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**TOKENIZATION AND ASSET PRICING: EXPANDING FINANCIAL
OBSERVABILITY OF REAL ASSETS. AN APPLICATION TO
ENERGY INFRASTRUCTURE IN VACA MUERTA**

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**Tokenization and Asset Pricing: Expanding
Financial Observability of Real Assets**
*An Application to Energy Infrastructure in Vaca
Muerta*¹²

UCEMA

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May 2026

1 Parts of the drafting and language editing of this paper were assisted using Microsoft Copilot Pro. All conceptual development, economic analysis, and conclusions are solely the author's.

2 "The author's views in this paper do not necessarily represent the view of Universidad del CEMA."

Abstract

Standard asset pricing theory defines the market portfolio as the aggregation of all risky assets in the economy. In practice, however, empirical implementations of models such as the Capital Asset Pricing Model (CAPM) rely almost exclusively on publicly traded equities and, to a lesser extent, corporate debt. As a result, a large set of economically relevant assets—particularly real estate, infrastructure, and physical capital—remain central to production and wealth accumulation but are largely absent from the observable and tradable asset set on which empirical asset pricing is based.

This paper argues that the tokenization of real-world assets (RWA) has the potential to narrow the gap between theoretical asset pricing frameworks and financial market practice by **expanding financial observability** rather than by altering underlying pricing theory. While prevailing regulatory approaches correctly emphasize that tokenization does not create new securities in a legal sense, we show that, from a financial perspective, the digital representation and economic fragmentation of previously indivisible and illiquid assets may alter their functional role within the asset space. **Tokenization can enable transferability, measurement, and price discovery for payoff streams that were previously non-transactable, thereby expanding the empirically observable set of risky assets.**

Building on contingent claims theory, this work clarifies that tokenization does not create new states of nature nor mechanically complete markets. Instead, **it may make previously unobservable or untradeable payoff dimensions financially observable**, expanding the span of traded payoffs without implying full market completeness. When tokenized instruments are designed to link cash flows to operational or physical performance variables, they may introduce payoff vectors not spanned by traditional equity or debt claims, thereby relaxing—though not eliminating—market incompleteness.

The paper illustrates these mechanisms through the case of energy infrastructure financing in Vaca Muerta, Argentina, where investors seeking passive exposure to sectoral growth have historically been limited to equity or debt issued by a small number of integrated operators. We argue that asset-backed, tokenized instruments linked to productive infrastructure can function as more direct financial proxies for real asset growth, complementing existing securities without displacing established regulatory frameworks.

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1. Introduction

1.1 Motivation: Real Assets and the Limits of Financial Observability

One characteristic of modern economies is that a substantial share of aggregate wealth is held in real and privately owned assets—including real estate, infrastructure, private businesses, fine art, natural resources, and physical capital—that are infrequently traded or not traded at all. Unlike publicly listed securities, these assets lack continuous market prices, standardized contracts, and high-frequency transaction data. Their economic value is therefore only imperfectly observable, inferred through appraisals, valuation models, or sporadic transactions rather than revealed through continuous market clearing.

The asset pricing literature has long recognized that limited observability and illiquidity are not merely practical inconveniences but fundamental constraints on valuation, risk measurement, and portfolio choice. When assets trade infrequently, prices are stale or missing, investors face irreversibility or delayed trading and equilibrium outcomes deviate systematically from frictionless benchmarks. In such environments, liquidity itself becomes a priced characteristic, and the absence of timely price signals weakens both risk sharing and capital allocation.

From an accounting and regulatory perspective, this lack of observability is formalized in the fair value hierarchy, where many real assets fall into Level 3 valuations³—those based on models using unobservable inputs and entity-specific assumptions. In asset-pricing terms, this classification signals that prices do not arise from continuous market clearing, payoffs lie outside the span of traded assets, and risk exposures are inferred rather than revealed. As a result, a large portion of economically relevant wealth remains financially opaque, despite being central to long-term investment and production.

This opacity has direct implications for asset pricing. In liquid markets, prices aggregate dispersed information and act as sufficient statistics for beliefs and risks; where prices are absent or delayed, that aggregation mechanism breaks down. Empirical work on private and illiquid assets shows that missing or infrequent prices bias return measurement, distort risk estimates, and weaken the empirical link between asset prices and macroeconomic states. In short, the limits of financial observability constrain how asset pricing theory maps to market practice, particularly for real-world assets that dominate long-horizon investment.

1.2 The Gap Between Asset Pricing Theory and Market Practice

Standard asset pricing theory is built on strong informational and market structure assumptions. Models such as CAPM, consumption-based asset pricing, and Arrow–Debreu

³Under U.S. GAAP, Level 3 inputs are unobservable inputs, used when neither quoted prices nor relevant market proxies are available. These inputs are typically based on entity-specific assumptions about cash flows, discount rates, liquidity, or risk premia (kpmg.com; viewpoint.pwc.com). In asset-pricing terms, a Level 3 classification signals that (i) prices do not arise from continuous market clearing, (ii) payoffs are not directly spanned by traded securities, and (iii) risk exposures are inferred rather than revealed. In the Argentine context, these features are reinforced by the structural thinness and illiquidity of local capital markets, which limit price discovery and increase reliance on model-based valuation. Thus, the fair value hierarchy provides a regulatory mapping of observability.

general equilibrium assume that payoffs are well defined, assets are tradable at known prices, and risks can be aggregated or diversified through portfolios. In these frameworks, no-arbitrage conditions ensure a tight link between risk and return, and state-contingent pricing provides a benchmark for optimal risk sharing.

Market practice departs sharply from these assumptions. Many economically important assets are non-marketable, thinly traded, or traded only episodically, leading to incomplete price discovery and segmented investor participation. Portfolio allocations in the presence of illiquid assets differ qualitatively from frictionless benchmarks: investors face trading constraints, state-dependent risk aversion, and compensation for illiquidity rather than for cash-flow risk alone. As a result, observed returns embed liquidity premia and segmentation effects that standard models treat as anomalies rather than structural features.

This divergence is particularly stark from the perspective of state-contingent pricing. While Arrow–Debreu theory provides a benchmark in which every future state of the world has an associated price, most risks tied to real assets—macroeconomic downturns, regulatory shifts, climate events, or local shocks—are only imperfectly hedged. Market incompleteness is therefore not a theoretical curiosity but a pervasive feature of real asset economies.

This paper adopts the view that the gap between theory and practice arises not from incorrect pricing equations, but from the fact that many economically relevant payoffs lie outside the observable and tradable asset space. The no-arbitrage logic of asset pricing remains intact; what is constrained is the set of payoffs to which it can be empirically applied.

1.3 Intended Contribution of This Work

This paper contributes to the asset pricing and financial market design literature by reframing real-world asset tokenization through the lenses of observability, tradability, and payoff structure, rather than through technological novelty or legal classification. Standard asset pricing models implicitly assume that economically relevant risks are observable and that their payoffs are spanned by traded securities. In practice, a substantial share of aggregate risk is embedded in assets that are economically central but financially invisible.

The first contribution is conceptual. The paper offers a unified framework linking the theoretical definition of the market portfolio, empirical asset pricing implementations, and institutional measures of observability. From this perspective, the exclusion of real assets from empirical models reflects limitations of the traded asset space rather than failures of equilibrium pricing.

The second contribution is interpretive. Tokenization is viewed not as a new asset class or a modification of pricing theory, but as financial infrastructure that may relax observability and transferability constraints. Tokenization does not create new states of nature, nor does it alter the stochastic discount factor. Rather, it may render previously unobservable or untradeable payoff dimensions financially observable, expanding the span of traded payoffs without implying full market completeness.

Third, the paper contributes to policy and institutional discussions by clarifying the limits of financial innovation. While tokenization may improve price discovery and risk sharing along

specific dimensions, it does not eliminate the structural sources of market incompleteness inherent in real asset economies. Recognizing these limits allows tokenization to be evaluated using standard asset pricing concepts—spanning, diversification, and incompleteness—without overstating its transformative potential.

Finally, this work adopts the functional perspective on financial innovation emphasized by Merton (2000), according to which financial analysis should focus on the economic functions performed by the financial system—such as risk sharing, intertemporal allocation, price discovery, and aggregation—rather than on particular institutional forms or technologies. From this viewpoint, when financial theory indicates that certain economically meaningful functions “should exist” but are not yet supplied in market practice, financial innovation may be understood as an attempt to fill that gap. Consistent with this perspective, the paper evaluates tokenization not as a new asset class or a modification of asset pricing theory, but as a potential financial infrastructure for performing missing functions related to the observability and tradability of real-asset payoffs. (Merton, 2000)

1.4 Structure of the Paper

The remainder of the paper is organized as follows.

Section 2 revisits the role of risky assets and the market portfolio in asset-pricing theory. It reviews the theoretical definition of the market portfolio, the assumptions underlying the Capital Asset Pricing Model, and the structural limitations of empirical implementations that rely exclusively on observable traded assets. The section concludes by characterizing real-world assets as economically relevant but financially invisible.

Section 3 introduces tokenization as financial infrastructure. It distinguishes legal representation from economic function, examines how asset fragmentation and transferability affect price discovery, and analyzes how tokenized real-world assets can expand the observable asset space. The section also discusses regulatory framing through the lens of functional equivalence.

Section 4 studies the implications of tokenization for the measurement of risk and return. It shows how physical assets can be mapped into measurable risk exposures, examines the consequences for portfolio construction and diversification, and evaluates how tokenized assets affect the empirical scope of asset-pricing models.

