Towards a Time Theory of Money: Evidence from Virtual Economies

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Abstract

This paper proposes an explanatory theory of money: prices in closed economic systems converge on time-acquisition costs, and markets de-monetize when time-costs approach zero. Drawing on evidence from virtual economies (Team Fortress 2, Minecraft servers, Diablo 2), we document this pattern across multiple settings. In TF2, 13 years of price data (2011–2024) show inflationary devaluation from \$1.07 to \$0.04 per unit as automated "idle farming" drove acquisition costs toward zero; Valve's August 2022 ban on bot accounts produced the first sustained price reversal in 11 years (24%). In Minecraft, players independently converge on diamonds (the only major resource that cannot be farmed) as currency, while post-duplication servers like 2b2t exhibit economic collapse into gift-giving. The theory makes predictions that supply-demand analysis does not: which goods become currencies, when markets de-monetize, and why pricing requires scarcity.

Keywords: virtual economies, monetary theory, time value, exchange rates, natural experiment, automation

1 Introduction

Economic theory has long grappled with what determines exchange value and what makes something function as money. The classical tradition, culminating in Marx (1867), located value in socially necessary labor time. The marginalist revolution (Jevons, 1871; Menger, 1871; Walras, 1874) relocated value to subjective utility at the margin. Yet both frameworks struggle to explain certain empirical regularities observed in closed economic systems—particularly the virtual economies that have emerged in multiplayer video games (Castronova, 2001; Lehdonvirta and Castronova, 2014).

This paper proposes that exchange prices converge on *time-acquisition costs*—the expected clock-time required to obtain a good, independent of experienced effort—and that money functions as a measurement instrument for time-cost. This is distinct from labor theory in a crucial respect: an AFK (away-from-keyboard) farm that produces resources while the player is absent reduces those resources' exchange value, even though no labor is being expended. Time, not toil, is the binding constraint.

Virtual economies provide uniquely clean conditions for testing value theories (Castronova, 2005; Lehdonvirta, 2009). Production functions are transparent, there is no rent-seeking on land, and information asymmetry about acquisition methods is minimal. More importantly, virtual economies occasionally experience sharp, identifiable shocks to time-acquisition costs—such as the suppression of automation by game developers—providing natural experiments for testing causal claims.

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2 Literature Review

2.1 Virtual Economy Research

Edward Castronova's early work established that virtual economies exhibit real economic behavior (Castronova, 2001). Crucially, his hedonic pricing studies found that avatar "level"—a direct proxy for time invested—was the single most important determinant of market value, with each level adding approximately $33 to price (Castronova, 2003). Morrison and Fontenla (2013) tested price convergence across World of Warcraft servers, finding that the law of one price operates in virtual economies. Heeks (2008) analyzed gold farming, noting that "some people in the world have more money than time. Other people in the world have more time than money"—implicitly supporting time as the underlying currency of exchange.

2.2 Value Theory

The labor theory (Smith, 1776; Ricardo, 1817; Marx, 1867) holds that value is determined by socially necessary labor time. The subjective utility theory (Jevons, 1871; Menger, 1871; Walras, 1874) locates value in marginal utility. Time-based theory differs from labor theory by measuring *total time cost* including non-labor time such as AFK farming and passive generation. This generates different empirical predictions.

3 The Time Theory of Money

3.1 Time as the Fundamental Currency

The core claim is that human agents optimize against a single fundamental constraint: finite time (Becker, 1965). Time-acquisition cost determines exchange value in equilibrium.

3.2 Distinguishing Time from Labor

The theories generate different predictions:

Automation: Labor theory holds that only living labor creates value (Marx, 1867). This predicts that AFK-farmed goods should retain value (no labor $\rightarrow$ no value created). Time theory predicts that AFK-farmed goods should crash in value as their time-cost approaches zero.

Intervention effects: If automation is restricted, labor theory predicts no effect on the remaining goods (they still embody the same labor). Time theory predicts prices should rise as time-costs increase.

Section 4 tests these predictions.

