

Provenance-Backed Securities: A Framework for Tokenizing Intangible Assets and Redistributing Ownership in the Age of Automation

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Abstract

Intangible assets now constitute approximately 92% of S&P 500 market capitalization and nearly \$80 trillion in global corporate value, yet the vast majority of intangible intellectual property—including genetic innovations, creative works, personal data, and accumulated human expertise—lacks any liquid secondary market, standardized valuation mechanism, or tradeable financial instrument [1,2]. The existing literature on real-world asset tokenization, projected to reach \$18.9 trillion by 2033, focuses overwhelmingly on financial instruments, bonds, and real estate, leaving a conspicuous theoretical gap: no comprehensive framework addresses the tokenization of performance-verified intangible assets with provenance-backed ownership claims [3]. This paper proposes a three-layer architectural framework—the Provenance Ledger, the Performance Oracle, and the Exchange Protocol—for creating a new class of digital securities whose value derives from verified provenance and empirically measured real-world performance data. The framework is demonstrated through an agricultural proof of concept (SeedBid, a patent-pending genetic asset exchange) and extended to seven additional market domains, including labor and human capital, creative works, patents, personal data, manufacturing processes, and scientific research. When applied to labor markets facing AI-driven displacement—with 92 million jobs projected for redundancy by 2030—provenance-backed securities offer a structural mechanism for converting accumulated human expertise into owned, tradeable, royalty-generating assets, thereby addressing the fundamental ownership gap that universal basic income, reskilling programs, and existing policy proposals fail to resolve [4]. This paper argues that provenance-backed securities represent a market-based pathway toward economic meritocracy by ensuring that the creators of intangible value retain ownership of the assets they produce.

Keywords: Provenance-Backed Securities, Real-World Asset Tokenization, Intangible Assets, Blockchain, Ownership Economics, Labor Displacement, Artificial Intelligence, Seed Genetics, Meritocracy, Dead Capital, Platform Cooperativism

1. Introduction: The Ownership Gap in the Intangible Economy

The composition of corporate value has undergone the most

consequential transformation in the history of modern capitalism. In 1975, tangible assets—property, plant, equipment, inventory, and other physical capital—represented 83% of the market

value of companies comprising the S&P 500 index, with intangible assets accounting for only 17%. By the end of 2025, this relationship had completely inverted: intangible assets now constitute approximately 92% of S&P 500 market capitalization, while tangible assets have been reduced to a mere 8% [1]. This 75 percentagepoint shift represents what Ocean Tomo has defined as an “economic inversion”—a transformation so sweeping that the firm’s study author, Matthew Johnson, described it as “a wholesale transformation in the nature of value creation whereby economic worth has migrated from what can be ‘touched’ to what can be ‘thought’” [1]. The magnitude and velocity of this transformation have no historical precedent. As Ocean Tomo co-founder and J.S. Held Chief Intellectual Property Officer James E. Malackowski observed: “While the Industrial Revolution required a century to unfold fully, the intangible revolution has occurred within a single human lifespan, with particularly rapid acceleration occurring in the 1985–2005 period when intangible asset market value increased from 32% to 79%—a remarkable 47 percentage point surge in just two decades” [1]. Globally, the picture is equally striking. In collaboration with Brand Finance, the World Intellectual Property Organization (WIPO) reported in February 2025 that global corporate intangible asset value had rebounded to an alltime high of approximately \$80 trillion—a 28% increase from 2023 and a 13fold increase since 1996 [5]. Technological innovations, particularly in artificial intelligence, continue to accelerate this trajectory by enhancing the value of software, marketing assets, customer relationships, and brand portfolios both as standalone assets and through synergistic effects.

Yet despite the enormity of this shift, a profound paradox lies at its center. The infrastructure for owning, valuing, and trading intangible assets remains remarkably primitive compared to the infrastructure developed over centuries for tangible property and financial securities. WIPO Director General Daren Tang, in his keynote opening at the 2025 IP Finance Dialogue, underscored this systemic blind spot: “some of the most valuable assets in modern firms never appear on the balance sheet” [5]. Tang characterized intangible assets as “the dark matter of our modern economy—invisible and unknown but exerting an increasingly heavy force on everything”. This paper terms the resulting structural disconnect the ownership gap—the fundamental misalignment between where economic value resides (intangible assets) and where ownership infrastructure exists (tangible assets and established financial instruments).

The ownership gap is not an abstraction. Consider: a corn breeder in Iowa who develops a novel drought-resistant genetic trait has no mechanism to price, trade, license, or collateralize that genetic intellectual property outside of a single seed sale. A radiologist in Chicago who has spent twenty years developing pattern-recognition expertise in diagnostic imaging has no instrument through which to own that expertise as a capital asset. A jazz musician in New Orleans whose compositions have been streamed millions of times has no transparent, performance-verified security through which to capture the ongoing value of that creative output. In each case, the intangible asset is productive—it generates economic value—but

it is not liquid. It cannot be traded, collateralized, or leveraged as capital. It is, in a precise economic sense, dead.

This formulation draws directly from the foundational work of Hernando de Soto. In *The Mystery of Capital* (2000), de Soto identified \$9.3 trillion in what he termed “dead capital” in developing nations: assets that exist physically but cannot be leveraged economically because they lack the formal property rights systems—titles, registries, standardized documentation—that allow assets to “lead a parallel life as capital” [6]. De Soto’s insight was revolutionary: the same physical house or parcel of land could be either a mere shelter or a capitalizable asset, depending entirely on whether it was embedded in a formal property system with documented provenance and transferable title. This paper argues that the developed world’s intangible economy suffers from an analogous condition—one that is, paradoxically, far larger in aggregate value. Trillions of dollars in intellectual property, genetic innovation, creative output, human expertise, and personal data exist as productive assets but cannot be leveraged as capital because they lack the provenance documentation, performance verification, and exchange infrastructure necessary to function as securities. The global intangible economy is, by this analysis, the largest pool of dead capital in human history.

The urgency of this problem is amplified by the arrival of artificial intelligence as a labor-displacing technology. The World Economic Forum’s *Future of Jobs Report 2025* projects that AI and information-processing technologies will transform 86% of businesses by 2030, displacing 92 million existing jobs while creating 170 million new roles—a net positive of 78 million, but one in which the displaced workers and the newly employed are largely not the same people [4]. When AI absorbs human expertise—a truck driver’s route knowledge, a radiologist’s diagnostic acumen, a machinist’s fabrication techniques—the human loses not only their employment but also the accumulated value of their expertise. No existing policy proposal—universal basic income, reskilling programs, public-private partnerships—addresses this fundamental ownership transfer.

This paper poses the following research question: Can a standardized, technology-enabled framework transform illiquid intangible assets into tradeable, performance-backed digital securities—and if so, what are the implications for ownership, labor markets, and economic meritocracy?

The paper makes five principal contributions to the literature:

- It proposes the **Provenance-Backed Security (PBS)** as a new financial instrument class, formally defined and distinguished from existing tokenized assets.
- It defines the **Three-Layer Architecture**—Provenance Ledger, Performance Oracle, and Exchange Protocol—as generalized infrastructure for PBS creation across any domain with documentable provenance and measurable performance.
- It demonstrates the framework through an **agricultural proof of concept**—SeedBid, a patent-pending genetic asset exchange—in a market characterized by oligopoly

concentration, information asymmetry, and chronic undervaluation of genetic intellectual property.