Section 5 places the analysis within contingent claims theory. It reviews the concepts of state-contingent payoffs and market completeness, identifies the sources of market incompleteness in real-asset economies, and interprets financial innovation as an expansion of the payoff space.

Section 6 integrates the preceding analysis to assess whether and how tokenized real-world assets can expand the span of traded payoffs and, in doing so, move markets toward greater—but not full—completeness. It discusses the design of state-contingent payoffs on real assets, the role of dimensionality in the payoff space, the distinction between asset-space expansion and full market completeness, and the limits and open questions that remain.

Section 7 applies the framework to energy infrastructure, with a focus on Vaca Muerta. It examines existing financial exposures to real-asset growth, the contractual structure of infrastructure and oilfield-services cash flows, and the role of tokenized infrastructure as a financial growth proxy, with particular attention to implications for passive investors.

Section 8 discusses broader implications for emerging markets, including the relationship between real assets, capital formation, and financial depth, the scope for tokenization beyond energy infrastructure, and institutional and regulatory considerations.

Section 9 concludes by summarizing the conceptual framework developed in the paper and clarifying its implications for asset-pricing theory. Rather than presenting empirical findings, the paper offers a structured way to think about tokenization as a mechanism for expanding the observable and tradable asset space and discusses how this perspective can inform future empirical modeling and measurement. The section also considers policy and market-design considerations considering ongoing uncertainty about the long-term effects of tokenization, and outlines directions for future research aimed at testing and operationalizing the framework proposed here.

2. Risky Assets and the Market Portfolio in Asset Pricing Theory

This section revisits the role of risky assets and the market portfolio in asset pricing theory. It reviews the theoretical definition of the market portfolio, the assumptions underlying the Capital Asset Pricing Model (CAPM), and the structural limitations that arise when empirical implementations are restricted to observable traded assets. The section concludes by characterizing real-world assets as economically relevant sources of risk that remain largely invisible within standard financial datasets.

2.1 The Theoretical Definition of the Market Portfolio

In asset pricing theory, the market portfolio plays a central role as the aggregation of all risky assets in the economy. In its most general formulation, the market portfolio includes every asset that delivers uncertain payoffs to investors, weighted by its market value. This definition is theoretical rather than institutional: it is not tied to any specific exchange, security type, or legal form, but reflects the totality of aggregate risk faced by economic agents (Sharpe, 1964; Merton, 1973).

Formally, let \mathcal{A} denote the set of all risky assets in the economy. The market portfolio M is defined as the value-weighted portfolio spanning all assets $i \in \mathcal{A}$, regardless of whether those assets are publicly traded, privately held, or institutionally observable. Under this interpretation, the market portfolio is intended to capture exposure to economy-wide sources of uncertainty, including risks arising from production, investment, and ownership of real assets. General equilibrium asset-pricing models therefore abstract from questions of asset visibility or tradability, assuming that all economically relevant risks are, at least conceptually, represented within the asset space (Cochrane, 2005).

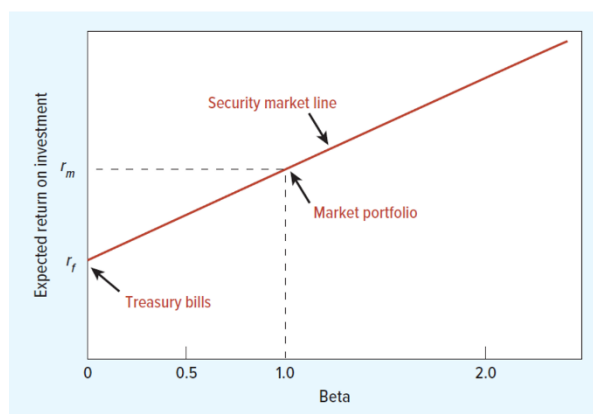


Figure 1: The Security Market Line (*SML*) and the Market Portfolio (*M*).

General equilibrium asset pricing models adopt this abstraction to derive equilibrium pricing relations, treating the asset universe as conceptually complete and postponing questions of observability or tradability. While this approach facilitates theoretical analysis, it leaves open the practical question of how the market portfolio is approximated when large components of economic wealth are not continuously traded or directly observable.

2.2 CAPM and the Assumption of Observable Risky Assets

The Capital Asset Pricing Model provides a tractable equilibrium relationship linking expected returns to exposure to the market portfolio (Sharpe, 1964; Lintner, 1965). In its standard form, the CAPM states that the expected excess return on asset i is proportional to its exposure to the market portfolio (i.e., systematic risk), measured by its beta:

$$\beta_i \equiv \frac{\text{Cov}(R_i, R_M)}{\text{Var}(R_M)}$$

where R_i denotes the return on asset i and R_M the return on the market portfolio.

This formulation reduces risk to a single sufficient statistic—the covariance of an asset’s return with the market portfolio—under the assumptions that investors hold mean–variance efficient portfolios and that idiosyncratic risk is fully diversified. Implicit in this framework is that the assets generating aggregate risk are observable and that their returns can be measured with sufficient frequency to enter portfolio choice and pricing decisions. As emphasized in subsequent interpretations, the theoretical market portfolio is broader than any single traded index and may include assets such as real estate, fine art, human capital, infrastructure and private businesses⁴ (Fama and French, 2004).

The tension arises when the assets that are economically important contributors to aggregate risk are not directly represented in the traded asset universe used for empirical implementation. Because beta is defined relative to the market portfolio, any omission of economically relevant assets from the observable asset universe affects not only return measurement but the empirical construction of systematic risk itself.

⁴ This stands in contrast to valuation practice, which largely depends on CAPM estimates derived from public markets, even though private businesses represent the overwhelming majority of firms worldwide.

Importantly, the theoretical market portfolio underlying CAPM is broader than any single traded index. As emphasized in subsequent interpretations, it may include assets such as real estate, private businesses, consumer durables, and human capital. The CAPM does not deny the existence of such assets; rather, it abstracts from the difficulty of observing and trading them when deriving equilibrium pricing relations.

2.3 Empirical Implementations and Their Structural Limitations

Empirical implementations of asset pricing models necessarily rely on observable data. In practice, the market portfolio is approximated using broad equity indices or combinations of traded financial instruments. Let $\tilde{\mathcal{M}} \subset \mathcal{A}$ denote the subset of assets for which prices and returns are readily observable. Empirical betas are therefore defined relative to the return $R_{\tilde{\mathcal{M}}}$, rather than the return on the true market portfolio R_M .

This reliance on observable traded assets introduces a well-known structural limitation. As emphasized by Roll (1977), the true market portfolio is unobservable in practice, which complicates both the testing and interpretation of equilibrium pricing models. Empirical asset pricing tests are thus conducted on a restricted asset space that may omit significant components of aggregate wealth.

Crucially, this limitation does not imply a failure of asset pricing theory itself. Instead, it reflects constraints on measurement and observability. Because beta is defined relative to the market portfolio, any omission of economically relevant assets from the observable asset universe affects not only return measurement, but the empirical construction of systematic risk itself. The distinction between the theoretical asset space \mathcal{A} and its empirical proxies $\tilde{\mathcal{M}}$ is therefore central to understanding both the scope and the limitations of standard pricing models.

2.4 Real-World Assets as Economically Relevant but Financially Invisible

A substantial share of economic activity and wealth creation occurs through real-world assets that are not fully captured by traded financial markets. Infrastructure projects, private equity, natural resource assets, and long-lived productive capital generate cash flows and risks that affect aggregate consumption and investment, yet often remain outside the set of assets with observable market prices.

From an asset pricing perspective, these assets are economically relevant as long as they belong to \mathcal{A} and contribute to aggregate risk. At the same time, they are financially invisible in the sense that their returns R_i are not directly observed, traded, or incorporated into the empirical construction of the market portfolio R_M or asset betas β_i . They are financially invisible in the sense that their risks are not directly observable, tradable, or priced through standard financial instruments (Cochrane, 2005; Roll, 1977). **In other words, their payoff vectors lie outside the span of traded assets used in empirical implementations.**

This gap between economic relevance and financial visibility motivates the remainder of this dissertation. Rather than interpreting it as a breakdown of pricing theory, the analysis that follows treats it as a feature of the asset space to which pricing models are applied. Subsequent sections explore whether—and under what conditions—financial innovations

such as tokenization might expand the observable and tradable asset set, thereby improving the empirical approximation of the theoretical market portfolio without altering the underlying no-arbitrage framework.

The presence of economically relevant but non-traded assets has long been recognized in asset-pricing theory. Merton (1993) shows that optimal portfolio choice must account for implicit or “shadow” assets—such as endowment income streams—that affect total wealth and risk exposure despite not being traded. Similarly, Mayers (1972) demonstrates that non-marketable assets alter equilibrium risk pricing by affecting investors’ effective exposure to aggregate risk, even when these assets lie outside the traded security set. In this sense, real-world assets such as infrastructure, physical capital, and contractual cash-flow streams can be understood as shadow components of aggregate wealth: they contribute to economic risk and return yet remain financially invisible because their payoff vectors lie outside the span of observable traded assets. (Merton, 1993; Mayers, 1972)

3. Tokenization as Financial Infrastructure

This section introduces tokenization as a form of financial infrastructure rather than as a new asset class or a modification of asset pricing theory. It distinguishes legal representation from economic function, examines how asset fragmentation and transferability affect price discovery, and analyzes how tokenized real-world assets may expand the observable asset space. The section concludes by discussing regulatory approaches through the lens of functional equivalence.

