Reducing Intermediaries in Agricultural Supply Chains Using Blockchain: Enhancing Farmer Income, Transparency, and Market Access

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ABSTRACT

Purpose: *This paper discusses how blockchain-enabled supply chain systems can help mitigate the excessive number of intermediaries in agricultural markets and increase value capture to smallholder farmers in developing economies, specifically India.*

Methodology: *The study uses an empirical method which is mixed in nature based on the primary data that was gathered on 420 farmers in three agro-climatic regions of Karnataka, and 68 agro-market intermediaries were surveyed. Also, five blockchain pilot projects that were implemented in the period between 2021 and 2025 were comparatively analyzed. The research combines field information with supply chain mapping and conceptual modelling using the suggested Decentralised Agricultural Value Realisation (DAVR) model.*

Findings: *According to the findings, the use of blockchain correlates with an average growth in farmer income by 38.4 percent and substantial time savings in the transaction time. The system increases transparency in price discovery, quality grading and payment settlement, thus lessening the reliance on intermediaries. Smart contracts are efficient replacements of crucial intermediary roles, which reduces inefficiencies and enhances trust throughout the supply chain.*

Originality/Value: *The paper introduces a new conceptual model, which is the DAVR, that highlights key intervention points whereby blockchain can replace intermediary functions. It gives empirical data on the pilot applications in the real world, and mentions the major obstacles to adoption, including evidence of digital illiteracy, lacking cold-chain infrastructure, and regulatory challenges. The results provide practical implications to policymakers, agri-fintech innovations, and cooperative institutions seeking to establish transparent and fair agricultural markets.*

Keywords: Agriculture and blockchain, smart contracts, intermediaries in the supply chain, farmer income, price transparency, decentralised ledger, agri-fintech, Karnataka, smallholder farmers, market access.

1. INTRODUCTION :

This disconnect between the price received by a farmer and that of a consumer is one of the most intractable inefficiencies of world food systems over 100 years. In India, a consistent pattern of studies that were carried out in the years 2015-2024 report that the farm-gate price of perishable commodities like tomatoes, onions, and leafy vegetables ranges between 18 to 35 percent to the retail price, various crops, season, and distance to market [1]. The rest goes to a chain of intermediaries - village-level traders, commission agents at regulated market yards (Agricultural Produce Market Committees, or APMCs), transporters, cold-storage operators, wholesale distributors and retailers - all of which add some logistical value, but whose aggregate margins are far greater than their functional value [2].

This intermediary capture has been the focus of the reform agenda of Indian agriculture over a long time. In 2016 Electronic National Agriculture Market (e-NAM) platform was introduced aiming to digitalise price discovery in APMC mandis. To develop collective bargaining power, Farmer Producer Organisations (FPOs) were encouraged. The Farm Laws 2020, which were later repealed, were aimed at enabling direct trade with APMCs. However, none of these interventions have had a smooth ride, either due to opposition or partial acceptance, or simply due to side effects, in part due to focusing on the symptom, high intermediary margins, rather than making a fundamental change in the trust architecture of the supply chain [3].

The blockchain technology is an alternative entry point. Instead of trying to control or get away with the intermediaries, policy mandates, blockchain establishes the informational environment in which the intermediaries become structurally superfluous in a number of their existing functions. The quality at harvest, temperature during transit, ownership transfer at each node, and payment settlement in near-real-time create quality in a distributed ledger that tracks produce at harvest time, temperature conditions during transit, ownership transfer at each node, and payment settlement in near-real-time eliminates the opaqueness that enables intermediary rents to exist [4]. Smart contracts can release payments when delivery is confirmed and the commission agents will not have to keep the money on behalf of farmers. The provenance information that consumers and retailers pay premiums to receive can be stored in non-fungible tokens which represent single lots of produce [5].

This article has three major contributions. First, it introduces novel survey evidence of income and market access impacts of blockchain adoption by smallholder farmers in Karnataka. Second, it works out the conceptual framework of the Decentralised Agricultural Value Realisation (DAVR) that charts the intermediary roles that blockchain can and cannot replace. Third, it determines the constraints the adoption is bound to and suggests a policy roadmap in a sequence.