- It extends the framework to **seven additional market domains**, establishing domain-agnostic applicability.
- It presents the **labor market thesis**: PBS as a structural solution to AI-driven displacement through the ownership of human capital assets—a mechanism for converting accumulated expertise into tradeable, royalty-generating securities.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature across four converging domains: intangible asset economics, real-world asset tokenization, ownership theory, and labor displacement. Section 3 presents the theoretical framework and formal definition of the PBS instrument and three-layer architecture. Section 4 demonstrates the framework through the agricultural proof of concept. Section 5 extends the framework across seven additional domains. Section 6 develops the labor market thesis in full. Section 7 discusses policy implications, acknowledges limitations, and concludes.

2. Literature Review: Converging Crises in Ownership, Valuation, and Labor

This paper draws upon and contributes to four bodies of literature that have, until now, developed largely in parallel: the economics of intangible assets, the emerging field of real-world asset tokenization, theories of ownership and the commons, and the growing scholarship on AI-driven labor displacement. Their convergence defines the intellectual space in which provenance-backed securities become both theoretically necessary and practically feasible.

2.1. The Intangible Asset Economy

The Ocean Tomo Intangible Asset Market Value (IAMV) Study, now spanning a 50-year panel of U.S. market data and 20 years of foreign market data, provides the most comprehensive longitudinal dataset on the tangible/intangible composition of corporate value. The 2025 edition, released in February 2026 by J.S. Held, documents the culmination of the “economic inversion”: the shift from 83% tangible and 17% intangible in 1975 to approximately 8% tangible and 92% intangible by the end of 2025 [1]. This represents, by any measure, a structural transformation of the capitalist economy. The accelerating period of 1985–2005, during which intangible asset market value surged from 32% to 79%, coincided with the commercialization of the internet, the explosion of software-driven business models, and the rise of brand and intellectual property as primary competitive advantages.

A particularly noteworthy finding from the 2025 study concerns the 2020–2025 period, during which S&P 500 IAMV remained remarkably stable at approximately 90% despite the Federal Reserve implementing the most aggressive monetary tightening cycle in four decades. Traditional financial theory predicts that intangible-intensive firms should be highly sensitive to interest rate changes due to their long-duration cash flows and limited collateral value. The observed stability challenges this prediction and suggests that intangible asset dominance has become structurally embedded in

corporate valuation, not merely a byproduct of low-interest-rate environments [1]. The WIPO and Brand Finance Global Intangible Finance Tracker (GIFT) 2024 corroborates these findings at a global scale. The United States leads as the most intangible-asset-intensive economy, with its top 15 firms’ intangible assets comprising 90% of total enterprise value. Ireland, Denmark, the Netherlands, the United Kingdom, and France follow closely. Notably, India has emerged as the only middle-income economy in the top 10, ranking eighth—a position driven by rapid growth in sectors rich in intangible assets, including software services, pharmaceuticals, and digital platforms [5].

Despite this enormous and growing value, the financial infrastructure for intangible assets remains grossly underdeveloped. At the WIPO IP Finance Dialogue 2025, Nicolas Konialidis, Technical Director at the International Valuation Standards Council (IVSCI), emphasized the challenge: “Valuation is not a checklist. It is the application of sound professional judgment” [5]. This statement, while intended to defend the rigor of professional valuation, inadvertently underscores the problem: intangible asset valuation remains an artisanal craft rather than a standardized, data-driven process. In stark contrast, tangible assets and financial securities benefit from centuries of developed valuation methodologies, market comparables, and regulatory frameworks. The consequences for capital formation are significant. Iynna Halilou, Partner at The MBA Fund and lecturer on Venture Capital at HEC Paris, presented evidence at the same dialogue that patent-owning startups are 6.4 times more likely to attract investment [1]. Yet the relationship is onedirectional: IP signals value but cannot itself serve as liquid, tradeable capital. Martin Brassell, Co-founder and CEO of Inngot Limited, captured this paradox precisely: “IP assets are not assets that either a business or its investors willingly let go—that means they have tremendous behavioral influencing power” he behavioral influencing power Brassell describes is a function of the asset’s genuine value; the illiquidity is a function of the infrastructure’s inadequacy.

2.2. Real-World Asset Tokenization: The Current Landscape

The tokenization of real-world assets (RWA) has emerged as one of the most closely watched developments in financial technology. In April 2025, Ripple and the Boston Consulting Group (BCG) published a landmark projection: the global market for tokenized real-world assets will grow from approximately \$0.6 trillion to \$18.9 trillion by 2033, with an intermediate milestone of \$9.4 trillion by 2030, representing a compound annual growth rate of 53% [3]. The report outlined a three-phase evolution model: (1) LowRisk Adoption, in which institutions tokenize familiar instruments such as money market funds and bonds; (2) Institutional Expansion, scaling into more complex assets including private credit and real estate; and (3) Market Transformation, in which tokenization becomes embedded in both financial and non-financial products. Early adopters including BlackRock, Fidelity, and JPMorgan are already operational in Phase 1, and a “flywheel effect”—in which institutional supply and investor demand reinforce each other—is accelerating adoption.

Perhaps no voice has lent greater legitimacy to the tokenization thesis than that of Larry Fink, Chairman and CEO of BlackRock, the world's largest asset manager. In his 2025 Annual Chairman's Letter to Investors, Fink declared that "every asset—can be tokenized," calling it nothing short of a "revolution" for investing [7]. Fink drew a historical parallel to the founding of the Amsterdam Stock Exchange in 1602:

For the first time, ordinary people didn't just watch the economy grow around them. They owned a share of that growth—a real, tradable share.

— Larry Fink, 2025 Annual Chairman's Letter to Investors

The parallel is instructive. The Amsterdam Stock Exchange democratized access to investment by creating standardized, transferable instruments representing ownership claims in productive enterprises. Tokenization promises an analogous democratization by reducing transaction costs, enabling fractional ownership, and creating 24/7 markets with near instantaneous settlement [7]. Fink identified digital identity verification as the principal remaining obstacle to full-scale tokenization.

However, a critical examination of the BCG-Ripple asset class breakdown reveals a conspicuous absence. The projected \$18.9 trillion is distributed across real estate (\$6.8 trillion), bonds and fixed income (\$3.2 trillion), mutual funds and ETFs (\$1.4 trillion), and other established financial instruments [3]. Intellectual property and intangible assets are entirely absent from these projections. The tokenization revolution, as currently conceived, applies exclusively to assets that already possess established valuation methodologies, market comparables, or discounted cash flow models. No framework within the existing tokenization literature addresses the far more challenging problem of tokenizing assets whose value derives from verifiable provenance and measurable performance rather than from existing market mechanisms. This gap is not merely an oversight; it is structural. Tokenizing a bond requires digitizing an instrument whose value is already well understood. Tokenizing a corn breeder's genetic innovation requires first solving the provenance problem (who created it and who owns it?), then solving the valuation problem (what is it worth and how do we know?), and only then enabling exchange. The three-layer architecture proposed in Section 3 addresses this structural gap.

2.3. Ownership Economics and the Commons

The theoretical foundations of this paper draw upon three pillars of ownership economics. The first is Ronald Coase's theory of the firm. In his seminal 1937 paper, "The Nature of the Firm," Coase argued that transaction costs determine whether economic activity occurs within hierarchical firms or through open market mechanisms. When the costs of using the market— search costs, bargaining costs, contracting costs, enforcement costs—exceed the costs of internal organization, firms emerge. When market transaction costs decline, activity shifts from firms to markets [8]. This framework proved remarkably predictive: the decline in information and communication costs over the past half century has driven precisely the shift from vertically integrated corporations to networked, platform-based economic activity that Coasean theory

anticipated.