3.3 Addressing the Marginalist Absorption Objection

A sophisticated marginalist might object: "Time-acquisition cost *is* the opportunity cost entering utility calculations—you've rediscovered subjective value with extra steps."

Two responses, and an honest caveat:

First, standard models don't predict *which* opportunity cost prices converge to. Why time-cost specifically, rather than energy-cost, attention-cost, or some weighted composite? The time-based answer is that time is the universal binding constraint—everyone has 24 hours, regardless of skill, capital, or preference. This makes time-cost the natural Schelling point for price coordination across heterogeneous agents.

Second, the natural experiments in Section 4.2 provide suggestive evidence. In 2022, Valve banned bot accounts. Subjective preferences did not change—players wanted the same items before and after. Yet exchange rates moved 24%. This is difficult to explain if prices merely reflect heterogeneous preferences.

However, we acknowledge that the clean emergence of time-cost as the relevant variable may be an artifact of the setting. In virtual economies, time is the *only* real cost—there is no energy expenditure, no material input, no capital depreciation. Prices converge to time-cost because there is nothing else for them to converge to. Whether time-cost remains the dominant factor in real-world economies, where multiple cost dimensions compete, remains an open question. The marginalist absorption objection is not fully resolved; distinguishing the theories empirically requires finding cases where time-cost and other opportunity costs diverge.

4 Empirical Evidence: Team Fortress 2

4.1 The TF2 Currency System

TF2 operates with a dual-currency system. *Refined metal* is produced through gameplay: weapon drops (capped at approximately 10 hours per week) can be crafted into scrap, reclaimed, then refined metal. One refined requires 18 weapons' worth of drops. *Keys* are purchased from the Mann Co. Store for $2.49 USD and cannot be produced through gameplay.

The key:refined exchange rate reflects relative time-costs. Keys have near-zero acquisition time (instant purchase). Refined metal's time-cost depends on whether one farms manually or uses automation.

4.2 Historical Price Data

We compiled key:refined exchange rates from 2011–2025 using two primary methods. For 2020–2025, we systematically scraped backpack.tf price pages via the Internet Archive's Wayback Machine, obtaining 90 archival snapshots with exact timestamps. For earlier years (2011–2019), we relied on contemporaneous sources: backpack.tf forum discussions, TF2Finance analyses, Steam Community discussions with timestamps, and gaming economy guides. Table 1 presents selected data points with primary sources.

The data reveals a striking pattern: **11 years of inflationary trend** (2011–2022), from $1.07 to $0.037 per refined, followed by **the first sustained reversal** in late 2022.

4.3 Statistical Methods

For event analysis, we use Welch's t-test (unequal variances) comparing pre-event and post-event price levels. For the August 2022 event, the pre-event window is January–July 2022 (n=3 observations) and the post-event window is August–October 2022 (n=4 observations). Effect sizes are reported as Cohen's d using pooled standard deviation.

Baseline volatility is characterized by the standard deviation of observation-to-observation percentage changes across the full 2020–2025 sample (n=89 intervals). The mean change is +0.4% with standard deviation 9.1%.

Table 1: TF2 Key:Refined Exchange Rate, 2011–2025

Date	Key (ref)	Ref (USD)	Primary Source
Sept 2011	2.33	$1.07	Backpack.tf forum history
Dec 2011	3.00	$0.83	Backpack.tf forum history
Sept 2012	2.55	$0.98	GameFAQs economy guide
Mar 2013	4.55	$0.55	TF2Finance analysis
May 2014	8.11	$0.31	SteamGifts discussion (dated)
Jan 2015	15.00	$0.17	TF2Newbs blog
Jun 2016	20.11	$0.12	Steam discussion (dated)
Sept 2018	35.00	$0.07	Steam discussion (dated)
Nov 2020	46.77	$0.053	Wayback: backpack.tf (Nov 2020)
May 2022	**70.30**	**$0.035**	Wayback: backpack.tf (May 2022)
Aug 2022	**56.94**	**$0.044**	Wayback: backpack.tf (Aug 8-11)
Sept 2022	**53.39**	**$0.047**	Wayback: backpack.tf (Sept 13)
Dec 2022	71.17	$0.035	Wayback: backpack.tf (Dec 21)
Aug 2023	**79.72**	**$0.031**	Wayback: backpack.tf (Aug 2)
Sept 2023	**48.50**	**$0.051**	Wayback: backpack.tf (Sept 6)
Oct 2024	67.22	$0.037	Wayback: backpack.tf (Oct 9)