2. LITERATURE REVIEW :

2.1 The Intermediary Problem in Agricultural Value Chains:

Agricultural intermediation economics has been a major topic of research ever since Stigler (1951) pioneered the research on the role of middlemen in competitive markets [6]. The presence of the intermediaries can be attributed to the fact that they render real services - aggregation, price discovery, quality certification, credit provision, and risk bearing, which are indeed expensive in geographically dispersed, perishable and information asymmetric environments [7]. It is not the issue of intermediation as such, but the monopolistic/oligopolistic market structures, which enable the intermediaries to collect their rents which are much higher than their competitive payoff [8]. Acharya and Agarwal (2004) showed that in mandis, commission agents would earn between 12 and 18 percent of the transaction value through explicit commissions and implicit manipulated weights and quality grades [9]. More recently Fafchamps and Hill (2008) revealed that despite the existence of alternative marketing channels, farmers who have poor access to market information and transport infrastructure default to those channels that they are familiar with, and accept prices below-market in exchange of certainty and access to credit [10].

2.2 Blockchain as a Supply Chain Tool:

Supply chain management This field of study received strong scholarly and commercial interest when Nakamoto (2008) pioneered the distributed consensus mechanism and Ethereum-based smart contract pioneering by Buterin (2014) [11,12]. Blockchain tackles three market failures common to supply chain situations: information asymmetry concerning the nature of products, contract enforcement when there are no trusted third parties, and coordination failures between dispersed producers [13]. One of the first comprehensive architectures of a blockchain-based food safety monitoring system was proposed by Tian (2016), showing how a system based on the use of QR-code-tagged produce would enable storing immutable data about the pesticide use, harvest date and cold-chain conditions [14]. Ge et al. (2017) took it further to demonstrate how compliance-based payments within agricultural export chains can by automated using smart contracts [15]. A more recent study by Kamble, Gunasekaran, and Arha (2019) employed technology acceptance modelling to determine the predictors of blockchain adoption among Indian agribusinesses and the results revealed that perceived usefulness and trust in the governance of platforms are the most prevalent predictors [16]. The gap in the literature is the lack of empirical literature on the effects of income, which is what this study fills.

2.3 Smart Contracts and Payment Settlement:

Smart contracts, or self-executable code that runs on a blockchain and ensures transacting parties agree to the terms are of particular interest to the delays in payments that plague agricultural deals. Traditional APMC markets provide farmers with interest-free working capital at the cost of the trader as payment up to 7 to 21 days following delivery [17]. This delay, and the credit risk that goes with it, can be removed by connecting payment release to events of verified delivery, performance on grading, or quality sensor information, which can be verified using smart contracts [18]. Nevertheless, smart contracts introduce new threats as well: bad code may be used, quality evaluation can be challenged leading to oracle issues, and blockchain transactions are irreversible, and thus, it is difficult to fix the mistakes [19].

3. RESEARCH METHODOLOGY :

3.1 Sample Design and Data Collection:

The study will use convenience sampling and data collection. This paper follows a mixed-methods research design incorporating both quantitative data on the farm level (survey data) and qualitative data in the form of key informant interviews and secondary data on blockchain pilot project reports. The study location is Karnataka, the 3 rd most agricultural productive state in India, that has immense agro-climatic and crop mix and market infrastructure diversities among 31 districts [20]. The stratified random sample size was 420 smallholder farmers in three agro-climatic zones, namely, the coastal zone (Dakshina Kannada and Udupi districts), the transitional semi-arid zone (Tumkur and Chikkaballapur), and the northern dry zone (Raichur and Koppal). Probability proportional to size sampling was used to select villages within each zone and households within the village were selected randomly through official land records. In October 2024-February 2025, trained enumerators conducted surveys in Kannada with a response rate of 93.6 percent

A semi-structured protocol was used to choose 68 agricultural market intermediaries who were interviewed separately. Five blockchain pilot projects (Agrichain Karnataka (2021), Farmer Connect (2022), AgriBit (2022-2023), Trust Harvest (2023-2024), and Green Ledger (2024-2025)) were examined using document review, platform data, and interviews with implementing organisations.

3.2 Analytical Framework:

Quantitative analysis used descriptive statistics, difference-in-differences (DiD) estimation, which isolates causal effect of blockchain adoption on income and multinomial logistic regression, which determines the determinants of adoption. Thematic coding was used to analyse the qualitative data in NVivo 14. The level of statistical significance was evaluated at the 5 percent level across all times and the strength of the study was checked by employing propensity score matching.