3.1 Legal Representation versus Economic Function

Tokenization refers to the digital representation of economic rights associated with an asset using distributed ledger technology. From a legal perspective, tokenization typically does not alter the nature of the underlying asset or the rights attached to it. Ownership, cash-flow entitlements, and creditor claims continue to be defined by existing legal instruments—such as securities, trusts, or contractual agreements—while tokens serve as a representation layer for those rights⁵.

From an economic perspective, however, legal form and economic function need not coincide. Asset pricing theory is concerned with payoffs and risks, not with the institutional vehicles through which those payoffs are represented. Whether an asset is held directly, through a security, or via a tokenized representation is irrelevant for pricing as long as the underlying economic claims remain unchanged.

This distinction is central to the interpretation of tokenization in this paper. Tokenization does not create new assets in the economic sense, nor does it modify the stochastic discount factor or equilibrium pricing relations. Instead, it alters how existing economic claims are recorded, transferred, and observed within financial markets. The relevance of tokenization

⁵ Consistent with this perspective, regulatory authorities in major jurisdictions treat tokenization as a change in the technological representation and market infrastructure of financial instruments rather than as the creation of a new asset class, applying existing securities frameworks based on economic function and risk (SEC, 2026; Comisión Nacional de Valores, 2025; IOSCO, 2025).

therefore lies in its potential impact on observability, transferability, and market participation, rather than in any intrinsic change to asset payoffs.

3.2 Asset Fragmentation, Transferability, and Price Discovery

A defining feature of tokenization is the ability to fragment ownership of assets that were previously indivisible or costly to subdivide. By allowing assets to be represented as collections of smaller, transferable units, tokenization lowers minimum investment sizes and broadens the set of potential market participants.

Fragmentation alone does not change the economic payoff of an asset. However, combined with improved transferability—such as continuous trading, reduced settlement frictions, or automated execution—fragmentation can affect price discovery. When ownership claims are easier to trade, prices can incorporate information from a wider set of investors and transactions, improving the frequency and granularity with which asset values are revealed.

From the perspective of asset pricing, these changes affect the measurement of returns rather than their theoretical determination. Assets whose cash flows were previously valued through infrequent transactions or appraisal-based methods may begin to generate observable price series once tokenized. This transition has implications for risk measurement, portfolio construction, and empirical testing, but does not alter the underlying equilibrium logic of pricing models.

3.3 Tokenized Real-World Assets and the Expansion of the Observable Asset Space

The relevance of tokenization for asset pricing arises from its potential to expand the observable asset space. As discussed in Section 2, asset pricing theory defines the market portfolio over the full set of risky assets \mathcal{A} , while empirical implementations rely on a restricted subset $\tilde{\mathcal{M}} \subset \mathcal{A}$ consisting of assets with observable returns.

Tokenization may relax this restriction by rendering the returns of certain real-world assets observable and tradable. When tokenized instruments generate price and return data that can be incorporated into financial datasets, assets that previously belonged to \mathcal{A} but not to $\tilde{\mathcal{M}}$ may enter the empirical approximation of the market portfolio.

This expansion does not imply that all real-world assets become observable or that markets approach full completeness. Rather, tokenization may incrementally widen the set of assets whose risks and returns are measured, improving the empirical representation of aggregate risk. In CAPM terms, this affects the construction of the market return R_M and, consequently, the estimation of asset betas β_i , without altering the theoretical pricing relation.

3.4 Regulatory Framing and Functional Equivalence

Regulatory approaches to tokenization increasingly emphasize functional equivalence: tokenized instruments are subject to the same regulatory treatment as traditional securities or financial contracts when they perform the same economic function. Under this view, tokenization is treated as a change in market infrastructure rather than as the creation of a new category of financial instruments.

This framing is consistent with the perspective adopted in this work. If tokenized assets confer the same economic rights and obligations as their traditional counterparts, then existing legal and regulatory frameworks can, in principle, be applied without modification. The regulatory relevance of tokenization lies in operational considerations—such as custody, settlement, disclosure, and investor protection—rather than in the fundamental economics of asset pricing.

By grounding tokenization in functional equivalence, regulators preserve the coherence of existing pricing and risk-sharing mechanisms while allowing for innovation in how assets are represented and traded. This approach reinforces the central claim of the paper: tokenization operates on the interface between economic assets and financial markets, potentially expanding observability and tradability without altering the underlying structure of asset pricing theory.

Taken together, tokenization could be viewed as a market-design innovation that may relax observability and transferability constraints in financial markets. The analysis does not presume that tokenization completes markets or creates new states of nature. Instead, it prepares the ground for the contingent-claims analysis in Section 5 and the application to energy infrastructure in Sections 6 and 7, where the conditions under which tokenized real-world assets expand the span of traded payoffs are examined more formally.

3.5 Why Tokenization Has Failed So Far

Before examining how tokenization affects the measurement of risk and return, it is useful to clarify why tokenization initiatives have, to date, largely failed to generate liquid and economically meaningful markets. This paper’s interpretation—tokenization as financial infrastructure that may expand observability and tradability—implies a testable qualitative prediction: **tokenization will not scale when it merely replicates existing market structures without expanding the effective payoff space or resolving the institutional prerequisites for liquidity.** Recent policy analysis reinforces this diagnosis, emphasizing that adoption remains scarce and concentrated in pilots, sandboxes, or narrow institutional deployments rather than in mature markets with sustained secondary trading.

3.5.1 Tokenization Without an Ecosystem: A Coordination Failure

Liquid markets do not arise from instruments alone. They require an ecosystem that jointly supplies (i) issuer willingness to originate instruments, (ii) investor demand supported by credible exit options, (iii) custody and onboarding services, (iv) trading and settlement infrastructure, (v) standardized identification and data conventions, and (vi) legal and regulatory certainty about claims and finality. In practice, tokenization has typically proceeded in fragmented “pockets” of activity, with platform-specific designs and limited interoperability. The result is a coordination failure: absent liquidity, investors hesitate; absent investors, issuers hesitate; absent both, intermediaries and infrastructures do not invest.

This coordination problem is especially acute for tokenized real-world assets that exist off-chain and are represented on-chain⁶ as “digital twins⁷.” In such cases, the token is not self-sufficient: its economic meaning depends on off-chain custody, enforceability of underlying rights, and credible assurance that the same asset is not tokenized multiple times or represented inconsistently across venues. When tokenization initiatives do not specify these institutional complements ex ante, they struggle to generate trust, standardization, and scale.

3.5.2 The Missing Business Case: Benefits Have Not Materialized at Scale

A second constraint is the absence of clear, measurable, materialized benefits at scale. While tokenization is often motivated by potential efficiency gains—automation, disintermediation, transparency, faster settlement, programmability—policy assessments emphasize that such benefits are hard to verify in small pilots and may require network effects to emerge. In the absence of a robust economic rationale supported by realized cost reductions or improved market functioning, institutions rationally delay investment and adoption.

Moreover, many benefits attributed to tokenization can be partially replicated within traditional infrastructures (e.g., via securitization, improved registries, and automation), which weakens the incremental value proposition of migrating to distributed ledgers for already-liquid markets. Where existing markets are trusted and efficient, tokenization tends to become an expensive duplication rather than a productivity improvement.

3.5.3 Liquidity Is Not Created by Fractionalization Alone

Tokenization is frequently associated with the promise of liquidity through fractional ownership of historically illiquid assets. However, fractionalization does not mechanically create liquidity. Liquidity emerges when a sufficiently broad set of investors is willing to trade at scale under standard terms and with confidence in custody, settlement, and legal enforceability. Where tokenization has targeted idiosyncratic, project-level claims without credible aggregation mechanisms or common trading venues, it has tended to produce fragmented micro-markets with thin order books and limited price discovery.

Fragmentation also creates pricing risk. If the same economic exposure trades on non-interoperable venues or in parallel on-chain and off-chain representations, liquidity may bifurcate and token prices may delink from conventional valuations of the underlying asset. This undermines the very observability and price discovery that tokenization is often claimed to enhance.

3.5.4 Payment Rails and Settlement Design

⁶ On-chain” denotes records and transactions executed on a distributed ledger, while “off-chain” denotes the underlying asset, legal rights, custody, and enforcement mechanisms that exist outside the ledger and give the on-chain representation its economic meaning

⁷ A “digital twin” refers to an on-chain digital representation of an asset that continues to exist and be governed off-chain, where the token records and transfers economic or ownership rights but does not itself constitute the underlying asset. In the context of tokenized real-world assets, digital twins rely on off-chain custody, legal enforceability, and institutional processes to ensure that the on-chain representation remains uniquely and consistently linked to the underlying physical or contractual asset.

Many tokenization narratives assume that instantaneous, atomic delivery-versus-payment settlement is inherently superior. Yet policy analysis highlights that the payment leg of settlement requires robust payment rails integrated with tokenized markets, and that the absence of suitable on-chain money (or reliable integration with traditional systems) has limited end-to-end deployment. Even where technical solutions exist, settlement design involves economic trade-offs.

Importantly, instant settlement can eliminate netting and increase pre-funding needs, raising intraday liquidity demands and potentially altering market-making and funding dynamics. For many institutional market participants, these trade-offs can make “T+0 everywhere” unattractive. Tokenization can support programmable settlement without requiring instant settlement; but designs that equate programmability with immediacy may inadvertently reduce trading flexibility and liquidity.