Nasser Arshadi (2024) has extended Coase's framework to argue that blockchain-based smart contracts and decentralized autonomous organizations (DAOs) represent "compelling alternatives to conventional corporate structures" because they substantially reduce the transaction costs that originally justified firm formation [9]. If Coase's theory predicts that lower transaction costs shift activity from firms to markets, then blockchain technology—by reducing verification costs, contracting costs, and enforcement costs to near zero—creates the conditions for a new class of market-mediated transactions in assets that previously required firm-level infrastructure to manage. Oliver Williamson's (1985) elaboration of transaction cost economics through the lens of asset specificity, bounded rationality, and opportunism provides the complementary analytical framework: blockchain-based provenance systems reduce opportunism by making asset histories transparent, and smart contracts reduce bounded rationality by automating complex contingent transactions [10].

The second pillar is Elinor Ostrom's theory of commons governance. In *Governing the Commons* (1990), for which she received the Nobel Prize in Economics in 2009, Ostrom demonstrated empirically that communities can successfully self-govern shared resources without either state intervention or privatization, provided that certain institutional design principles are satisfied. Her Institutional Analysis and Development (IAD) framework identified eight design principles for sustainable commons governance: clearly defined boundaries, congruence between appropriation and provision rules, collective-choice arrangements, monitoring, graduated sanctions, conflict-resolution mechanisms, minimal recognition of rights to organize, and nested enterprises for larger systems [11]. These principles, originally derived from the study of irrigation systems, fisheries, and forests, prove remarkably applicable to the design of digital asset exchanges—a point developed in Section 3. The third pillar is de Soto's property rights framework, discussed in the introduction. De Soto's central insight—that the same asset can be either dead capital or living capital depending on whether it is embedded in a formal property system—provides the theoretical foundation for this paper's central argument. De Soto identified six effects of a functioning property system: fixing the economic potential of assets, integrating dispersed information into one system, making people accountable, making assets fungible, networking people, and protecting transactions [11]. Each of these effects is precisely what the three-layer PBS architecture is designed to produce for intangible assets.

More recently, Harvard Business School's Ownership Project, founded in 2024 within the Institute for Business in Global Society (BiGS) and led by Nien-he Hsieh and Ethan C. Rouen, has begun systematic examination of how ownership structures shape economic outcomes. The project's founding premise is that "how ownership is structured is foundational for any economy: Ownership shapes the exchange of goods and services between buyers and sellers, grants access and control over capital and

resources, and mediates the governance of economic enterprises” [12]. Its inaugural Worker Ownership Conference, held May 12–13, 2025, signaled growing institutional recognition that ownership structures—not merely employment structures—are determinative of economic equity.

2.4. Labor Displacement and the Automation Crisis

The World Economic Forum’s Future of Jobs Report 2025, drawing on data from over 1,000 companies, projects that global job disruption will equate to 22% of total employment by 2030 [4]. The net figures—170 million new roles created, 92 million existing roles displaced, yielding a net positive of 78 million—mask a deeply unequal distribution. The fastest-growing skills are AI and big data, networks and cybersecurity, and technological literacy; the fastest-declining roles include cashiers, administrative assistants, and clerical workers. The displaced and the newly employed are largely disjoint populations, separated by skill requirements, geographic concentrations, and access to retraining [4].

The existing policy landscape offers four principal responses to automation-driven displacement, each with significant structural limitations:

Universal Basic Income (UBI): UBI provides sustenance but not ownership. It does not create assets, enable wealth accumulation, or transform workers from dependents into stakeholders. UBI is, fundamentally, a consumption subsidy rather than a capital formation mechanism. Reskilling and upskilling programs: These assume that sufficient new roles exist and that displaced workers can access, afford, and complete the necessary training. They do not address the value of expertise already accumulated over careers that may span decades. Public-private partnerships: Typically employer-driven, these maintain the employer-employee relationship rather than creating ownership. They redistribute employment opportunities but do not redistribute ownership of the value created by human expertise.

Platform cooperativism: Trebor Scholz (2023) has demonstrated that worker-owned digital platforms are operationally viable, with more than one million workers worldwide now employed in platform cooperatives. The Drivers Cooperative, for example, retains 85–90% of fares for its driver-owners, compared to the roughly 60–70% that Uber and Lyft pass through [13]. However, platform cooperatives redistribute revenue; they do not create a tradeable asset class from worker expertise. A cooperative driver cannot trade, collateralize, or accumulate equity in their driving expertise as an appreciating asset. Yochai Benkler’s *The Wealth of Networks* (2006) anticipated this structural challenge: commons-based peer production could organize creative labor, but without property-rights infrastructure, the value created would remain uncapitalizable [14]. The common thread across all four approaches is that none addresses the fundamental ownership question: Who owns the value created by human expertise when that expertise is absorbed by AI? When an autonomous driving AI absorbs a truck driver’s twenty years of route knowledge, the expertise is extracted and corporatized. The worker loses both the

job and the accumulated value of the knowledge. This paper argues that this extraction represents a novel form of capital appropriation for which no existing framework provides redress.

3. The Three-Layer Architecture: A General Framework for Provenance-Backed Securities

This section introduces the formal definition of the Provenance-Backed Security (PBS) and the three-layer architecture through which such securities are created, valued, and exchanged.

Definition. A Provenance-Backed Security (PBS) is a digital financial instrument whose value is derived from two interdependent pillars: (a) verified provenance—the documented chain of creation, custody, contribution, and ownership of an underlying intangible asset, anchored to an immutable distributed ledger—and (b) measurable performance—empirically verified output data, continuously collected and published, that serves as the basis for ongoing valuation and returns calculation.

A PBS is distinguished from existing tokenized assets in a fundamental respect. A tokenized bond derives its value from the issuer’s creditworthiness and the predetermined terms of the debt obligation; the token is merely a digital wrapper around a pre-existing valuation mechanism. A PBS derives its value from the underlying intangible asset’s own documented history and empirically observed performance. The provenance is not incidental to the value—it constitutes the value. A genetic trait without documented lineage, a creative work without authenticated authorship, an expertise portfolio without verified employment history—each is, economically, an unverifiable claim rather than a capitalizable asset. The three-layer architecture provides the infrastructure through which PBS are created, maintained, and exchanged.

3.1. Layer 1: The Provenance Ledger

Function: The Provenance Ledger establishes and maintains an immutable, cryptographically verified record of creation, authorship, chain of custody, contribution history, and ownership claims for the underlying intangible asset.

Technical Implementation: The ledger is implemented as a blockchain-anchored distributed system with cryptographic verification of identity (via public-key infrastructure and decentralized identifiers) and temporal ordering (via consensus-validated timestamping). The design draws from the principles established in Nakamoto’s (2008) foundational Bitcoin whitepaper regarding immutable, trustless record-keeping, while extending those principles to identity-linked provenance documentation rather than anonymous value transfer [15].

Economic Function: The Provenance Ledger solves de Soto’s “dead capital” problem for intangible assets. De Soto (2000) demonstrated that the formal property system accomplishes six essential functions: it fixes the economic potential of assets, integrates dispersed information, makes people accountable, makes assets fungible, networks people, and protects transactions

[6]. The Provenance Ledger accomplishes each of these functions for intangible assets that have historically existed outside any formal property system. A corn breeder's genetic innovation, once documented on the Provenance Ledger with verified identity, authenticated lineage data, and timestamped creation records, is transformed from an informal, unverifiable claim into a formal, transferable, collateralizable property right.