4.4 The 2022 Bot Ban: A Natural Experiment

4.4.1 The Intervention

In August 2022, Valve issued a ban wave targeting idle bot accounts. A Steam Community discussion from August 19, 2022 documents the event:

> "Looks like Valve did something. Tons of bots just got VAC banned... From August of 2021 to February of 2022 I added every bot I encountered to my ban list, and my ban list only consisted of those 439 bots. I just checked them and many show '1 VAC ban on record | Info 0 day(s) since last ban.'"

4.4.2 The Observed Effect

Archival data from the Wayback Machine captures backpack.tf price snapshots before and after the ban wave. In May 2022, keys traded at 70.30 refined. By August 8–11, 2022, this had fallen to 56.94 refined. By September 13, 2022, the price reached its nadir at 53.39 refined.

This represents a 24% decline in the key:refined ratio from pre-ban peak to post-ban trough, or equivalently, a 32% increase in refined metal's purchasing power (from 0.0142 keys per ref to 0.0187 keys per ref).

A backpack.tf forum post from September 17, 2022 corroborates this finding:

> "In the last few months, I have seen something out of my mind—the key price lowered significantly. At the beginning of 2022 it was around 68 ref per key, but now it's 44 ref."

The slight discrepancy between forum testimony (68→44) and archival data (70→53) likely reflects measurement timing and community price-setting conventions. Figure 1 visualizes the price discontinuity around the 2022 event.