3.5.5 Custody, Identification Standards, and Legal Finality

For tokenized real-world assets, custody is not merely operational; it is economically central. Custodians and trusted intermediaries play a key role in onboarding investors, safeguarding reserve or underlying assets, enforcing uniqueness of token–asset linkage, and ensuring continuity of claims under stress. Limited maturity or availability of custody services tailored to tokenized instruments has therefore constrained adoption.

In addition, the lack of standardized identification solutions and industry conventions—covering token identifiers, messaging standards, and accounting treatment—has inhibited interoperability and integration with traditional systems. Legal uncertainty remains a further constraint: depending on jurisdiction, holding a token may not confer legally recognized ownership of the underlying asset; settlement finality and the enforceability of smart contracts may be unclear; and bankruptcy treatment may be uncertain. These uncertainties raise required returns and reduce institutional demand, limiting the emergence of liquid markets.

3.5.6 Replication vs. Market Extension: A Misaligned Use Case

Taken together, these constraints suggest that tokenization has often failed because it has been deployed as a technological overlay—replicating existing financial markets—rather than as a mechanism to extend the span of tradable claims and expand financial observability. Where markets are already liquid and well served by existing infrastructure, the incremental economic value of tokenization is limited. Conversely, where markets are structurally incomplete—because economically relevant payoff streams are not observable or tradable—tokenization may be valuable, but only when embedded in market design that resolves custody, enforceability, standardization, and liquidity aggregation.

This paper’s perspective therefore treats the limited success of tokenization to date not as a refutation of standard asset pricing theory, but as evidence that liquidity is not a property of “tokens” per se; it is a property of institutions, market design, and the tradability of payoff vectors. Tokenization can contribute to asset pricing practice only when it expands the empirically observable asset space (and potentially the span of traded payoffs) rather than merely changing the technological form of existing claims.

3.6 Tokenization and Trust Structures: Functional Equivalence and Conceptual Distinctions

Given the widespread use of trust-based structures, such as fideicomisos financieros, in real-asset finance, it is important to clarify the relationship between tokenized instruments and traditional trust vehicles within the framework developed in this paper. In particular, it is useful to distinguish between economic equivalence⁸ in payoff space and differences in market design and observability, as conflating these dimensions may lead to misinterpretation of the role of tokenization.

From an asset-pricing perspective, a fideicomiso already constitutes a complete financial security in the relevant sense: it defines a segregated pool of assets, specifies contractual cash-flow rules, and issues claims with well-defined payoff vectors across states of nature. To the extent that certificates of participation or debt issued by a fideicomiso are tradable, they already map economically relevant real-asset cash flows into explicit financial claims. Under standard asset-pricing theory, the legal form through which these claims are issued is irrelevant; what matters is the structure of payoffs and their exposure to aggregate risk.

Under the premises of this paper, a token representing an interest in a fideicomiso does not create a new economic claim, nor does it alter the underlying payoff vector, the stochastic discount factor, or the state space. In this sense, tokenization is not a substitute for the fideicomiso as a security, but rather an alternative representation and transfer layer for the same underlying claim. A tokenized fideicomiso interest and a traditionally recorded fideicomiso certificate are therefore equivalent in payoff space and indistinguishable for purposes of asset pricing.

The relevance of tokenization arises at a different level. While fideicomisos succeed in legally isolating assets and defining contractual cash flows, they often fail to generate continuous price discovery, deep secondary-market liquidity, or systematic inclusion in empirical representations of the market portfolio. Project-level trust structures tend to produce idiosyncratic, thinly traded claims whose prices are observed episodically, if at all. As a result, even though the underlying payoff vectors exist economically, they may remain empirically invisible for asset-pricing applications.

Within this framework, tokenization matters only insofar as it affects observability, transferability, and liquidity aggregation, rather than the economics of the claim itself. Tokenization can improve the recording, transfer, and servicing of fideicomiso-type claims, potentially lowering frictions and increasing the frequency and granularity with which prices are observed. However, tokenization by itself does not guarantee liquidity or market relevance. If applied at the level of individual projects or isolated trust structures, tokenization merely replicates existing fragmentation and does not expand the effective market portfolio.

⁸ Throughout this paper, equivalence refers to equivalence in payoff space and risk exposure, not to legal form or technological implementation.

This distinction is central to the analysis developed later in the paper. The contribution of tokenization is not to replace trust-based securitization, but to support market designs in which economically similar claims are aggregated into fungible, portfolio-level instruments capable of sustaining liquidity and price discovery. In such cases, tokenization operates as part of a broader market architecture that may render certain real-asset payoff streams empirically relevant for asset pricing, without altering their underlying economic nature or implying full market completeness.

4. Tokenization and the Measurement of Risk and Return

From an asset-pricing perspective, extending financial analysis to non-traded assets is not primarily a problem of new theory, but one of measurement and implementation. As emphasized by Merton (2000), the mathematical and pricing frameworks required to analyze such assets already exist; the central challenge lies in measuring exposures, designing contracts, and embedding those claims within viable market structures. In this paper, tokenization is therefore interpreted as a measurement and mapping technology: a mechanism that can translate physical or contractual cash-flow processes into observable return series, without altering the underlying pricing equations, the stochastic discount factor (SDF), or the state space of uncertainty (Merton, 2000). Tokenization can therefore be understood as a measurement technology at the asset level and as a market-design innovation at the portfolio level; observability is a necessary condition for liquidity, but not a sufficient one.

This section examines the implications of tokenization for the measurement of risk and return. Building on the distinction between the theoretical asset space and its empirical proxies introduced in Section 2, and on the interpretation of tokenization as financial infrastructure developed in Section 3, the analysis clarifies how physical assets can be mapped into measurable risk exposures. It then considers the consequences for portfolio construction and diversification and evaluates how tokenized real-world assets affect the empirical scope of standard asset pricing models.

4.1 From Physical Assets to Measurable Risk Exposures

Asset pricing theory defines risk in terms of the joint distribution of asset returns with aggregate economic outcomes. In equilibrium models such as the CAPM, this notion is operationalized through the covariance of an asset's return with the return on the market portfolio. As emphasized earlier, this framework presumes that asset returns are observable so that systematic risk can be measured.

Many real-world assets, such as infrastructure, productive equipment, and privately held capital, generate economically meaningful cash flows but lack observable return series. Their risks therefore remain unmeasured in empirical applications, even though they contribute to aggregate uncertainty. In practice, exposure to these assets is inferred indirectly through corporate securities, where heterogeneous sources of risk are bundled within equity or debt claims.

Tokenization alters this mapping by enabling cash flows associated with physical assets to be represented as tradable financial claims. When tokenized instruments generate prices and returns, previously unobservable risks become measurable. Importantly, this does not change the underlying economic risk of the asset; it changes the ability of financial markets to observe, record, and quantify that risk. From a valuation perspective, tokenization functions as a **measurement technology**, translating physical cash-flow processes into financial return series that can enter standard risk metrics.

4.2 Implications for Portfolio Construction and Diversification

The expansion of the observable return space has direct implications for portfolio construction. In mean–variance frameworks, diversification depends on the covariance structure among asset returns. When certain economically relevant assets are absent from the observable asset universe, investors cannot explicitly account for their contribution to portfolio risk, even if those assets materially affect aggregate outcomes.

By making additional return streams observable, tokenization may allow investors to diversify across a broader range of underlying economic activities. Assets whose cash flows are driven by infrastructure usage, physical production, or long-term service contracts may exhibit covariance patterns that differ from those of traditional equities and bonds. Including such assets in portfolios can therefore improve diversification along dimensions that were previously inaccessible.

At the same time, tokenization does not eliminate fundamental limits to diversification. Risks that are highly correlated across assets or tied to non-contractible states of nature remain difficult to hedge. The contribution of tokenization lies not in removing systematic risk, but in allowing investors to allocate and price it more precisely by expanding the set of observable return streams.

4.3 Tokenized Assets and the Empirical Scope of Asset Pricing Models

The implications of tokenization extend beyond individual portfolio choice to the empirical implementation of asset pricing models. As discussed in Section 2, empirical tests of models such as the CAPM rely on proxies for the market portfolio constructed from observable assets. When large components of economic wealth are omitted, the empirical market return differs from the theoretical object assumed by the model.

Tokenized real-world assets may narrow this gap by expanding the subset of assets whose returns are observed and incorporated into financial datasets. As additional asset classes enter the observable universe, the construction of the market portfolio becomes more representative of aggregate economic risk. This affects the measurement of both the market return and asset-specific betas, without altering the theoretical pricing relation itself.

In this sense, tokenization widens the empirical scope of asset pricing models. It does not resolve conceptual challenges associated with unobservable states or incomplete markets, nor does it imply that markets approach theoretical completeness. Rather, it improves the alignment between theory and data by bringing previously invisible sources of risk into the measurable asset space.

Illustrative Example: Infrastructure Risk Measurement in Vaca Muerta

Consider an item of oilfield services infrastructure deployed in Vaca Muerta under a rental contract—such as a fracking pump or compression unit. Economically, the asset generates relatively stable rental income, exhibits upside linked to well activity, and embeds operational flexibility through redeployment if a contract ends. Prior to tokenization, these cash flows are not directly observed by financial markets; exposure to them is bundled within the equity and debt of operating companies.

