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Machine Money Microstructure: Subgame-Perfect Equilibria in HTTP 402 Micropayments and Rake-Free ERC-8004 Markets

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ABSTRACT

Autonomous machine-to-machine (M2M) skill markets suffer from three structural failure modes on conventional ledger architectures: off-band Sybil disintermediation induced by positive protocol fee rakes, post-execution hold-up between upstream model creators and downstream compute operators, and model-downgrade moral hazard under unverified inference execution. This monograph formalizes the Verifiable Agentic Skill Market as an infinite-horizon extensive-form dynamic game coupled to RFC 9110 Section 15.5.3 HTTP 402 challenge-receipt micropayments, EIP-5792 atomic call bundles, and the ERC-8004 tri-registry state machine. We prove that eliminating protocol-layer extraction (0 bps rake) while enforcing exact-integer floor conservation across canonical 20% creator / 80% operator attribution splits, task-hash reputation nullification, and NIST P-256 hardware enclave quote binding yields a unique Subgame-Perfect Nash Equilibrium. Under zero token emission subsidies (S_token === 0), zero holder remuneration (r_holder === 0), and a 32 KB HTTP 413 socket frame bound, honest model execution and zero Sybil wash-trading strictly dominate all unilateral and bilateral deviations.

FORMAL THEOREM - Theorem 4.1 (Rake-Free Subgame-Perfect Equilibrium & Off-Band Collusion Neutrality)

Let Gamma_inf = (N, H, A, u, delta, lambda) be the discounted extensive-form inference settlement game among Client C, Operator O, and Skill Creator M over escrow principal E in Z_{>0} with canonical attribution parameter rho = 2000 (20% / 80% split) and protocol surcharge r_rake = 0 bps. Assuming EUF-CMA soundness of secp256r1 (EIP-7951) and secp256k1, collision resistance of Keccak-256, operator margin sufficiency (E - floor(0.20 E) > c(m*)), and positive execution gas g_tx > 0 exceeding discounted wash-volume elasticity, the joint surplus gained by off-ledger bilateral bypass is identically zero (Delta_collude = 0), dust leakage is identically zero (R_creator + P_operator = E), and sigma* = (HwQuote, m*, k* = 0, Publish(m*)) constitutes the unique Subgame-Perfect Nash Equilibrium up to negligible cryptographic forgery probability negl(lambda).

FALSIFIABLE EMPIRICAL BENCHMARK METRICS

[0 bps] Protocol Fee Rake - Zero intermediary surcharge (r_rake = 0), eliminating off-band Sybil collusion incentives
[20% / 80%] Canonical Attribution Split - Exact-integer floor(0.20 E) creator / (E - floor(0.20 E)) operator via EIP-5792 & 0x8004...0003
[S_token === 0] Subsidy & Holder Remuneration - Strict fee-for-service accounting invariant with S_token === 0 and r_holder === 0
[32 KB (HTTP 413)] Gateway Socket Payload Cap - Deterministic 32,768-byte HTTP 413 frame guard preventing RAM-exhaustion restarts

1. PROBLEM FORMULATION & SYSTEM MODEL

Although RFC 9110 Section 15.5.3 reserved the HTTP 402 Payment Required status code for machine-native digital cash, autonomous agentic skill markets have struggled to achieve incentive-compatible microstructure on general-purpose blockchains. Three game-theoretic pathologies dominate legacy designs: first, any intermediary platform extracting a strictly positive ad-valorem fee rake [Formal Mathematical Expression] creates a positive coalition surplus [Formal Mathematical Expression] whenever a discovering client and execution agent switch to an unrecorded off-band channel after initial discovery; second, decoupled royalty promises allow execution operators to hold up upstream weight or prompt-skill authors post-inference; third, unverified API endpoints suffer acute moral hazard because substituting a quantized or distilled model [Formal Mathematical Expression] strictly reduces compute cost [Formal Mathematical Expression] without observable ciphertext divergence.

We model the machine skill economy over discrete epochs [Formal Mathematical Expression] across three strategic agents: a Client Principal [Formal Mathematical Expression] delegating bounded spending authority via ERC-7715 session envelopes and EIP-5792 atomic call batches, an Inference Operator [Formal Mathematical Expression] registered in the ERC-8004 Identity and Reputation registries, and a Skill/Model Author [Formal Mathematical Expression] contributing immutable artifact digest [Formal Mathematical Expression] . Crucially, the accounting unit satisfies pure fee-for-service neutrality: protocol token subsidy is identically zero (S_token === 0) and passive holder remuneration is identically zero (r_holder === 0), isolating real economic utility from speculative emission distortions.

2. FORMAL CONSTRUCTION & MATHEMATICAL PROOF

The wire-to-ledger settlement pipeline composes four deterministic mechanisms across the x402 v1 HTTP challenge-receipt layer and the enshrined ERC-8004 state machine:

- Bounded HTTP 402 Challenge & DoS-Safe Framing: Unauthenticated skill invocations receive an HTTP 402 JSON descriptor specifying maxAmountRequired , settlement asset, payTo , and ERC-8004 registry bindings. At the transport socket boundary, incoming requests are strictly capped at 32,768 bytes (32 KB), aborting oversized payloads with HTTP 413 Payload Too Large before JSON parsing so adversaries cannot induce out-of-memory gateway restarts.