Design Principles: The governance of the Provenance Ledger draws directly from Ostrom's (1990) IAD framework, adapted for digital commons. Clearly defined boundaries determine who may register assets and under what verification requirements. Congruence rules ensure that the costs of maintaining provenance records (provision) are proportional to the benefits of asset tradability (appropriation) [11]. Collective-choice arrangements allow registered participants to shape ledger governance through transparent voting mechanisms. Monitoring is accomplished through cryptographic audit trails. Graduated sanctions address provenance fraud or misrepresentation. Conflict-resolution mechanisms handle disputed ownership claims through arbitration protocols. These are not merely aspirational features; they are structural requirements for a system in which trust substitutes for centralized authority.

3.2. Layer 2: The Performance Oracle

Function: The Performance Oracle captures, validates, and publishes empirically measured performance data associated with provenance documented assets, providing the "earnings report" equivalent for intangible securities.

Mechanism: Performance data is collected through domain-appropriate channels: IoT sensors and field instrumentation (for agricultural genetics), streaming and licensing platforms (for creative works), commercial adoption and citation databases (for patents), predictive accuracy metrics (for personal data), and verified work-output assessments (for human capital). Data feeds are validated through multiple independent sources, reducing reliance on any single attestation. Algorithmic performance scoring normalizes cross-domain data into standardized quality and consistency metrics.

Economic Function: The Performance Oracle provides the informational infrastructure that enables market-based pricing of intangible assets. Just as corporate securities derive value from quarterly earnings reports, audited financial statements, and forward guidance, PBS derive value from continuously updated, third-party-verified performance data. This directly addresses the valuation opacity identified by Konialidis: by replacing subjective "professional judgment" with empirical performance data, the Performance Oracle transforms intangible asset valuation from an artisanal craft into a data-driven, algorithmically assisted process.

The Performance Oracle is the distinguishing innovation that separates PBS from all existing classes of tokenized assets. Tokenized bonds derive value from the issuer's credit rating—an assessment of the entity. PBS derive value from the asset's

own measurable output—an assessment of the thing itself. This distinction is foundational: it means that PBS valuation improves with every additional data point, creating an information-rich security that becomes more accurately priced over time.

3.3. Layer 3: The Exchange Protocol

Function: The Exchange Protocol provides the marketplace infrastructure for listing, pricing, trading, and settling PBS transactions.

Components: The protocol comprises five integrated subsystems: (1) an automated valuation engine that processes provenance depth, performance data, and demand signals to compute indicative pricing; (2) an ordermatching system supporting limit orders, market orders, and auction mechanisms; (3) a smart-contract escrow layer that holds assets and consideration during settlement; (4) an automated settlement system that executes ownership transfer upon satisfaction of all conditions; and (5) a compliance-verification module that ensures regulatory requirements are met prior to transaction finalization.

Economic Function: The Exchange Protocol creates liquidity for previously illiquid assets, completing the transformation from dead capital to living capital. Drawing on Coase (1937) and Arshadi (2024), the protocol reduces transaction costs—search, bargaining, contracting, enforcement—below the threshold at which intangible asset transactions become economically viable in an open marketplace [8,9]. The result is a market in which a genetic innovation, a creative work, or a portfolio of human expertise can be bought, sold, licensed, fractionally owned, and collateralized with transaction costs approaching those of established financial markets.

Regulatory Considerations: PBS that represent fractional ownership claims with expected returns derived in part from the efforts of a platform operator would likely satisfy the four-prong test established in *SEC v. W.J. Howey Co.*, 328 U.S. 293 (1946): (1) an investment of money, (2) in a common enterprise, (3) with an expectation of profits, (4) derived from the efforts of others. The framework acknowledges and incorporates securities regulation compliance as a foundational design requirement [16]. This is a deliberate contrast with much of the blockchain and tokenization literature, which has historically treated regulatory compliance as an afterthought or obstacle. PBS are designed to function within the existing regulatory architecture, not to circumvent it.

3.4. The Interaction Model and Formal Valuation

The three layers interact in a self-reinforcing cycle. The Provenance Ledger establishes what the asset is and who owns it. The Performance Oracle establishes what the asset does and how well. The Exchange Protocol establishes what the asset is worth and enables ownership transfer. This creates a virtuous feedback loop: deeper provenance documentation increases trust, which attracts more performance data, which enables more accurate valuation, which drives greater liquidity, which in turn creates stronger incentives to document provenance. The system

is designed to become more valuable and more accurate with each transaction and each data point.

The valuation of a Provenance-Backed Security can be expressed formally as a function of six variables:

$$V(\text{PBS}) = f(P_d, P_r, O_y, O_c, D_s, L_m)$$

Where:

P_d = Provenance depth (number of verified links in the chain of custody and contribution history)

P_r = Provenance reliability (composite cryptographic verification score reflecting identity confidence, temporal integrity, and attestation quality)

O_y = Output yield (measurable performance metric of the underlying asset, domain-specific: bushels per acre for seed genetics, streaming revenue for creative works, licensing income for patents)

O_c = Output consistency (variance in performance over time, reflecting asset reliability)

D_s = Demand signal (market interest expressed through trading volume, watchlist additions, inquiry frequency, and bid depth)

L_m = Liquidity multiplier (exchange depth, bid-ask spread compression, and time-to-settlement, reflecting the market's ability to efficiently intermediate transactions)

The function f is not specified as a closed-form equation at this stage of the framework's development; its precise functional form will require empirical calibration through market data from operational PBS exchanges. However, the key theoretical claim is that $V(\text{PBS})$ is monotonically increasing in P_d , P_r , O_y , and L_m , monotonically decreasing in O_c (where O_c represents variance), and conditionally increasing in D_s subject to fundamental-value anchoring through the performance oracle. This structure ensures that PBS valuation is anchored to verifiable fundamentals rather than to speculative sentiment alone—a critical design distinction from many existing digital asset classes.

4. Agricultural Proof of Concept: The Seed Genetic Asset Exchange

This section presents SeedBid as the empirical demonstration of the PBS framework applied to agricultural genetic intellectual property—a domain characterized by extreme market concentration, chronic undervaluation of independent innovation, and a well-documented market failure in genetic IP monetization.

4.1. The Market Failure

The global commercial seed market, estimated at approximately \$77–93 billion in 2025 depending on the methodology and scope of analysis, is one of the most concentrated markets in global agriculture.¹ A June 2025 report by ETC Group and GRAIN documented the extent of this concentration: Bayer, Corteva, Syngenta, and BASF control 56% of the global commercial seed market and 61% of the global pesticides market, meeting the standard economic definition of an oligopoly in which four firms control more than 40% of market share [17]. At the national level, concentration is even more pronounced. In the United States, the

top four seed companies control 83.9% of the corn seed market and 78.1% of the soybean seed market [18].

The economic consequences of this concentration are well documented. Between 1990 and 2020, genetically modified seed prices rose approximately 463%, while the crop commodity prices that farmers receive rose only 56% [18]. In more recent terms, U.S. corn seed costs per acre increased from approximately \$66 in 2000 to \$293 in 2024—a 344% increase that dramatically outpaced inflation, input cost growth, and commodity price appreciation. As Keith Fuglie of the USDA Economic Research Service has documented, this divergence reflects not the inherent cost of genetic innovation but the pricing power conferred by market concentration.