Once tokenized, the same asset may generate a return series reflecting rental income, utilization-linked upside, and redeployment outcomes. These returns can be measured, included in empirical datasets, and evaluated in terms of their covariance with aggregate market returns. From an asset pricing perspective, the risk of the infrastructure asset has not changed, but its contribution to systematic and diversifiable risk has become observable. This example illustrates how tokenization can convert economically relevant but financially invisible risks into measurable inputs for portfolio construction and asset pricing, setting the stage for the contingent-claims analysis developed in the following sections.

Taken together, section 4 intention is to clarify that the primary contribution of tokenization to asset pricing lies in measurement rather than theory modification. By transforming physical cash flows into observable return series, tokenization allows standard asset pricing tools to be applied to a broader set of economically relevant assets. The next sections build on this insight by examining how such expansions interact with market incompleteness and by formalizing the conditions under which tokenized real-world assets expand the span of traded payoffs.

5. Contingent Claims Theory and Market Incompleteness

This section situates the analysis within contingent claims theory. It reviews the concepts of state-contingent payoffs and market completeness, examines the structural sources of market incompleteness in real asset economies, and interprets financial innovation as an expansion—rather than an elimination—of the payoff space. Throughout, the section emphasizes that financial instruments map states of nature into payoffs but do not create new states, a distinction that is central to the interpretation of tokenization developed in subsequent sections.

5.1 State-Contingent Payoffs and Market Completeness

Contingent claims theory represents uncertainty through a set of mutually exclusive and collectively exhaustive states of nature. Let $S = \{1, \dots, S\}$ denote the set of states. A state-contingent payoff specifies a realization for each state, and can be represented as a vector in \mathbb{R}^S . In this framework, uncertainty is mapped directly into vectors of consumption or cash flows.

The canonical representation is provided by Arrow–Debreu securities, each of which delivers one unit of the numeraire in exactly one state and zero in all others (Arrow, 1953; Debreu, 1959). If all Arrow–Debreu securities are traded, the payoff space coincides with \mathbb{R}^S , and any contingent consumption plan can be replicated through portfolios of existing securities.

More generally, let $X \subset \mathbb{R}^S$ denote the linear span of payoff vectors generated by traded assets. A financial market is complete if and only if $X = \mathbb{R}^S$. Under completeness, asset prices admit a unique vector of state prices, and competitive equilibria are Pareto-optimal, with risks fully shared across agents state by state, as established by the fundamental theorems of welfare economics (Arrow and Debreu, 1954).

Two properties of this framework are essential for what follows. First, market completeness is a property of the payoff structure, not of the number or sophistication of traded instruments. What matters is whether the payoff vectors generated by traded assets discriminate across states, i.e., whether they span the state space. Second, completeness is an exacting benchmark. While analytically convenient, it relies on the existence of a sufficiently rich set of contractible and tradable state-contingent claims—a condition that is rarely satisfied in practice (Flood, 1991; Drechsel, 2025).

Importantly, states of nature are treated as primitives in this framework. Financial securities do not create states; they map states into payoffs. This distinction underlies the analysis of market incompleteness in real asset economies and the role of financial innovation considered below.

5.2 Sources of Market Incompleteness in Real Asset Economies

Real asset economies deviate systematically from the conditions required for market completeness. A primary source of incompleteness arises from the limited state-discriminating power of real asset cash flows. Infrastructure assets, productive capital, and natural resource projects typically generate payoffs that co-move across a wide range of contingencies. When multiple states of nature lead to identical or nearly identical cash flows, the mapping from states to payoffs is not injective. In such cases, no portfolio of claims written on those assets can distinguish among those states, and market incompleteness is structural rather than institutional.

A second source of incompleteness is non-contractibility and imperfect observability of states. Many economically relevant contingencies—such as regulatory changes, political interventions, technological disruptions, or force-majeure events—are difficult to verify ex post or to encode in enforceable contracts. Even when such states are conceptually well defined, the absence of verifiable signals prevents the creation of corresponding contingent claims (Magill and Quinzii, 2002).

Dynamic considerations further exacerbate these limitations. In multiperiod settings, the state space expands rapidly with the horizon, while information about distant contingencies becomes increasingly diffuse. Although the Arrow–Debreu framework can be extended formally to multiperiod environments, the estimation and interpretation of state prices then rely on strong assumptions regarding stationarity, discretization of uncertainty, and the

stability of the underlying economic structure (Banz and Miller, 1978; Breeden and Litzenberger, 1978).

Finally, institutional frictions—including transaction costs, regulatory constraints, limited participation, and cognitive or organizational limits—restrict the practical feasibility of trading a sufficiently rich set of contingent claims. These frictions do not merely hinder implementation; they shape the effective payoff space that markets can sustain, reinforcing incompleteness even in financially sophisticated economies (Cochrane, 1991; Magnani and Wang, 2025).

Taken together, these factors imply that market incompleteness in real asset economies reflects both economic and financial constraints: some states are economically relevant but non-contractible, while others generate payoffs that lie outside the span of traded assets.

5.3 Financial Innovation as an Expansion of the Payoff Space

Within contingent claims theory, financial innovation can be interpreted as an attempt to expand the payoff space spanned by traded instruments. Derivatives, structured products, and contractual innovations repackage existing cash flows into new payoff profiles, allowing risks to be redistributed across states more flexibly. From a formal perspective, such instruments may enlarge the linear span X of traded payoff vectors and improve risk sharing along specific dimensions.

However, a central implication of contingent claims theory is that financial innovation does not create new states of nature, nor does it generate new information about existing states. Derivative securities derive their payoffs from underlying assets; they can only span risks already embedded in those assets' cash-flow structures. Innovation therefore expands the payoff space only insofar as the underlying assets themselves discriminate across states (Brunnermeier, 2008).

Options provide a particularly clear illustration. By introducing nonlinear payoffs at different strike levels, options can enhance state discrimination when the underlying asset's payoff varies monotonically across states. In such cases, options may allow the construction of synthetic contingent claims and improve the spanning of the payoff space. Conversely, when underlying payoffs are flat or clustered across multiple states, no menu of options—regardless of strike granularity—can separate those states. Options then reshuffle existing incompleteness rather than resolve it.

From this perspective, financial innovation should be understood as a partial and local relaxation of financial incompleteness, not as a general solution to it. Innovations can improve the allocation of contractible and observable risks, but they do not alter the underlying state space or eliminate fundamental sources of uncertainty. Persistent risk premia and state-dependent discounting in real asset markets therefore reflect not a lack of financial sophistication, but the intrinsic limits imposed by the structure of real asset cash flows and the nature of economic uncertainty itself.

This interpretation provides the foundation for the analysis in Section 6, which examines whether and how tokenized real-world assets may expand the span of traded payoffs in economically meaningful ways without implying full market completeness.

6. Tokenized Real-World Assets and the Completion of Markets

This section integrates the preceding analysis to assess whether, and under what conditions, tokenized real-world assets (RWA) can expand the span of traded payoffs in financially meaningful ways. Building on contingent claims theory, the discussion emphasizes that tokenization does not alter the set of states of nature \mathcal{S} , nor does it imply full market completeness. Instead, the focus is on whether tokenized instruments can enlarge the payoff space $X \subset \mathbb{R}^{\mathcal{S}}$ by rendering previously unobservable or untradeable payoff dimensions contractible and tradable.

6.1 Designing State-Contingent Payoffs on Real Assets

Let $\mathcal{S} = \{1, \dots, S\}$ denote the set of states of nature and $X \subset \mathbb{R}^{\mathcal{S}}$ the linear span of payoff vectors generated by traded assets. Incomplete markets arise when $X \neq \mathbb{R}^{\mathcal{S}}$, so that some state-contingent payoffs cannot be replicated.

Tokenized real-world assets can be viewed as attempts to introduce new payoff vectors into X by designing contracts whose cash flows are explicitly linked to operational, physical, or contractual performance variables of underlying real assets. Examples include revenues tied to infrastructure throughput, capacity utilization, production volumes, or regulated compensation mechanisms. Formally, such instruments define payoff vectors whose components vary with realizations of these variables across states.

Crucially, the introduction of such instruments does not create new states of nature. The state space \mathcal{S} remains fixed. What changes is the mapping from states to payoffs: tokenization may allow certain economically meaningful distinctions across states to be reflected in traded payoff vectors where previously only coarse or aggregated payoffs were observable.

Whether a given tokenized instrument contributes to market completeness therefore depends on whether its payoff vector is linearly independent of existing traded payoffs. If the new instrument introduces variation across states that was not previously spanned, it enlarges X ; if not, it is redundant from a spanning perspective.

6.2 Tokenization and the Dimensionality of the Payoff Space

The potential contribution of tokenized RWA can be interpreted through the dimensionality of the payoff space. Let $\dim(X)$ denote the dimension of the span of traded payoffs. Financial innovation increases $\dim(X)$ only if it introduces payoff vectors that are not linear combinations of existing ones.

Tokenization may increase $\dim(X)$ through two channels. First, by enabling the fractionalization and transferability of assets that were previously indivisible or illiquid, tokenization may bring economically existing payoff vectors into the traded asset space.

Second, by isolating specific components of real asset cash flows—such as operational performance, contractual triggers, or physical output—tokenized instruments may generate payoff vectors that differ from those of traditional equity or debt claims.

However, this expansion is conditional. If real asset cash flows co-move across states in the same way as existing traded securities, tokenization does not increase $\dim(X)$, even if it improves liquidity or price discovery. In such cases, tokenized instruments enhance observability without expanding the payoff span.

Thus, tokenization should be understood as a mechanism that may increase the dimensionality of the payoff space in specific contexts, rather than as a general tool for spanning all economically relevant risks.