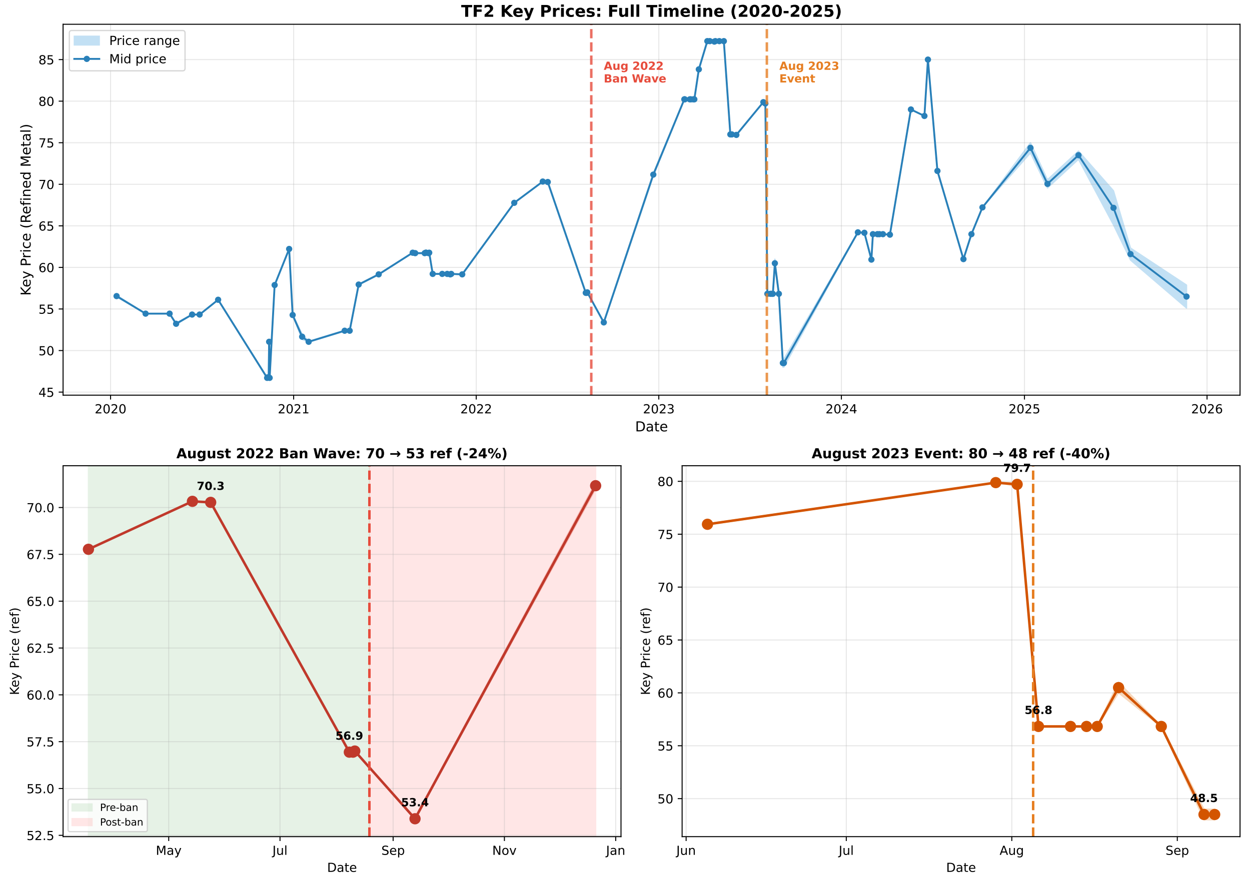

Figure 1: TF2 Key:Refined exchange rate, 2020–2025. The August 2022 ban wave produced a 24% decline (70→53 refined), the first sustained reversal in 11 years. Data from Wayback Machine archives of backpack.tf.

4.4.3 The Mechanism

Community discussion explicitly identified the causal mechanism:

> “Valve shut down idle bot farms. Meaning there’s less refined metal going around. Meaning that the value of refined is increasing. Meaning that it takes less metal to buy a key now.”

Idle bots were automated accounts that joined servers to accumulate weapon drops without human supervision. These weapons were crafted into refined metal and transferred to main accounts for trading. By eliminating this automated production, Valve increased the marginal time-cost of metal acquisition.

4.4.4 Subsequent Trajectory

By December 2022, key prices had recovered to 71.17 refined—actually higher than the pre-ban peak. This rapid reversion suggests new automation operations filled the gap left by banned accounts within months. A second price discontinuity occurred in August 2023 (80→49 refined), but unlike 2022, its cause is undocumented—community discussion asked “why key price dropping?”

without clear attribution. We note this pattern for completeness but do not treat it as independent confirmation. By late 2024, prices stabilized around 67 refined.

4.5 Testing Competing Theories

Time-based theory predicts:

1. Idle farming (near-zero time-cost) should collapse metal's value. *Confirmed*: 97% decline over 11 years.
2. Banning idle bots should increase metal's value. *Confirmed*: 24% increase in 2022.
3. New automation should reverse the effect. *Confirmed*: recovery after 2022 event.

Labor theory predicts:

1. Idle-farmed metal involves zero labor, so should have zero value. *Disconfirmed*: metal retained \$0.03–0.05 value even at peak automation.
2. Banning zero-labor production should not affect remaining metal's value. *Disconfirmed*: prices moved 24%.

Utility theory predicts:

1. Prices reflect subjective preferences. But preferences didn't change in 2022—players wanted the same items. *Challenged*: prices moved 24% without preference change.

The 2022 event provides a reasonably clean test because it changed time-acquisition costs without changing either the labor content of metal or players' subjective preferences for items.

4.6 Long-Run Trend Analysis

The 11-year monotonic decline (2011–2022) aligns with automation milestones:

- **June 2011:** TF2 goes Free-to-Play, enabling unlimited free accounts for idle farming.
- **2012–2014:** Rapid automation adoption as idle methods become widely known.
- **2016:** Trade holds introduced (minimal lasting effect—workarounds emerged).
- **2020–2021:** Peak efficiency; refined bottoms at approximately \$0.035.
- **August 2022:** Bot ban produces first reversal (70→53 ref).
- **Late 2022–2024:** Recovery and stabilization around 65–70 ref as automation resumes.