For independent breeders—those who develop novel genetic traits outside the corporate research infrastructure of the Big 4—the market failure is even more acute. An independent breeder who develops a drought-resistant corn variety has, at present, no mechanism to price, trade, license, or collateralize that genetic intellectual property independently. The genetics are embedded within the seed; the IP value is captured by the corporations that control distribution channels, not by the innovators who create the genetic improvements. The breeder can sell seed, but they cannot sell genetic IP as a standalone asset. There is no exchange, no standardized instrument, and no secondary market. The regulatory environment has begun to respond. In September 2025, the USDA and the Department of Justice signed a formal Memorandum of Understanding targeting anti-competitive behavior in seed, fertilizer, and equipment markets. The Independent Professional Seed Association (IPSA) has actively advocated for antitrust enforcement against the Big 4. However, regulatory enforcement alone cannot create the market infrastructure necessary for genetic IP to function as a tradeable asset class.

4.2. The SeedBid Implementation

SeedBid (U.S. Patent Application No. 64/048,095, filed April 24, 2026; Trademark Application, Serial No. 99786179) is a blockchain-anchored exchange that implements the three-layer PBS architecture for seed genetic intellectual property. The platform is designed to transform genetic innovation from a single-sale commodity into a liquid, tradeable, performance-backed asset class.

Provenance Ledger Implementation: SeedBid maintains an immutable blockchain record of genetic lineage, breeder identity, chain of custody, and ownership transfers for each seed lot and genetic line. Every registered genetic asset includes cryptographically verified breeder credentials, documented parentage and cross-pollination history, geographic origin data, and timestamped creation and registration records. This provenance chain establishes the formal property documentation that genetic IP has historically lacked, transforming informal breeder knowledge (“I developed this variety from a cross between Line A and Line B in 2019”) into verifiable, transferable, legally documentable property claims.

Performance Oracle Implementation: SeedBid integrates IoT sensor data —temperature, humidity, soil composition, precipitation, solar radiation— with agronomic performance metrics including germination rates, days to maturity, yield per acre, disease resistance scores, and pest tolerance levels. Critically, these performance data are linked to specific genetic identifiers on the Provenance Ledger, creating what is effectively the “earnings report” for each genetic line. A corn variety’s performance across multiple environments, growing seasons, and management practices becomes a continuously updated, empirically verified record that directly informs market valuation.

Exchange Protocol Implementation: SeedBid’s automated valuation engine computes fair market value for genetic IP based on provenance depth (generational lineage, breeding history), performance data (crossenvironment yield performance, consistency, disease resistance), and demand signals (query frequency, watchlist additions, bid activity). Smartcontract escrow manages transactions, ensuring that ownership transfers and licensing arrangements execute automatically upon satisfaction of all conditions. The marketplace supports multiple transaction types: outright genetic IP sales, licensing arrangements, fractional ownership, and royaltystream securities.

4.3. Implications for Independent Breeders and Market Competition

The SeedBid implementation has four significant implications for the structure of agricultural genetic markets:

First, for the first time, independent breeders can monetize genetic IP through licensing, fractional ownership, and secondary market trading—not solely through seed sales. A breeder who develops a superior droughtresistant trait can license that trait to multiple seed producers, sell fractional ownership stakes to investors, and receive ongoing royalties as the trait is deployed across acreage—all without surrendering the underlying IP.

Second, performance verification eliminates information asymmetry. In the current market, buyers rely on corporate marketing claims and limited trial data to assess genetic value. On the SeedBid exchange, buyers access verified, multi-environment, multi-season performance data linked to specific genetics on the provenance ledger. This breaks the marketing-driven pricing model that sustains oligopoly margins and replaces it with performance driven price discovery.

Third, the exchange creates genuine price discovery for genetic IP. When genetic innovations are traded on an open exchange with transparent provenance and performance data, market forces—not oligopoly pricing power—determine value. The 463% divergence between seed prices and commodity prices documented by the USDA becomes subject to competitive correction.

Fourth, the SeedBid framework aligns with Ostrom’s (1990) design principles for common-pool resource governance: clearly defined boundaries (verified breeders with documented credentials), congruent rules (performance-based pricing that rewards

genuine innovation), collective-choice arrangements (exchange participants shape trading parameters), monitoring (IoT oracle data providing continuous verification), and conflict resolution (arbitration protocols for disputed provenance claims) [11].

5. Beyond Agriculture: Extending the PBS Framework Across Intangible Asset Classes

The agricultural proof of concept establishes the viability of the three-layer PBS architecture in a specific domain. This section demonstrates the framework’s extensibility by mapping it to seven additional intangible asset classes, arguing that the architecture is domain-agnostic: applicable wherever an intangible asset possesses documentable provenance and measurable performance.

5.1. Creative Works and Intellectual Property

The Asset: Music compositions and recordings, visual art, literature, design works, film and video content, and other creative output.

Provenance: Creator identity and authentication, creation timestamp, collaboration and contribution records, version history, derivative work lineage, and rights chain-of-custody.

Performance: Streaming and playback counts, licensing revenue, synchronization placements, cultural impact metrics (awards, critical reception), citation and remix frequency, and audience engagement data.

Current Liquidity: Limited and heavily intermediated. Royalty markets exist (e.g., Royalty Exchange, Hipgnosis Songs Fund) but are opaque, accessible primarily to institutional investors, and structured around catalogs rather than individual works or creative contributions.

PBS Application: Transparent, royalty-backed securities in which creators retain provenance-documented ownership and receive performance-linked returns. A songwriter could tokenize their catalog as PBS, with provenance documenting their authorship and contribution to each work, performance oracles feeding real-time streaming and licensing revenue, and the exchange protocol enabling fractional ownership and secondary trading. This directly addresses the structural inequity of current music industry economics, in which labels and publishers historically capture the majority of long-term value from creative works while the creators who produce them hold minimal equity.

5.2. Patents and Trade Secrets

The Asset: Inventions, processes, formulations, and proprietary methodologies protected by patent filings or maintained as trade secrets.

Provenance: Inventor identity, filing date, prosecution history, priority chains, continuation and divisional relationships, and assignment records.

Performance: Licensing revenue, commercial adoption rate, citation count in subsequent patent filings, derivative innovation frequency, and litigation outcomes.

Current Liquidity: Near zero for the vast majority of patents. While WIPO reports that global IP filings nearly doubled in the preceding decade to approximately 20 million in 2023, and annual cross-border IP payments exceed \$1 trillion globally, individual patents remain fundamentally illiquid. Patent assertion entities (PAEs) represent the closest analog to a secondary market, but their adversarial, litigation-driven model is economically inefficient and socially contentious [19].

PBS Application: Patent-backed securities with performance-verified valuation, enabling fractional ownership of patent portfolios and creating a transparent secondary market for innovation. University technology transfer offices, independent inventors, and corporate R&D departments could all participate as issuers, with performance oracles tracking commercial adoption and revenue generation.

5.3. Personal Data

The Asset: Behavioral data, preference profiles, health data, location histories, and other personally generated digital exhaust. **Provenance:** Individual identity verification, collection provenance (how, when, and where data was generated), consent records, and processing history.

Performance: Predictive accuracy when used in model training, advertising revenue generated per profile, research utility scores, and data freshness.

Current Liquidity: Zero for individuals. The digital advertising industry represents approximately 1.1% of U.S. GDP [20]. Alphabet alone generated advertising revenue equivalent to approximately 0.85% of U.S. GDP in 2023. The individuals whose behavioral data generates this value receive no direct compensation.