Table 1: Sample Distribution by Agro-Climatic Zone and Crop Type

Zone	Districts	n	Primary Crop	Avg. Holding (ha)	Prior Mkt. Channel
Coastal	Dakshina Kannada, Udupi	138	Areca nut, Coconut, Paddy	1.42	APMC / FPO
Transitional Semi-Arid	Tumkur, Chikkaballapur	154	Tomato, Grapes, Mulberry	0.98	Commission Agent
Northern Dry Zone	Raichur, Koppal	128	Cotton, Sorghum, Tur dal	2.11	Village Trader
Total	**6 Districts**	**420**	–	**1.48**	–

4. THE DECENTRALISED AGRICULTURAL VALUE REALISATION (DAVR) MODEL :

The DAVR model has five functional layers where blockchain technology directly replaces or complements existing intermediary functions. In contrast to the previous models, which assume that blockchain can be viewed as one technological intervention, DAVR acknowledges that adoption is a stratified process, and that every layer has particular welfare impacts on various stakeholder groups [21].

Layer 1: Identity & Provenance Registration
On-chain record of farm land plot, crop planted, use of inputs and harvest date, which is registered through mobile app or RFID tag. None of the controversy on the source, and end to end traceability of farm to fork is possible.

Displaces: Certification of village trader position.

Layer 2: Automated Quality Grading
IoT sensors, computer vision cameras and certified third party graders post the quality scores into the ledger. Smart contract automatic updates price schedules depending on confirmed grade eliminating personal agent evaluation.

Displaces: Quality grading of commission agents.

Layer 3: Transparent Price Discovery
On-the-fly bid/ask matching on a blockchain auction module that has permission. Publicly available historic price information. Connects to e-NAM APIs in order to be able to have price visibility with the farmers who are in remote areas.

Displaces: Opaque price-setting mechanisms of mandi.

Layer 4: Smart Contract Payment Settlement
Payments to be made automatically when delivery confirmed. Settlement in UPI or CBDC that has been accomplished in less than 24 hours. Removes the 721 day payment cycle which acts as an interest free loan between farmer and trader.

Displaces: payment holding as an agent.

Layer 5: Market Access Linkage
Certified farmer records on chain and accepted by processors, exporters and chain stores. Provenance NFTs have quality and sustainability premiums with end consumers, establishing a direct connection with revenue.

Displaces: Agent-broker role of access to buyers.

The DAVR model is in two significant ways different than previous models. To begin with, it clearly outlines the types of intermediary roles blockchain can transfer (information brokerage, payment custody, quality certification) and those it cannot (physical logistics, last-mile cold storage, and social credit relationships). Second, it acknowledges that layers rely on each other, i.e. price discovery cannot operate in the absence of quality grading which in turn is based on credible provenance registration. These implications of sequencing have practical consequences: sequencing platforms that bypass lower levels have a higher probability of failing at higher levels.

5. BLOCKCHAIN ADOPTION AND FARMER INCOME :

The key empirical conclusion of this paper is that farmers that were involved in at least one of the five blockchain pilot projects realized an average increase in net farm income by 38.4 percent, compared to similar non-adopters in a two-year follow-up period. This was statistically significant ($p < 0.01$) and strong to the propensity score matching on pre-adoption income, landholding size, and type of crop, as well as distance to the closest APMC.
Three sub-effects that led to the increase in income and were to the tune of about 22 and 9 percentage points and 7 percentage points respectively were related to improved price realisation, reduction in post-harvest losses and faster payment settlement respectively [23].

Table 2: Pre- and Post-Adoption Farm Income Comparison (Mean Values, INR/year)

Category	Non-Adopters (n=268)	Adopters (n=152)	Difference	% Change	p-value
Pre-intervention net income	₹ 82,460	₹ 84,120	₹ 1,660	+2.0%	0.41 (ns)
Post-intervention net income	₹ 86,340	₹ 1,16,500	₹ 30,160	+34.9%	< 0.001
Price realisation (% of MSP)	71.4%	91.8%	+20.4 pp	+28.6%	< 0.001
Post-harvest loss rate	18.2%	10.4%	−7.8 pp	−42.9%	< 0.01
Payment receipt (days)	14.2 days	3.1 days	−11.1 days	−78.2%	< 0.001
DiD estimate (net income)	₹ 28,500 (95% CI: ₹ 24,800 – ₹ 32,200)		–	**+38.4%**	**< 0.001**

Fig. 1: Net farm income comparison between blockchain adopters and non-adopters, before and after platform intervention. Green bar indicates statistically significant gain ($p < 0.001$). Source: Primary survey data (n=420).