6.3 Asset Space Expansion versus Market Completeness

It is important to distinguish between expansion of the asset space and market completeness. Market completeness, in the Arrow–Debreu sense, is a stringent benchmark that requires the span of traded payoff vectors to coincide with the full state-contingent payoff space \mathbb{R}^S . As emphasized by Merton (2000), this notion should be understood as a theoretical reference point rather than a realistic description of actual financial markets. The literature on incomplete markets further highlights that structural sources of incompleteness, such as non-contractible states, limited state discrimination of cash flows, and institutional frictions, persist even in highly developed financial systems (Magill and Quinzii, 2002). In this context, asset-space expansion refers to an increase in the set of traded instruments or in the observability of payoff vectors, whereas market completeness requires that the span of traded payoffs fully coincides with \mathbb{R}^S . Tokenization may expand the span of traded payoffs along specific dimensions, but it does not imply, nor require, full market completeness (Merton, 2000; Magill and Quinzii, 2002).

Tokenization clearly operates on the asset side: it may expand the set of tradable claims and enlarge X . But enlargement of X does not imply that $X = \mathbb{R}^S$. Structural sources of incompleteness—such as non-contractible states, limited state discrimination of cash flows, and horizon-related uncertainty—remain binding.

From this perspective, tokenization can move markets toward greater (but not full) completeness by improving spanning along particular dimensions. The resulting markets remain incomplete, but the set of risks that can be priced and shared expands relative to a baseline in which real assets are financially invisible.

This distinction is central to the interpretation of tokenization within contingent claims theory. Tokenization does not overturn the Arrow–Debreu benchmark; it operates within its constraints.

6.4 Limits and Open Questions

The analysis highlights several limits to the role of tokenized RWA in completing markets. First, the effectiveness of tokenization depends on the underlying variability of real asset cash flows across states. When payoffs are flat or highly correlated across states, no contract

design can induce state discrimination. Second, the contractibility and verifiability of performance variables impose practical limits on which payoff dimensions can be traded. Third, dynamic considerations—such as long horizons, evolving technologies, and regulatory uncertainty—restrict the feasibility of defining and pricing state-contingent claims over time.

These limits point to open questions for future research. Under what institutional conditions does tokenization meaningfully increase $\dim(X)$? Which types of real assets are most amenable to state-contingent contract design? How do tokenized payoffs interact with existing financial instruments in equilibrium portfolios? Addressing these questions requires both theoretical refinement and empirical validation.

Taken together, the analysis suggests that tokenization should be understood as a market-design innovation that may expand the span of traded payoffs without eliminating market incompleteness. This perspective provides the foundation for the application developed in Section 7, which examines tokenized energy infrastructure as a potential financial proxy for real asset growth.

Proposition 1 (Tokenization, Payoff Spanning, and Market Incompleteness)

Let $S = \{1, \dots, S\}$ denote the set of states of nature and let $X \subset \mathbb{R}^S$ denote the linear span of payoff vectors generated by traded financial instruments. Markets are complete if and only if $X = \mathbb{R}^S$.

Consider a real-world asset whose economic cash flows vary across states but are not traded or are only coarsely represented in existing financial markets. The introduction of tokenized instruments backed by such assets may expand the payoff space X if, and only if, the payoff vectors associated with the tokenized instruments are linearly independent of existing traded payoffs.

Tokenization does not alter the set of states of nature S and does not, by itself, imply market completeness. Instead, it may increase $\dim(X)$ by rendering previously unobservable or untradeable payoff dimensions contractible and tradable. Market incompleteness persists whenever structural features—such as non-contractible states, limited state discrimination of cash flows, or dynamic uncertainty—prevent X from spanning \mathbb{R}^S .

7. Application: Energy Infrastructure and Vaca Muerta

This section applies the conceptual framework developed in Sections 2–6 to energy infrastructure, with a focus on the Vaca Muerta shale formation in Argentina. The objective is to illustrate how tokenization of real-world infrastructure assets may expand the observable and tradable asset space, improve the empirical mapping between real asset growth and financial returns, and widen the effective market portfolio used in asset pricing—without altering the underlying no-arbitrage framework.

7.1 Financial Exposure to Real Asset Growth: Current Alternatives

Vaca Muerta represents one of the largest unconventional oil and gas reserves globally and has become a central driver of Argentina’s medium-term growth prospects. Despite the economic relevance of the underlying physical assets—wells, pipelines, compression equipment, and oilfield services infrastructure—financial exposure to this growth has been historically limited.

In practice, investors seeking exposure to energy infrastructure growth in Vaca Muerta rely primarily on:

1. **Equity of integrated energy operators**, whose returns bundle upstream, midstream, financial, and regulatory risks.
2. **Corporate debt**, which offers limited upside participation and embeds credit risk unrelated to physical asset performance.
3. **Private investments or project finance**, which are typically illiquid, concentrated, and inaccessible to passive or diversified investors.

As a result, the financial instruments available to investors provide only indirect and coarse proxies for real asset growth. The underlying physical capital that drives production and cash flows remains largely financially invisible, despite being economically central.

From an asset pricing perspective, this implies that the market portfolio used in empirical models systematically omits a large class of economically relevant assets. The consequence is not a failure of pricing theory, but a restriction of the observable asset universe.

7.2 Infrastructure, Oilfield Services, and Contractual Cash Flows

A defining feature of oil and gas infrastructure is that cash flows are typically governed by **contractual arrangements rather than residual corporate claims**. Assets such as fracking pumps, compressors, or completion equipment are often deployed under rental or service contracts that specify:

- fixed or quasi-fixed rental fees,
- variable components linked to utilization or production,
- contractual termination clauses, and
- operational flexibility, including redeployment to alternative wells.

These contractual structures generate cash flows that differ fundamentally from those of equity or debt. In particular, they embed **real options**—such as the option to redeploy equipment when a well ceases production—that are economically valuable but rarely isolated in traded securities.

Before tokenization, these cash-flow profiles exist economically but are not directly observable or tradable. Exposure to them is bundled within the balance sheets of operating firms, obscuring the underlying payoff structure and limiting the ability of investors to price and allocate risk efficiently.

7.3 Tokenized Infrastructure as a Financial Growth Proxy

Tokenization of infrastructure assets alters this mapping by allowing contractual cash flows and embedded optionality to be represented as tradable financial claims. By fractionalizing ownership and linking tokenized securities to specific performance variables—such as rental income, production-linked upside, or redeployment value—tokenization can render previously unobservable payoff dimensions financially observable.

Importantly, tokenization does not create new states of nature. The economic contingencies affecting infrastructure assets—well productivity, contract termination, or redeployment opportunities—exist independently of financial representation. What tokenization changes is the mapping from states to traded payoffs, expanding the span of observable claims without implying full market completeness.

From an asset pricing perspective, this expansion has a direct implication: tokenized infrastructure assets can function as more direct financial proxies for real asset growth than traditional corporate securities. Rather than accessing infrastructure exposure through equity claims that bundle multiple sources of risk, investors can hold claims whose payoffs are more tightly linked to the performance of physical capital.

7.4 Implications for Passive Investors and the Market Portfolio

The implications for passive investors are particularly significant. Standard implementations of the Capital Asset Pricing Model define the market portfolio as the aggregation of all risky assets, but in practice rely on a narrow subset of publicly traded securities. The omission of real-world infrastructure assets implies that the empirical market portfolio is incomplete, even relative to the theoretical benchmark.

By expanding the observable and tradable asset space, tokenized real-world assets may widen the effective market portfolio used in empirical asset pricing. This does not alter the CAPM pricing equation or the underlying stochastic discount factor. Instead, it improves the empirical representation of aggregate risk by incorporating assets whose payoffs were previously excluded.

For passive investors, this widening allows:

- improved diversification across sources of economic risk,
- more precise exposure to real asset growth,
- and a clearer separation between stable income, cyclical upside, and real-option value.

Tokenization therefore complements existing financial instruments rather than displacing them. It moves empirical practice closer to the theoretical definition of the market portfolio, while preserving the structural features of market incompleteness emphasized in contingent claims theory.

Section 7 – Annex: A Contingent-Claims Representation of Tokenized Oil & Gas Infrastructure

This annex develops a simple conceptual model illustrating how tokenized infrastructure assets used in oil and gas production can be represented within contingent claims theory.

The purpose is not valuation, but to clarify the economic structure of cash flows, embedded optionality, and the mechanism through which tokenization may expand the span of traded payoffs without implying market completeness.

7.A.1 The Physical Asset and Economic Environment

Consider a single piece of productive infrastructure—such as a hydraulic fracturing pump—deployed under a rental or service contract with an oil and gas operator. The asset generates cash flows through two channels:

1. **A fixed or quasi-fixed rental fee**, paid while the equipment is deployed.
2. **A variable upside component**, linked to the level of well production or utilization.

The asset also embeds operational flexibility: if the well ceases production or the contract expires, the equipment may be redeployed to another well, generating a continuation value. This redeployment flexibility constitutes a real option intrinsic to the physical asset.

7.A.2 States of Nature

Let uncertainty be summarized by a finite set of states of nature:

$$S = \{s_1, s_2, s_3\}$$

with the following interpretation:

- s_1 : The well operates at normal or high production levels.
- s_2 : The well operates at low production levels.
- s_3 : The well ceases production or the rental contract terminates.

These states are economic primitives. They exist independently of any financial representation and are not created by tokenization.