PBS Application: Personal data securities owned by individuals, structured to pay dividends when corporate AI systems, advertising platforms, or research institutions utilize their data for model training, ad targeting, or analysis. The provenance ledger documents data ownership and consent; the performance oracle tracks data utilization and value generation; the exchange protocol enables individuals to set terms, negotiate compensation, and trade data rights as standardized instruments.

5.4. Scientific Research

The Asset: Datasets, methodologies, experimental findings, analytical frameworks, and computational models.

Provenance: Researcher identity, institutional affiliation, methodology documentation, peer review history, replication records, and data provenance chains.

Performance: Citation impact, replication success rate, commercial application, policy influence, and downstream research enabled.

PBS Application: Research-backed securities that provide scientists with ongoing returns when their findings are commercially applied, integrated into policy, or used as foundational data in subsequent research. This creates a direct economic incentive for rigorous, replicable research and provides an alternative funding mechanism to the grant-dependent model that currently dominates academic science.

5.5. Manufacturing Processes

The Asset: Production methods, quality control innovations, operational improvements, supply chain optimizations, and fabrication techniques.

Provenance: Development history, facility records, engineering documentation, continuous improvement records, and inventor/contributor identification.

Performance: Defect rates, throughput metrics, efficiency improvements, cost reductions, and yield increases attributable to the process innovation.

PBS Application: Process IP securities enabling manufacturers—and, critically, the individual engineers, machinists, and line workers who develop process innovations—to monetize operational improvements beyond their own production lines. A machinist who develops a novel fabrication technique that reduces defect rates by 30% could tokenize that process innovation as a PBS, with performance oracles tracking outcomes in every facility that licenses the technique.

5.6. Labor and Human Capital

The application of the PBS framework to labor markets represents the most transformative—and most urgently needed—extension of the architecture.

This domain is addressed in detail in Section 6.

5.7. Biological and Genetic Assets Beyond Agriculture

The agricultural proof of concept generalizes naturally to other biological domains. In pharmaceuticals, drug compound IP could be documented on the provenance ledger with full synthesis and clinical trial lineage, performance tracked through efficacy data and clinical outcomes, and traded on the exchange protocol. In biotechnology, engineered organism IP could be similarly structured. In environmental science, carbon sequestration performance data—verified through remote sensing, soil sampling, and atmospheric measurement—could form the basis for PBS that link land management practices to quantifiable climate outcomes.

5.8. Cross-Domain Analysis

Table 1 presents a comparative analysis of the three-layer architecture across all eight domains, identifying common structural patterns and domainspecific adaptations.

Domain	Provenance Ledger	Performance Oracle	Exchange Mechanism	Current Liquidity
Seed	Genetic	IoT yield	Licensing,	Near zero
Genetics	lineage, breeder ID, chain of custody	data, germination rates, disease resistance	fractional ownership, royalty streams	
Creative Works	Creator ID, timestamps, collaboration records	Streaming counts, licensing revenue, cultural impact	Royaltybacked securities, fractional catalog ownership	Low, heavily intermediated
Patents	Inventor ID, filing history, priority chains	Licensing revenue, adoption rate, citation count	Patentbacked securities, portfolio fractionalization	Near zero
Personal Data	Individual ID, collection provenance, consent	Predictive accuracy, ad revenue per profile	Datadividend securities, usage-based compensation	Zero for individuals
Scientific Research	Researcher ID, methodology, peer review	Citation impact, replication success, commercial use	Researchbacked securities, downstream royalties	Zero
Manufacturing	Development history, contributor ID, documentation	Defect rates, throughput, efficiency gains	Process IP securities, cross-facility licensing	Near zero
Human Capital	Education, credentials, project history, verified skills	Work output, efficiency, quality scores, outcomes	Expertisebacked securities, AI-training royalties	Zero
Bio/Pharma	Synthesis history, clinical trial lineage, contributor ID	Efficacy data, clinical outcomes, adoption rates	Compound IP securities, outcomelinked instruments	Low, institutional only

Table 1: Three-Layer PBS Architecture: Cross-Domain Mapping

The cross-domain analysis reveals three structural commonalities. First, every domain exhibits the same fundamental pattern: productive intangible assets that generate measurable economic value but lack the property-rights infrastructure to function as capital. Second, in every domain, the three-layer architecture maps cleanly: provenance can be documented, performance can be measured, and exchange can be facilitated. Third, the current liquidity across all eight domains ranges from zero to low—confirming that the “dead capital” thesis applies broadly to the intangible economy, not merely to the agricultural case.

The framework’s strength lies in its generality. The same architectural principles that enable a corn breeder in Iowa to tokenize their genetic IP can enable a jazz musician in New Orleans to tokenize their catalog, a data scientist in Bangalore to tokenize their expertise, or a pharmaceutical researcher in Basel to tokenize a drug compound. The provenance performance-exchange structure is invariant across domains; only the specific data sources, performance metrics, and regulatory requirements differ.

6. Provenance-Backed Securities and the Future of Work: Toward an Ownership-Based Meritocracy

This section develops the paper’s most consequential argument: that provenance-backed securities offer a structural solution to AI-driven labor displacement by converting accumulated human expertise into owned, tradeable, royalty-generating capital assets. The argument proceeds in five steps: the displacement mechanism, the failure of existing policies, the PBS solution, the meritocracy thesis, and illustrative scenarios.

6.1. The Displacement Mechanism

The World Economic Forum’s 2025 projections—92 million jobs displaced, 170 million created, a net positive of 78 million—

describe the aggregate arithmetic of technological disruption. But the aggregate obscures the distributional reality. The 170 million new roles are concentrated in AI and big data, networks and cybersecurity, and technological literacy—fields that require significant retraining and, in many cases, fundamentally different cognitive aptitudes than the 92 million roles being displaced [4]. The displaced truck driver does not become an AI engineer. The eliminated administrative assistant does not become a cybersecurity analyst. The workers who lose their jobs and the workers who gain new ones are, in the main, different people.

More fundamentally, AI-driven displacement operates through a mechanism that is structurally distinct from all previous technological disruptions. The Industrial Revolution displaced manual labor but did not extract accumulated knowledge. A hand-loom weaver displaced by the power loom lost their job but retained their knowledge of textiles, patterns, and fiber behavior— knowledge that could be redeployed in new contexts. AI displacement, by contrast, extracts and replicates the knowledge itself. When a diagnostic AI system is trained on a radiologist’s twenty years of pattern-recognition expertise, the AI absorbs not merely the task but the accumulated judgment, the tacit knowledge, the experiential learning that constitutes the radiologist’s professional value. The human’s expertise does not disappear; it is appropriated—transferred from the worker who created it to the corporation that deployed the AI system.

This represents a novel form of capital appropriation. In traditional labor economics, workers sell their time and effort but retain their skills and knowledge. In the AI economy, workers’ accumulated expertise is extracted, encoded, and corporatized—and once extracted, the worker is no longer needed. The expertise becomes a corporate asset; the worker becomes redundant. No existing framework provides a mechanism for the worker to retain

ownership of the value that their expertise generates after it has been absorbed by an AI system.

6.2. The Failure of Current Policy Proposals

Each of the four principal policy responses to automation-driven displacement, reviewed in Section 2.4, addresses symptoms rather than the underlying structural cause. Universal Basic Income treats displaced workers as dependents who require sustenance. It provides no ownership, no asset creation, no wealth accumulation, and no mechanism for the worker to participate in the economic value generated by the AI systems that absorbed their expertise.

UBI is a floor, not a ladder.