The increase in income was uneven among the type of crops. The highest absolute gains (mean +₹38,200/year) were seen among perishable crop farmers like tomato, leafy vegetables, and banana growers since blockchain provenance and quality tracking enabled them to reach organised retailers that would otherwise not have purchased unverified smallholders. Less perishable commodities (cotton, tur dal) increased by less by farmers (+ ₹19,400/year) which was mainly due to payment settlements and more efficient logistics that matched [24].

6. TRANSPARENCY AND PRICE REALISATION :

In addition to income, blockchain use brought about quantifiable shifts in the price formation transparency. The end price paid to farmers in the traditional APMC markets was often lower than the posted rates in the market because of the weighing scale manipulation, nondisclosed commissions and downgrading of the quality of produce with impunity. In the blockchain systems under consideration, all these practices could not or could only be instantly visible to the farmer via a smartphone interface [25].

Real-time price display was the most powerful mechanism of transparency. The competition among the buyers could be observed visually when farmers were able to see the bids of more than one buyer on their mobile screens, which was available in three out of five platforms investigated. In qualitative interviews commission agents recognised that their power to offer a take-it-or-leave-it price to farmers had been badly undermined. One of the respondents in Tumkur said: "Previously, a farmer would arrive with two quintals of tomatoes and I would tell him the price but now he presents me with his phone and says there is another buyer who is giving him more. I cannot do what I used to do."

Table 3: Transparency and Market Conduct Metrics Across Five Blockchain Pilot Projects

Pilot Project	Year	Crop Focus	Farmers	Transparency Score*	Price Premium (%)	Dispute Rate (pre/post)
Agrichain Karnataka	2021	Areca nut, Coconut	840	6.8 / 10	+12.4%	22% / 4%
FarmerConnect	2022	Tomato, Onion	1,240	7.9 / 10	+19.8%	31% / 3%
AgriBit	2022–23	Cotton, Sorghum	2,180	7.2 / 10	+14.2%	18% / 5%
TrustHarvest	2023–24	Grapes, Pomegranate	3,460	8.4 / 10	+24.6%	27% / 2%
GreenLedger	2024–25	Leafy veg., Banana	5,120	8.9 / 10	+28.3%	29% / 2%

*Price Transparency Score measured on a 10-point Likert scale administered to farmers regarding perceived fairness and clarity of price formation. Source: Platform administrative data and author surveys.

Agri chain 2021	Farmer Connect 2022	Agri Bit 2022–23	Trust Harvest 2023–24	Green Ledger 2024–25
+12.4%	**+19.8%**	**+14.2%**	**+24.6%**	**+28.3%**

Fig. 2: Price premium realised by blockchain platform participants over matched non-participants across five pilot projects (2021–2025). Darker shading denotes higher premium. Source: Platform administrative data and author calculations.

7. MARKET ACCESS AND BUYER DIVERSIFICATION :

Among the most significant findings in terms of structure, one is related to market access diversification. Before adoption of blockchain, more than 85 percent of the marketed surplus of a representative sample of farmers was transacted with a single buyer, the village trader or merchant with whom that farmer was used to doing business. Following the adoption of blockchain, the median farmer, in a single harvest year, traded with 3.4 different types of buyers, such as organised retailers (28%), food processors (19%), export aggregators (12%), and hospital/institution supply chains (8%) [26].

The effects of this diversification of buyers stretch beyond immediate income. When the tomato price dropped to lower than the cost of production three weeks in May 2024, farmers on the FarmerConnect and TrustHarvest platforms could reroute supply to processing units with contracted prices, which did not result in the total loss farmers in the same area realized without a platform [27].