7.A.3 Economic Payoffs of the Untokenized Asset

Let:

$R > 0$ denote the fixed rental fee,

$U_1 \geq U_2 \geq 0$ denote production-linked upside in states s_1 and s_2 ,

$V > 0$ denote the value of the option to redeploy the asset in state s_3 .

The economic payoff vector of the physical asset can be written as:

$$\pi = \begin{bmatrix} R + U_1 \\ R + U_2 \\ V \end{bmatrix} \in \mathbb{R}^3$$

This payoff vector exists economically regardless of whether the asset is traded. Prior to tokenization, however, this vector is not directly observable or tradable in financial markets;

investors typically gain exposure only indirectly, through the equity or debt of integrated operators.

7.A.4 Tokenization and Payoff Decomposition

Tokenization allows the economic payoff π to be decomposed into distinct, tradable claims. Consider three classes of tokenized securities:

7.A.4.1 Rental Token

A claim on the fixed rental fee:

$$x^{(R)} = \begin{bmatrix} R \\ R \\ 0 \end{bmatrix}$$

7.A.4.2 Production-Linked Token

A claim on variable production-related upside:

$$x^{(U)} = \begin{bmatrix} U_1 \\ U_2 \\ 0 \end{bmatrix}$$

7.A.4.3 Redeployment Option Token

A claim on the value realized upon redeployment:

$$x^{(O)} = \begin{bmatrix} 0 \\ 0 \\ V \end{bmatrix}$$

The original economic payoff satisfies:

$$\pi = x^{(R)} + x^{(U)} + x^{(O)}$$

7.A.5 Payoff Matrix Representation

Stacking these tokenized claims yields the payoff matrix:

$$\mathbf{X} = \begin{bmatrix} R & U_1 & 0 \\ R & U_2 & 0 \\ 0 & 0 & V \end{bmatrix}$$

Each column represents a traded security; each row corresponds to a state of nature.

If $U_1 \neq U_2$ and $V > 0$, the columns of \mathbf{X} are linearly independent. Tokenization therefore introduces payoff vectors that were previously absent from the traded asset space, expanding the span of traded payoffs.

7.A.6 Implications for the Payoff Space

Let $X \subset \mathbb{R}^3$ denote the span of payoff vectors generated by traded assets prior to tokenization, typically consisting of equity and debt issued by operating firms. The introduction of tokenized infrastructure claims expands this space to:

$$X' = \text{span}(X \cup \{x^{(R)}, x^{(U)}, x^{(O)}\})$$

If the new payoff vectors are not spanned by existing securities, then:

$$\dim(X') > \dim(X)$$

This is the precise sense in which tokenization expands the payoff space. The state space S remains unchanged, and market completeness is not implied unless $X' = \mathbb{R}^3$, which need not hold.

7.A.7 Interpretation Through CAPM Betas

Although contingent claims theory provides the structural foundation, it is useful to interpret these payoffs through the lens of standard asset pricing intuition.

- The **rental token** exhibits relatively stable payoffs across production states and is expected to have low covariance with the market portfolio, resembling low-beta infrastructure income.
- The **production-linked token** is positively correlated with commodity prices and sectoral activity, implying a higher market beta.
- The **redemption option token** pays off in a state associated with local or idiosyncratic shocks and may exhibit low or even negative correlation with aggregate market returns.

Before tokenization, these distinct risk exposures are bundled within corporate securities, obscuring their individual contributions to systematic risk. Tokenization allows these exposures to be observed, priced, and allocated separately.

7.A.8 Relation to Market Incompleteness

Despite this expansion of the payoff space, markets remain incomplete. States that generate identical or highly correlated real asset cash flows cannot be separated by any contract design, and non-contractible sources of uncertainty persist. Tokenization therefore relaxes financial incompleteness locally—by expanding the span of traded payoffs—without eliminating its structural sources.

7.A.9 Relevance for Energy Infrastructure Financing

In contexts such as Vaca Muerta, where investors seeking exposure to sectoral growth have traditionally relied on the securities of a small number of integrated operators, tokenized infrastructure assets offer a more direct financial proxy for real asset performance. By unbundling fixed income, production upside, and real-option value, tokenization

complements existing securities and improves financial observability without altering the underlying pricing framework.

8. Broader Implications for Emerging Markets

This section discusses the broader implications of the framework developed in this paper for emerging markets. It focuses on the relationship between real assets, capital formation, and financial depth; the scope for tokenization beyond energy infrastructure; and the institutional and regulatory considerations that condition its relevance.

8.1 Real Assets, Capital Formation, and Financial Depth

A defining characteristic of many emerging markets is the central role of real assets in economic growth combined with limited financial depth. Infrastructure, natural resources, and productive capital account for a large share of aggregate wealth and investment needs, yet financial systems often provide only narrow and indirect channels for accessing these assets. As a result, capital formation is frequently constrained not by the availability of economically viable projects, but by the limited ability of financial markets to mobilize savings toward them.

From an asset-pricing perspective, this disconnect implies that a substantial portion of aggregate risk resides outside the observable and tradable asset space. Standard financial instruments capture only a subset of the risks associated with real-asset-driven growth, leading to a structural gap between economic activity and financial representation. This gap manifests in higher financing costs, reliance on balance-sheet-intensive intermediaries, and episodic access to capital rather than continuous market-based funding.

By expanding the set of assets whose cash flows can be represented, traded, and priced, tokenization may contribute to greater financial depth. The mechanism emphasized in this paper is not leverage or regulatory arbitrage, but improved **observability** and **risk allocation**. When real-asset cash flows become measurable and investable, financial markets can intermediate savings more efficiently, potentially lowering the cost of capital for productive investment without altering the underlying risk structure of the economy.

8.2 Tokenization Beyond Energy Infrastructure

While the application developed in this paper focuses on energy infrastructure, the framework extends naturally to other classes of real-world assets common in emerging markets. Transportation infrastructure, logistics assets, agricultural equipment, renewable energy projects, and industrial facilities often share key characteristics: long-lived physical capital, contractual or usage-based cash flows, and limited access to liquid financing.

In each case, the relevance of tokenization depends on whether it can render economically meaningful cash flows observable and tradable. Assets whose revenues are governed by enforceable contracts or measurable physical performance are particularly amenable to this approach. Conversely, assets whose returns are highly discretionary or politically contingent may remain difficult to represent through financial claims, regardless of technological form.

This perspective underscores that tokenization is not universally applicable, nor is it a substitute for institutional quality. Its potential lies in selectively expanding the observable asset space where underlying economic conditions permit, rather than in attempting to financialize all forms of wealth. The framework developed here provides a way to assess such applicability without presuming market completeness or transformational effects.

8.3 Institutional and Regulatory Considerations

The effectiveness of tokenization in emerging markets is conditioned by institutional and regulatory environments. Secure property rights, enforceable contracts, and credible market oversight are prerequisites for transforming physical cash flows into reliable financial claims. Where these foundations are weak, tokenization may improve operational efficiency but will not fundamentally alter risk perceptions or pricing.

Regulatory approaches that emphasize functional equivalence—treating tokenized instruments according to their economic substance rather than their technological form—are particularly relevant in this context. By integrating tokenized assets into existing capital-market frameworks, such approaches reduce legal uncertainty and allow innovation to focus on market access, transparency, and settlement efficiency.

Importantly, institutional considerations reinforce the central theme of the paper: tokenization does not change the economics of assets or eliminate risk. It affects how risks are represented, measured, and allocated within financial markets. Emerging markets that leverage tokenization as part of broader efforts to deepen financial systems may therefore benefit from incremental, rather than radical, improvements in capital formation

Section 8 — Annex: The Vaca Muerta Token as a Liquidity-Creating Instrument

A central implication of the functional perspective is that viable financial markets are built on aggregation and standardization of economic exposures, rather than on atomized trading of underlying assets. As argued by Merton (1995), financial functions are more stable than financial institutions, and competitive market evolution tends to favor structures that concentrate liquidity and improve efficiency in performing those functions. This insight motivates the portfolio-level design emphasized in the VM Token, where aggregation of infrastructure assets into a single, fungible claim is treated as a prerequisite for price discovery and secondary-market liquidity.

8.A.1 Purpose of the Annex

This annex introduces the **Vaca Muerta (VM) Token** as a concrete application of the theoretical arguments developed in the paper. The VM Token is presented as an illustrative market-design example of the framework, not as a normative prescription or necessary implementation. Its objective is not to provide implementation details, legal structures, or smart-contract specifications, but rather to clarify:

- why a dedicated market instrument is required for real-asset tokenization to generate liquidity,
- how the VM Token is conceptually designed to address this problem,

- and how it relates to asset pricing and market completeness.

The annex can be read independently and may be omitted without loss of generality for readers interested purely in the theoretical contribution.

8.A.2 The Liquidity Problem in Real-Asset Tokenization

As discussed throughout the paper, tokenization of real assets has largely failed to deliver liquid secondary markets. The core issue is structural:

- most tokenization models replicate **project-level claims**,
- traded in **segmented, asset-specific markets**,
- with limited participation and shallow order books.

From an asset-pricing perspective, these tokens represent idiosyncratic, non-spanning claims that cannot enter the market portfolio. Tokenization alters the representation of ownership, but not the underlying market structure.

Liquidity, therefore, remains absent not because of technological limitations, but because the relevant economic aggregation problem is left unsolved.

8.A.3 Conceptual Shift: From Tokenized Assets to a Tokenized Market Portfolio

The VM Token is built on a different premise:

Liquidity in real assets emerges only when individual claims are aggregated into a fungible, diversified, marketable instrument.