Reskilling and upskilling programs treat the problem as a skills mismatch rather than an ownership transfer. They assume that the displaced truck driver can be retrained as an AI engineer—an assumption that ignores age, aptitude, geographic constraints, and the sheer scale of the transformation required. More critically, reskilling programs implicitly accept that the worker’s previously accumulated expertise has zero residual value once the AI system has absorbed it. This is economically false: the expertise has been absorbed precisely because it is valuable. Public-private partnerships maintain the employer-employee relationship, redistributing employment opportunities rather than ownership of value. They do not create any mechanism for workers to own, accumulate, or trade the assets created by their expertise. Platform cooperativism, as developed by Scholz (2023), demonstrates that worker-owned platforms are operationally viable. More than one million workers worldwide now participate in platform cooperatives that distribute a greater share of revenue to workers [13]. But cooperatives redistribute revenue; they do not create tradeable assets. A driver in a cooperative earns a greater share of each fare, but their driving expertise—their accumulated knowledge of routes, traffic patterns, passenger management, and vehicle operation—remains economically intangible. They cannot trade it, collateralize it, or accumulate equity in it.

The common thread is revealing: none of these proposals address the fundamental question of ownership. Who owns the value created by human expertise when that expertise is absorbed by AI? Under current structures, the answer is unambiguous: the corporation that deployed the AI system. The worker, whose decades of accumulated expertise made the AI possible, owns nothing.

6.3. The PBS Solution: Human Capital Securities

The three-layer PBS architecture, when applied to labor markets, creates a structural mechanism for workers to own, accumulate, trade, and receive ongoing returns from their expertise—including after that expertise has been absorbed by AI systems.

Provenance Ledger for Human Capital: An immutable, worker-owned record of education, training, certifications, employment history, project contributions, skill development, and professional accomplishments. This is not a resume—a self-reported, unverified, static document that serves the employer’s informational needs. It is

a provenance chain: third-party verified (by educational institutions, employers, clients, and professional bodies), continuously updated (with each project, skill acquisition, and contribution), owned by the worker (portable across employers, not controlled by any single entity), and cryptographically secured (tamper-proof and independently auditable). The human capital provenance ledger does for worker expertise what a land title registry does for real property: it transforms an informal, unverifiable claim into a formal, transferable, collateralizable property right.

Performance Oracle for Human Capital: Verified work-output metrics continuously feed the worker’s performance record. These include project outcomes (did the project succeed?), efficiency improvements (did the worker’s contribution improve processes?), quality scores (did the output meet or exceed standards?), peer assessments (how do colleagues and collaborators rate the contribution?), client satisfaction (did the work product deliver value?), and revenue contributions (can the worker’s contribution be linked to measurable economic outcomes?). The performance oracle transforms subjective managerial assessment (“this is a good employee”) into verified, quantified, continuously updated performance data (“this worker’s contributions generated a measurable 12% improvement in throughput across three projects, verified by independent audit”).

Exchange Protocol for Human Capital: A marketplace where expertisebacked securities can be listed, valued, and traded. The exchange supports multiple instrument types: direct expertise licensing (an expert makes their documented knowledge available for a fee), fractional ownership (investors purchase stakes in a worker’s expertise portfolio, receiving returns as that expertise generates value), and—most critically for the AI displacement scenario—**AI training royalties**. When an AI system is trained on data derived from a worker’s provenance-documented expertise, the PBS generates royalty-like returns to the worker. The expertise does not disappear when the worker is displaced; it becomes a royalty-generating asset that continues to produce returns as long as the AI system operates.

6.4. The Meritocracy Thesis

A functioning meritocracy requires two conditions: (1) that contributions be measurable, and (2) that contributors be compensated in proportion to the value of their contributions. Current labor markets fail on both counts. Contributions are measured crudely, through hours worked, managerial assessments, and position in organizational hierarchies. These measures systematically undervalue expertise, creativity, and tacit knowledge while overvaluing organizational seniority and political skill. Compensation is distributed not by value created but by market power: the employer’s bargaining position, the worker’s replaceability, and the prevailing wage in the geographic labor market. A senior radiologist in Detroit and a senior radiologist in San Francisco may possess identical expertise but earn dramatically different incomes solely due to geographic labor market conditions—conditions that are orthogonal to the value of their diagnostic skill.

PBS create the infrastructure for a genuine meritocracy by addressing both conditions. The provenance ledger documents who contributed. The performance oracle measures what they contributed and how much value that contribution generated. The exchange protocol ensures they are compensated in proportion to that value—not through employer-mediated wages but through market-priced, ownership-based returns on their documented and verified expertise. Larry Fink’s historical parallel, drawn from his 2025 Annual Letter, is apt: when the Amsterdam Stock Exchange opened in 1602, “for the first time, ordinary people didn’t just watch the economy grow around them. They owned a share of that growth—a real, tradable share” [7]. Fink was describing the democratization of financial capital. PBS propose an analogous democratization of human capital: for the first time, ordinary workers would not merely contribute their expertise to the economy; they would own a share of the value that expertise generates—a real, tradeable share.

6.5. Illustrative Scenarios

Three scenarios illustrate how PBS would function in practice for workers facing AI displacement:

Scenario 1: The Senior Radiologist. Dr. Elena Vasquez has spent 22 years developing expertise in mammographic pattern recognition. Her provenance ledger documents her medical education (verified by the institution), her residency and fellowship (verified by the training hospital), her board certifications (verified by the professional board), and 22 years of diagnostic performance data (verified by her employer’s quality assurance system)—including a false-negative rate consistently in the top decile nationally. When the hospital deploys a diagnostic AI system trained substantially on Dr. Vasquez’s case archive, her expertise is absorbed by the AI. Under current structures, Dr. Vasquez is laid off. Under the PBS framework, Dr. Vasquez’s provenance-documented expertise becomes a royalty-generating security. Every case the AI system processes using pattern-recognition capabilities derived from her documented expertise generates a micro-royalty, deposited into her PBS account. Her expertise does not disappear; it becomes a capital asset that generates returns for the rest of her life.

Scenario 2: The Logistics Coordinator. Marcus Chen has spent 18 years as a logistics coordinator for a national freight company. His provenance ledger documents his certifications, his route optimization decisions, his weather-avoidance strategies, and the performance outcomes of his logistics plans—including a documented 14% improvement in on-time delivery rates over his tenure. When the company deploys an autonomous fleet management AI trained on Marcus’s historical routing data, his expertise is absorbed. Under the PBS framework, Marcus’s accumulated performance data, documented on the provenance ledger, represents a tradeable asset. The AI system’s routing decisions, to the extent they are derived from Marcus’s documented expertise, generate ongoing royalty returns. Marcus can also license his expertise PBS to other logistics companies seeking to train their own AI systems, creating a secondary market for verified logistics expertise.

Scenario 3: The Master Machinist. Ingrid Hoffmann has spent 30 years developing precision fabrication techniques for aerospace components. Her techniques, documented on the provenance ledger with process descriptions, engineering drawings, and performance data, have reduced defect rates by 37% compared to industry averages. When her employer digitizes her techniques for integration into computer-controlled manufacturing systems, her knowledge is extracted. Under the PBS framework, Ingrid’s manufacturing process IP—documented, performance-verified, and anchored to the provenance ledger—becomes a licensable, tradeable security. Every facility that deploys her techniques generates returns proportional to the measurable performance improvement her innovations provide.