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Commission Agent / Village Trader	**33%**	■■■■■■■■■■■■
Organised Retailer	**28%**	■■■■■■■■■■
Food Processor	**19%**	■■■■■■■
Export Aggregator	**12%**	■■■■
Institution / Hospital Supply	**8%**	■■■

Fig. 3: Distribution of buyer types transacted with by blockchain adopter farmers post-intervention. Block symbols represent relative share visually. Source: Primary survey data.

8. BARRIERS TO ADOPTION AND CONSTRAINTS ON SCALE-UP :

Although blockchain offers considerable benefits in terms of income and transparency, only 36.2 percent (152 out of 420 farmers) of the survey sample uses it. It is equally significant to find out why most people have not yet adopted yet it is important to record the benefits of adoption. The data provided gave rise to four types of barriers.

8.1 Digital Literacy and Smartphone Access:

The reason given most often by the non-adopters - 68 percent - was lack of familiarity with smartphones and digital applications. The penetration of smartphone among the rural households in Karnataka has been reported to be about 74 percent, but the multi-step agricultural application capability is still low among the farmers who are above the age of 45 and women farmers who form 38 percent of the sample [28].

8.2 Cold-Chain Infrastructure Deficits:

Blockchain brings about informational efficiency, but informational efficiency without physical infrastructure cannot be used to support perishable crops. In northern dry zone sample, 54 percent of the non-adopters who provided lack of access to cold storage within 20 kilometres as the rationale not to participate. In the case of damage of produce caused by improper cold-chain management, smart contracts generate conflict instead of payments [29].

8.3 Regulatory and Legal Ambiguity:

Contracts based on blockchain lack yet to be given a definitive legal status in the Indian contract law or agricultural commodity laws. The Agricultural Produce (Grading and Marking) Act, 1937, and the Legal Metrology Act, 2009, do not consider the grades produced by IoT-sensors as legally binding. Until this loophole is resolved, conflicts that cannot be settled using on-chain methods will have to be resolved in a civil court, which is not feasible when dealing with a few thousand rupees [30].

8.4 Social Resistance from Incumbent Intermediaries:

Disruption does not passively receive commission agents and traders. A number of interviewees claimed that there were active attempts by existing intermediaries to deter the use of platforms - such as misinformation on the reliability of the platform, threats of cut-off of credit and in two cases recorded, the coordination of group boycotts to buy platforms that were using rival platforms [31].

Table 4: Ranked Barriers to Blockchain Adoption Among Non-Adopter Farmers (n=268)

#	Barrier Category	% Primary Barrier	% Secondary Barrier	Severity (1–5)	Policy Addr.?	Intervention Type
1	Digital literacy / smartphone skills	68.3%	14.2%	4.2	Yes	Training programmes
2	Cold-chain infrastructure gap	54.1%	28.7%	4.6	Yes	Capital investment
3	Social resistance / credit dependency	42.5%	31.3%	3.8	Partially	FPO strengthening
4	Legal / regulatory ambiguity	38.8%	22.4%	3.5	Yes	Legislation
5	Internet connectivity unreliability	34.7%	40.3%	3.4	Yes	BharatNet expansion
6	Distrust of platform governance	28.4%	18.7%	3.1	Partially	Governance standards
7	Language / interface barriers	22.0%	35.8%	2.9	Yes	Localisation
8	Transaction costs / fees	18.3%	12.1%	2.6	Yes	Fee subsidy

9. POLICY IMPLICATIONS AND ROADMAP :

The results are a sequenced policy roadmap that can be applied by governments on a state and central level to achieve the gains of blockchain supply chains in the agricultural sector without having to wait until the organic market adoption process has reached a sufficient size [32]. The roadmap shown below has three phases between 2025 and 2035.

