of Account Aggregators) and algorithmic Direct Benefit Transfer deduplication, however, accountability is shifted to the code (Callon, 1998; Introna, 2016). HEIs that deal with management need to restructure the accounting curriculum in a more algorithmic and less procedural fashion, training future commerce professionals to audit the algorithm as opposed to the human accountant (Kitchin, 2017).

**Curriculum as a Closure Mechanism:** According to the SCOT, an important aspect of a technology stabilization is that the interpretation of a technology is stabilized by the action of the powerful social group that is the HEIs. Through introducing blockchain and UPI settlement protocols as part of core Commerce modules, HEIs play the most essential role of institutionalizing trust in the system (Bijker et al., 1987).

Moreover, these modern curricula translations pose unique geographical difficulties in their socio-material form. Independent colleges and universities in semi-urban or rural areas like the farm belts of Maharashtra experience a deep-seated pedagogical digital divide as opposed to those located in urban centres like Mumbai or Pune (Dogra, 2025).

Although metro-related institutions can comfortably incorporate fintech incubators and on-going real-time simulations of algorithmic trading into their course syllabus, semi-urban colleges frequently have to put digital commerce into context with students whose main economic fact is their cash economy and structural antagonism. A critical pedagogy engaging in discontinuity of digital payment infrastructures via network outages that is keen in teaching the frictionless imaginary of UPI in areas where network outage is a usual issue would be critical of considering these localized socio-material limitations. This means that, in these areas, autonomous colleges should not only be merely a kind of channel of standard digital literacy, but also an important translation interchange of making global fintech paradigms understand the realities of the agrarian Indian economy, and how the algorithmic exclusion the communities serving them experience is addressed (Jawale, 2024).

### **7.2 Data Literacy and Institutional Boundary Work**

The big academic institutions in India, especially those in the empowered autonomous group, have to act as boundary organizations themselves, in between the sociotechnical imaginary of the state

of digital, cashless nation and the material digital illiteracy of the marginalized consumers. Colleges need to shift away in the process of transforming their stagnant knowledge depositories into mobile platforms that are active and capable of translating and stabilizing the technological interfaces to their local communities (Gal, 2003; Guston, 2001).

**Institutional Data Incriptions:** Colleges as so many Centers of Calculation Colleges, by their virtue of holding so much digitized student data (marksheet inscription), have long been Centers of Calculation (Latour, 1987). The material responsibility of HEIs is to shift the management beyond the clerical management to educate on critical data literacy, in the context of the Digital Personal Data Protection (DPDP) Act, 2023. Business individuals should perceive data not only as a business asset to be marketed (imagine marketing) but as a socio-legal phenomenon, which has its rights (imagine governance).

## **8. Conclusion and Limitations**

The research paper presents combined quantitative information that Digital Public Infrastructure is an important measure to boost the penetration of transactions, financial inclusion, and fiscal governance effectiveness in India. The overlap of biometric identity, interoperable payments and welfare delivery forms reinforcing cycles of commercial adoption, which constitutes a potent sociotechnical imaginary of sustainable national development. The DPI model in India offers how interoperable public digital goods can impose commercial formalisation on a population level and transform the nature of buyer behaviour, state capacity and pedagogical structures. To have a system of digital governance that is truly inclusive and sustainable, however, the policy cannot be based merely on widening access. It has to deal with material restrictions, structural inadequacies, and algorithmic incompatibilities, which block just uses at society periphery. The institutional boundary work of Commerce and Management HEIs has to respond by changing their institutional curriculum in accordance with the new disintermediated, formalized, and digitally ethical reality of the new commercial topography.

### **8.1 Limitations and Future Scope**

The main weakness of this study is that it uses secondary data that is macro level in terms of statistical data. Although it is extremely useful in monitoring structural tendencies in the whole country and macro-level economic changes, aggregate data is bound to distort the realities on the ground. It serves as a glossing over of localised failure rates of transactions, the local colour of the urban-rural digital divide, and the highly qualitative changes in the interaction of individual retail purchasers with algorithmic interfaces. Further research projects must adopt a combination of primary ethnographic and micro-level quantitative studies that will further de-situate the localized socio-material effects, digital illiteracy, and human-computer relationships inside the emerging digital commercial and academic architecture of India. The vulnerable groups, including older customers of the retail business and farmers working in rural areas, who often encounter UPI and biometric systems, should be a specific focus of future research, as they experience high material friction and digital mistrust when using these technologies. Ethnographic research of such populations may shed light on the effects of algorithmic exclusion like failure of biometric authentication as a result of manual work on their psychological trust with state-mandated digital

communication infrastructure (Jawale, 2024). In the end, these localized offline realities are important to comprehend to develop socio-technical redundancy into the structure of digital governance in India.

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