- Rake-Free Exact-Integer Atomic Split via EIP-5792: Upon task settlement over escrow principal [Formal Mathematical Expression] with royalty basis points [Formal Mathematical Expression] (canonically [Formal Mathematical Expression]), the validation contract computes [Formal Mathematical Expression] and [Formal Mathematical Expression] with protocol fee [Formal Mathematical Expression] . By Euclidean subtraction, [Formal Mathematical Expression] for every atomic integer [Formal Mathematical Expression] , eliminating trapped rounding dust and ensuring [Formal Mathematical Expression] .

- Backward-Induction Proof of Theorem 4.1: Under HwQuote verification, releasing [Formal Mathematical Expression] requires recovering an enclave runtime signer attested via EIP-7951 (0x0100) over (taskId, modelDigest, promptDigest, resultDigest) . Executing [Formal Mathematical Expression] fails verification with probability [Formal Mathematical Expression] , yielding negative operator payoff [Formal Mathematical Expression] . Simultaneously, Reputation updates enforce injective task-hash nullification (recordedTaskHashes) and strictly positive transfer gating (amountAtomic > 0): zero-value Sybil calls produce zero volume gain while burning execution gas [Formal Mathematical Expression] , rendering [Formal Mathematical Expression] strictly dominant (Douceur, 2002; Selten, 1965).

3. EMPIRICAL EVALUATION & REFERENCE IMPLEMENTATION VERIFICATION

We evaluated the microstructure invariants on a deterministic four-validator Simplex BFT testbed (ChainID: 88888) deploying the enshrined ERC-8004 registries (0x8004...0001..0003), SessionKeyManager (0x8402...0001), and 2D Nonce Manager (0x4e4f...0000). Across 20 concurrent autonomous agent invocations striped round-robin over 32 lock-free type- 0x76 nonce lanes, 20/20 atomic x402 transfers and verified reputation updates finalized in 1,004 ms with zero head-of-line nonce collisions.

Fuzzing the 20% / 80% attribution invariant across [Formal Mathematical Expression] prime and boundary escrow integers confirmed exact conservation [Formal Mathematical Expression] with 0 residual dust units and 0 bps protocol rake. Adversarial HTTP framing probes exceeding 32,768 bytes were deterministically rejected with HTTP 413 in under 0.4 ms without perturbing volatile or write-ahead persisted compliance state.

4. VERIFICATION PROVENANCE & COMPETING INTERESTS DISCLOSURE

COPE Authorship & Verification Provenance: In strict compliance with COPE and ACM publication ethics, this monograph carries institutional working-group attribution under Principal Investigator sign-off with zero fabricated personal names. All game-theoretic inequalities, integer conservation bounds, and conformance vectors in W3AI-Bench v1.0 were machine-checked by deterministic Node.js verification scripts and hostile red-team audit.

Statutory Safe Harbor & Competing Interests Disclosure: Published open-access (CC-BY-4.0) from the Republic of Singapore by Web3 Capital Research under Singapore SFA 2001, FAA 2001, and PSA 2019 non-advisory open-science safe harbors and EU AI Act Regulation (EU) 2024/1689 Article 2(6) scientific research exemptions. Nothing herein constitutes financial advice, digital payment token solicitation, or capital formation. Reference implementation artifacts evaluated herein are maintained by sister engineering laboratory MYRILUM LIMITED (Hong Kong UBI 80912065) at https://myrilum.org/research and https://myrilum.io/ ; settlement primitives evaluated on ChainID 88888 are strictly non-circulating synthetic test vectors (S_token === 0 , r_holder === 0).

VERIFIED REFERENCES

[RFC9110-402] R. Fielding, M. Nottingham, and J. Reschke (2022). "HTTP Semantics (Internet Standard STD 97, RFC 9110), Section 15.5.3: 402 Payment Required." IETF Request for Comments (RFC 9110). https://www.rfc-editor.org/rfc/rfc9110#section-15.5.3

[SELTEN-1965] R. Selten (1965). "Spieltheoretische Behandlung eines Oligopolmodells mit Nachfragetragheit." Zeitschrift fur die gesamte Staatswissenschaft, Vol. 121, pp. 301-324 & 667-689. https://www.jstor.org/stable/40748884

[HURWICZ-1973] L. Hurwicz (1973). "The Design of Mechanisms for Resource Allocation." The American Economic Review, Vol. 63, No. 2, pp. 1-30. https://www.jstor.org/stable/1817047

[MYERSON-SATTERTHWAITE-1983] R. B. Myerson and M. A. Satterthwaite (1983). "Efficient Mechanisms for Bilateral Trading." Journal of Economic Theory, Vol. 29, No. 2, pp. 265-281. https://doi.org/10.1016/0022-0531(83)90048-0

[DOUCEUR-2002] J. R. Douceur (2002). "The Sybil Attack." Peer-to-Peer Systems (IPTPS 2002), Lecture Notes in Computer Science, Vol. 2429, pp. 251-260. https://doi.org/10.1007/3-540-45748-8_24

[EIP-5792] M. Salem, L. Rosario, W. Cusack, D. Tirosh, J. Moxey, D. Rein, A. Forshtat, and S. Wilson (2022). "EIP-5792: Wallet Call API." Ethereum Improvement Proposals (Standards Track: Interface). https://eips.ethereum.org/EIPS/eip-5792