PHASE 1: FOUNDATION 2025 – 2027	**PHASE 2: SCALING** 2027 – 2030	**PHASE 3: MAINSTREAMING** 2030 – 2035
➢ Have law on blockchain evidence admissibility. ➢ Requirement of open API interfaces to e-NAM. ➢ 100 agri-districts Digital literacy camps. ➢ Subsidise IoT sensor kits to FPOs. ➢ Pilot CBDC to settle agri payments. ➢ Design agri-blockchain sandbox. ➢ Goal 50,000 farmers registered cke Goal State-level agri-blockchain authority developed.	➢ 500 block HQs Cold-chain investment. ➢ Inter-operability between agri platforms by states. ➢ FPO-based blockchain nodes in 1000 clusters. ➢ Compulsory quality assessment through IoT of notified crops. ➢ Export certification by blockchain provenance. ➢ 5 million farmers onboarded: ➢ Target National agri-blockchain public infrastructure.	➢ Provenance of cross-border trade accepted. ➢ 1 out of 80% of produce with consumer QR codes. ➢ Credit scoring of farm loans based on blockchain. ➢ Integration with PM Kisan and crop insurance. ➢ India as agri-blockchain standard setter worldwide. ➢ Goal: 80 million farmers boarded.

Fig. 4: Three-phase policy roadmap for scaling blockchain adoption in Indian agricultural supply chains. Source: Authors' framework based on survey findings and comparative pilot analysis.

The nearest intervention that is the most urgent is legislative. The admissibility of evidence stored on blockchain must be expressly mentioned in amendments to the Indian Evidence Act, as well as in the commodity trading laws. Devoid of this, smart contracts are still contractually ambiguous and buyers can still renegotiate terms that are not on the platform [33].
The second priority is infrastructure investment. The research establishes that blockchain systems implemented in localities with available cold storage and trustworthy internet connectivity had 2.8 times more uptake as compared to localities with no such facilities. Platform deployment should not be followed by investment in agricultural cold-chain, but should be accompanied by it [34].

10. DISCUSSION :

The data collected confirms a tepid-optimistic outlook of the potential of blockchain in agricultural supply chains. The income gains reported- an average of 38.4 percent in two years- are enormous by any definition and the processes by which they occur (better price realisation, less post-harvest loss, faster payment settlement) are well-founded both in theory and in the testimony of farmers. Of particular interest, the discovery that diversification of buyers increases to a median of one buyer type to 3.4 buyer types is intriguing, as it indicates that blockchain does not only optimize the conditions of existing transactions, but also rearranges what transactions can occur [35].
Meanwhile, the results of the study warn against technological determinism. Blockchain does not necessarily crowd out intermediaries, but rather it sets the informational conditions in which some of the functions of middlemen might become unnecessary, but whether or not the latter actually occurs is dependent on how well the technology is accessible to the farmers, the physical infrastructure on which the technology relies, and the social and political economy in which it is embedded [36].
The main contribution of the DAVR model is that it acknowledges that the adoption of blockchain is not a two-dimensional process but a multi-layer process. Platforms starting with provenance registration (Layer 1) and payment settlement (Layer 4) - the two that have the most straightforward value proposal

and the simplest smart contract logic - have been found to retain farmers at pilot data rates that are many times higher [37].

11. CONCLUSION :

This essay has explored the possibility and the actuality of the blockchain technology as a means of decreasing the intermediary capture in agricultural supply-chains, based on original empirical data of 420 small-holder farmers in Karnataka and five blockchain pilot projects between 2021 and 2025. The key result, which is that the likelihood of blockchain adoption is linked to a 38.4 percent net farm income growth, is one of the best estimates that have been so far presented in the literature supported by the difference-in-differences approach and propensity score matching.

The Decentralised Agricultural Value Realisation (DAVR) model worked out in the present paper offers a conceptual lexicon to implementation practitioners: five functional layers, all of which have replaced a particular intermediary role, in the order of identity registration to market access linkage. The practical usefulness of the model is that it is specific, that is, it does not only indicate what the blockchain can do in agriculture, but what it cannot and in what sequence it should be tried.

The proposed policy roadmap, which is a three-stage, 10-year programme that starts with legislative and infrastructure base, followed by scaling led by cooperatives then to national mainstreaming, is ambitious but feasible due to the current digital public infrastructure in India, the growing network of FPOs, and the proclaimed government goal of doubling farmer incomes. These binding constraints are not technical, but infrastructural, regulatory and social.

There are three gaps that could not be addressed by this study and they should be tackled by the future research. First, long-run dynamics of incomes - do incomes continue to gain, or do mediators evolve and regain market power? Second, gendered impacts- are women who are farmers getting the same opportunities offered by blockchain platforms? Third, international comparability - how do the Karnataka results relate to the blockchain agriculture applications in sub-Saharan Africa, Southeast Asia, and Latin America?

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