Rather than tokenizing compressors, rigs, or infrastructure projects individually, the VM Token represents a claim on an aggregate pool of productive infrastructure assets held within a common trust.

Economically, the VM Token is closer to:

- an infrastructure REIT,
- an index fund,
- or a portfolio security,

than to a project token.

This aggregation transforms a set of illiquid, non-spanning assets into a single tradable claim capable of supporting price discovery and continuous trading.

8.A.4 The VM Token as a Liquidity-Creating Instrument

The VM Token is designed so that:

- all secondary-market trading occurs in a single token,
- liquidity is concentrated rather than fragmented,

- and price discovery reflects the value of the underlying infrastructure portfolio as a whole.

Liquidity is thus created not by facilitating exit from individual assets, but by forcing all entry and exit to occur through a common, fungible instrument.

This mirrors the historical role of:

- REITs in real estate,
- ETFs in equities,
- and index securities in otherwise illiquid asset classes.

8.A.5 Yield Capitalization and Endogenous Token Supply

A key element of the VM Token is its **yield-capitalization model**.

Rather than distributing operating cash flows as dividends:

- income generated by infrastructure assets remains within the trust,
- increasing the net asset value of the portfolio,
- and is reflected through proportional adjustments in token supply.

This mechanism ensures that:

- the token remains NAV-anchored,
- liquidity is not periodically drained by forced cash distributions,
- and returns accrue through capital accumulation rather than payout timing.

From an asset-pricing standpoint, the VM Token behaves as an **accumulating claim on productive capital**, which is particularly appropriate for infrastructure assets with long economic lives.

8.A.6 Partial Market Completion Through Portfolio Assignment (Overview)

While the VM Token provides a liquid market portfolio, investors are heterogeneous in their risk preferences and expectations.

To accommodate this without fragmenting liquidity, the model introduces a **secondary allocation layer** that allows investors to redirect portions of their yield exposure to specific asset subsets, subject to strict constraints. Importantly:

- portfolio assignment does not create new tradable securities,
- does not alter the supply or liquidity of the VM Token,
- and operates entirely as a redistribution of cash-flow exposure.

This mechanism increases the span of effective payoffs available to investors, improving risk sharing while preserving a single liquid market.

8.A.7 Relation to Market Completeness and Asset Pricing

Liquidity creation here refers to secondary-market tradability of an aggregate claim and should not be interpreted as completeness in the Arrow–Debreu sense. The VM Token does not attempt to create fully complete Arrow–Debreu markets. Instead, it provides a **pragmatic increase in market completeness** by:

- aggregating real assets into a tradable portfolio claim,
- enabling relative exposure adjustments without segmentation,
- and reducing liquidity and idiosyncratic risk premia.

In this sense, the VM Token serves as a bridge between real assets and the financial market portfolio, allowing infrastructure cash flows to be priced, traded, and allocated using standard asset-pricing intuition.

8.A.8 Scope and Limitations

The VM Token is not designed to:

- eliminate fundamental asset risk,
- guarantee liquidity under all market conditions,
- or replace detailed project-level due diligence.

Its purpose is narrower and more precise:

- to create a market structure in which real assets can be held, traded, and priced in a manner consistent with modern portfolio theory.

8.A.9 The VM Token versus a Traditional Trust Structure & Concluding Remark

The VM Token illustrates the central thesis of this work in the sense that tokenization contributes to market efficiency only when it is embedded within an appropriate market-design architecture. Liquidity in this framework arises from institutional arrangements governing aggregation, fungibility, and market access, rather than from tokens or technological representations per se. The VM Token therefore serves as an example of how tokenization can become economically meaningful when it is used to support liquidity-creating market design rather than merely to digitize ownership claims.

This distinction also clarifies why the VM Token is not equivalent to a traditional fideicomiso, even though it relies on a trust structure for asset custody and legal isolation. A trust defines ownership and cash-flow rights, but does not, by itself, create a liquid market. In typical trust-based structures, claims remain asset- or series-specific, secondary trading is fragmented or episodic, and liquidity is not endogenously generated.

By contrast, the VM Token is designed as a market instrument rather than an issuance vehicle. It forces aggregation of multiple infrastructure assets into a single, fungible claim; concentrates all secondary-market trading in one instrument; and capitalizes cash flows at

the portfolio level. The trust therefore functions as a supporting legal container, while liquidity creation arises from market design rather than from the trust structure itself.

9. Future Research Directions

The limited success of tokenization to date reflects not a failure of the mechanism analyzed in this paper, but its frequent application to assets that were already observable, tradable, or institutionally liquid. This paper has argued that the principal tension between standard asset pricing theory and market practice is not a failure of equilibrium pricing logic, but a restriction of the empirically observable and tradable asset space. In theory, the market portfolio aggregates all risky assets in the economy. In practice, empirical proxies are built from a narrow subset of publicly traded instruments, while a large share of economically relevant wealth—real estate, infrastructure, productive equipment, private businesses, and other long-lived capital—remains financially opaque due to illiquidity, infrequent trading, and limited price discovery. The result is a systematic mismatch between the theoretical object to which models such as the CAPM refer and the dataset to which those models are typically applied.

Within this framing, tokenization is interpreted neither as a new asset class nor as a modification of asset pricing theory, but as financial infrastructure that may relax constraints on observability and transferability. Tokenization does not create new states of nature, nor does it change the stochastic discount factor. Its potential contribution is narrower and more disciplined: it may render specific real-asset payoff streams measurable and tradable, thereby expanding the empirical universe of risky assets and, in some cases, enlarging the span of traded payoffs without implying full market completeness.

A key implication of this approach is that the limited success of tokenization to date is not anomalous. As discussed in Section 3.5, adoption has remained scarce and concentrated in pilot environments, largely because many tokenization initiatives have attempted to replicate existing market structures without resolving ecosystem prerequisites—liquidity aggregation, custody, legal enforceability, settlement design, identification standards, and interoperability. In this sense, tokenization fails when it is treated as a technological substitute for liquidity. It becomes economically meaningful only when it is embedded in market design that expands financial observability and supports credible price discovery for previously invisible payoff streams.

9.1 Theoretical Implications for Asset Pricing

The analysis reinforces the central distinction between (i) the state space of economic uncertainty and (ii) the payoff space spanned by traded instruments. Market completeness is a property of payoff spanning, not of technological sophistication. Tokenization operates, at most, on the payoff side: it may introduce or reveal payoff vectors that were previously absent from empirical datasets by transforming physical and contractual cash flows into observable return series.

This perspective suggests several theoretical directions. One is to formalize models in which observability and tradability are endogenous—so that the “empirical market portfolio”

evolves as new claims become measurable. Another is to examine how risk premia in incomplete markets change when previously unspanned payoff dimensions become tradable, even if the underlying state space remains unchanged. A third is to analyze equilibrium interactions between traditional securities that bundle heterogeneous risks (corporate equity and debt) and tokenized claims that unbundle specific real-asset payoffs, potentially affecting beta estimation, factor structure, and the interpretation of systematic risk in empirical work.

9.2 Policy and Market Design Implications

From a policy standpoint, the framework supports a technology-neutral orientation: what matters is not the token form, but the economic function and the risks of the instrument and the market infrastructure supporting it. The relevant questions concern custody and safeguarding of underlying assets, disclosure and transparency, legal enforceability of claims, settlement and payment integration, operational resilience, and investor protection. Designs that increase fragmentation—by dispersing liquidity across non-interoperable venues or creating parallel on-chain and off-chain representations—risk undermining price discovery and investor confidence rather than improving them.

More broadly, the analysis implies that tokenization should be evaluated as a market design choice: it can expand the observable asset space only under institutional arrangements that concentrate liquidity, standardize claims, and maintain credible linkages between on-chain representations and off-chain rights. Where these conditions do not hold, tokenization may improve recordkeeping but is unlikely to change pricing, risk allocation, or the effective market portfolio in economically meaningful ways.

9.3 Directions for Future Research

The framework in this paper is conceptual and calls for empirical and institutional validation. Several research directions follow naturally.

First, empirical work can test whether tokenized real-world asset returns exhibit covariance structures that are distinct from those of traditional equity and debt, and whether including such assets changes estimates of the market portfolio and systematic risk exposures. Second, comparative work across asset classes can identify which underlying cash-flow processes are most amenable to tokenization as a measurement technology—particularly where payoffs are governed by enforceable contracts or verifiable operational variables. Third, case-based research can evaluate whether improvements in observability translate into reduced financing costs, improved risk sharing, or broader investor participation, distinguishing technological feasibility from economically meaningful market adoption.

Finally, future work should deepen the link between tokenization and the theory of incomplete markets: under what conditions does tokenization increase the dimension of the traded payoff space, and when does it merely improve observability without expanding spanning? Answering this question requires integrating contractual design, institutional infrastructure, and asset pricing into a single empirical agenda—especially in emerging-market contexts where real assets dominate investment opportunities while financial depth remains limited.

Concluding Perspective

Tokenization is best understood as a potential bridge between economically relevant real assets and the market portfolio used in asset pricing practice. It does not complete markets in the Arrow–Debreu sense, and it does not alter the core no-arbitrage logic of asset pricing. Its contribution is conditional: tokenization can narrow the gap between theory and practice only when it expands the observable and tradable asset space through credible institutional design. In this sense, liquidity is not a feature of tokens; it is a feature of market architecture.

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