In each scenario, the PBS framework accomplishes what no existing policy proposal achieves: it converts the worker’s accumulated expertise from a depletable employment attribute (lost when the job ends) into a durable capital asset (retained and income-generating regardless of employment status). The worker is no longer merely a labor input to be displaced; they are a capital owner whose assets generate returns.

7. Policy Implications, Limitations, and Conclusion Policy Recommendations

The implementation of provenance-backed securities at scale will require coordinated policy action across four domains:

Securities Regulation for PBS. Regulatory bodies—the U.S. Securities and Exchange Commission (SEC), the European Securities and Markets Authority (ESMA), and their counterparts—should develop classification guidelines for provenance-backed securities. The four-prong Howey test provides a starting point for analysis, but may require adaptation for instruments whose value derives from continuously verified performance data rather than from the managerial efforts of a central promoter [16]. Regulatory sandboxes, already established in the UK (FCA), Singapore (MAS), and the UAE (ADGM) for fintech innovation, could provide initial environments for PBS market testing under regulatory supervision. The goal is not deregulation but appropriate regulation: a framework that protects investors while enabling the legitimate creation of a new asset class.

Data Sovereignty and Expertise Ownership Legislation. Legal frameworks must establish clear individual ownership of personal data and expertise data used in AI training. The European Union’s General Data Protection Regulation (GDPR) provides a foundation for data protection but does not extend to ownership, compensation, or capital formation rights. Legislation should establish that when an individual’s documented, provenance-verified expertise is used to train an AI system, the individual retains a legally enforceable ownership interest in the derived economic value. This extends de Soto’s property rights formalization from tangible assets in developing nations to intangible assets in the developed world’s digital economy.

Intellectual Property Reform. Current IP regimes protect formal inventions (through patents), creative expressions

(through copyright), and brand identities (through trademark). They do not protect accumulated expertise, process knowledge, or performance data as property rights. Legislative frameworks should recognize provenance-documented intangible assets—including human capital, operational innovations, and empirically verified expertise—as protectable property rights eligible for tokenization and exchange. This is not a radical expansion of IP law; it is the logical extension of existing property-rights principles to asset classes that have emerged since those principles were last significantly updated.

Education and Workforce Development Integration. If PBS are to function as a genuine meritocratic infrastructure, provenance documentation must be integrated into education and training from the earliest stages of skill development. Students should begin building their human capital provenance portfolio—verified educational achievements, project contributions, skill demonstrations—from the beginning of their professional preparation. By the time they enter the workforce, they should possess a documented, verified, continuously growing provenance chain that forms the foundation of their human capital security.

Limitations and Future Research

This paper proposes a framework; it does not claim to have solved every implementation challenge. Several categories of limitation warrant explicit acknowledgment.

Technical Limitations: Blockchain scalability remains a concern for applications requiring high-throughput provenance documentation across millions of workers and billions of data points. Oracle reliability—ensuring that performance data feeds are accurate, tamper-resistant, and independently verifiable—is a non-trivial engineering challenge. Privacy concerns in provenance documentation must be addressed: workers must control what information is shared with whom, and granular permission systems must be designed that balance transparency with privacy. Interoperability between PBS exchanges across domains and jurisdictions will require standardization efforts that have yet to begin.

Economic Limitations: Market adoption faces a bootstrapping challenge common to all two-sided platforms: the exchange needs both asset issuers and investors to function, but neither side has incentive to participate without the other. The agricultural proof of concept (SeedBid) addresses this through a concentrated market with clearly identified participants and well documented pain points; other domains may face more diffuse adoption challenges. Liquidity in early-stage PBS markets may be thin, resulting in volatile pricing and wide bid-ask spreads. Regulatory uncertainty across jurisdictions creates compliance risk that may deter institutional participation.

Theoretical Limitations: The framework assumes that provenance can be reliably documented and performance can be meaningfully measured for all intangible assets. This assumption holds strongly for assets with clear authorship and quantifiable outputs (seed

genetics, patents, creative works) but may weaken for assets characterized by highly tacit or contextual knowledge—the kind of expertise that the expert themselves cannot fully articulate. Michael Polanyi’s (1966) insight that “we can know more than we can tell” identifies a boundary condition for the PBS framework: assets whose value resides in unarticulable tacit knowledge may be difficult to document on any provenance ledger, however sophisticated [21].

Proposed Research Agenda: Four priorities for future research emerge from this analysis. First, empirical validation through the SeedBid agricultural proof of concept, with publication of market data on price discovery, liquidity development, and breeder adoption rates. Second, simulation modeling of PBS adoption in labor markets, examining the conditions under which human capital securities achieve sufficient adoption to function as a meaningful displacement buffer. Third, regulatory analysis of PBS classification across major jurisdictions (United States, European Union, United Kingdom, Singapore, United Arab Emirates), identifying harmonization opportunities and regulatory barriers. Fourth, theoretical refinement of the valuation model, including empirical estimation of the functional form of $V(\text{PBS})$ using data from operational exchanges [22].

8. Conclusion

This paper began with an empirical observation: the composition of corporate value has undergone a 75 percentage-point inversion over the past fifty years, from 83% tangible to 92% intangible. It proceeded to identify a paradox: despite \$80 trillion in global intangible asset value, the infrastructure for owning, valuing, and trading most intangible assets remains primitive. And it named this paradox: the intangible economy is the largest pool of “dead capital”—in de Soto’s precise sense—in human history. Not because these assets lack productive value, but because they lack the property rights infrastructure to function as capital.

The provenance-backed security, through the three-layer architecture of Provenance Ledger, Performance Oracle, and Exchange Protocol, provides that infrastructure. The Provenance Ledger solves the documentation problem, establishing verifiable ownership of intangible assets. The Performance Oracle solves the valuation problem, providing continuously updated, empirically verified data on asset performance. The Exchange Protocol solves the liquidity problem, creating markets where previously illiquid assets can be traded, fractionalized, and collateralized. The agricultural proof of concept demonstrates that the framework is not merely theoretical. SeedBid applies the three-layer architecture to a \$77–93 billion market in which oligopoly concentration has driven a 463% increase in seed prices while commodity returns rose only 56%—a market in which independent breeders who create genuine genetic innovation have had no mechanism to capture the value of their contributions.

The framework’s extensibility to creative works, patents, personal data, scientific research, manufacturing processes, biological assets, and—most urgently—human capital in labor markets facing AI

displacement suggests that provenance-backed securities represent not merely a financial innovation but a structural mechanism for preserving economic meritocracy in the age of automation. When 92 million workers face displacement by AI systems that have absorbed their expertise, the question is not merely “Where will they find new jobs?” but “Who will own the value of what they created?” PBS provide an answer: the workers themselves. Four centuries ago, the Amsterdam Stock Exchange transformed the concept of ownership by giving ordinary people a “real, tradable share” in the productive economy. Provenance-backed securities propose the same transformation for the intangible economy—an economy in which the most valuable assets are not things that can be touched but things that can be thought, created, and verified. The Industrial Revolution created the factory. The Digital Revolution created the platform. The Intangible Revolution requires the provenance-backed security—or the creators of the world’s most valuable assets will own nothing.

Notes

1 Market size estimates for the global seed industry vary significantly depending on scope (commercial seeds only vs. all seeds), methodology (revenue vs. value chain), and source. Mordor Intelligence estimates approximately \$77 billion (2025); Cognitive Market Research estimates \$59.3 billion; Maximize Market Research estimates \$93 billion. This paper cites the range to acknowledge methodological variation. The concentration ratios reported by ETC Group/GRAIN (2025) and USDA (2023) are based on commercial seed market revenue and are consistent across sources.

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