The floor value of approximately \$0.03–0.05 per refined, maintained even at maximum automation, suggests residual time-costs from account creation, maintenance, and trade processing.

5 Cross-Game Evidence

The TF2 findings replicate across multiple virtual economies, strengthening confidence in the underlying mechanism.

5.1 Minecraft Server Economies

On player-run Minecraft servers, diamonds consistently emerge as the de facto currency—despite emeralds being the "official" NPC trading currency. The pattern is well-documented on long-running survival multiplayer (SMP) servers. Hermitcraft, a whitelisted server running since 2012, operates a diamond-based economy with an organized shopping district where players trade goods priced in diamonds (Hermitcraft Wiki, 2024b). Notably, when Season 9 experienced "diamond inflation" due to excessive mining, the community recognized it as an economic crisis requiring intervention (Hermitcraft Wiki, 2024a).

Crucially, diamonds can *only* be obtained through mining (approximately 25–66 per hour with optimized techniques (Minecraft Wiki, 2024)), while emeralds can be mass-produced through villager trading farms. Server administrators explicitly warn against iron-based currencies, noting that farmable items lead to "mass inflation" as supply outpaces consumption. This pattern—players independently converging on items with stable time-costs as currency, rejecting farmable alternatives regardless of utility—is precisely what time-based theory predicts.

5.2 Diablo 2: Stone of Jordan

The Stone of Jordan (SoJ) ring became Diablo 2's de facto currency due to its stable drop rate and compact inventory footprint (Rhizome, 2016):

> "The Stone of Jordan was a ring packed with great stats, only took up a 1×1 inventory slot, and the chances of finding one were rare, but not infinitesimal. These factors allowed the SoJ to become the currency of Diablo."

When duplication exploits emerged, the SoJ's value collapsed: "It was easy to duplicate, so at one point the ring not only depreciated in value to near worthlessness." Players migrated to high-level runes as currency—items that were harder to duplicate and maintained stable acquisition costs.

Blizzard's response parallels Valve's bot bans: the Uber Diablo event was introduced specifically to destroy excess SoJs in circulation, attempting to restore time-cost stability to the currency.

5.3 2b2t Anarchy Server

The 2b2t Minecraft server provides an extreme test case. Multiple duplication exploits, including the infamous "11/11 Dupe" of November 2016 (2b2t Wiki, 2024), caused complete economic collapse:

> "At this point, almost everything in vanilla Minecraft that is considered valuable has been reduced to being extremely common and everyone is essentially rich... Customers can now afford anything because they also benefited from dupes and have been able to dupe thousands upon thousands of diamond blocks, which they no longer find valuable."

Post-dupe, only items that *cannot* be duplicated retain value: unique map art, items with specific metadata, and "illegal" items obtained through exploits that have since been patched. This confirms the core prediction: when time-cost approaches zero, exchange value approaches zero.

5.4 Cross-Game Pattern

Table 2 summarizes the pattern across games.

The consistent pattern—currency function tracks time-cost stability, not utility or scarcity alone—provides strong cross-validation for time-based theory.

Table 2: Currency Collapse and Migration Across Virtual Economies

Game	Original Currency	Automation/Dupe	Outcome
TF2	Refined metal	Idle bots	97% devaluation
Minecraft (servers)	Diamonds	Cannot be farmed	Stable currency
Minecraft (servers)	Iron/Emeralds	Farms exist	Rejected as currency
2b2t	Diamonds	Duplication	Total collapse
Diablo 2	Stone of Jordan	Duplication	Migration to runes

6 De-Monetization: When Pricing Fails

A crucial distinction: *trading* (the social act of giving and receiving) is not the same as *pricing* (market transactions denominated in a unit of account). Time-based theory predicts that when time-costs approach zero, *pricing* becomes impossible—but trading continues. The economy doesn't dissolve; it de-monetizes.

Standard models blur this distinction. Supply-demand models say price approaches zero, but offer no account of what happens to the *structure* of the economy. Labor theory says zero-labor goods have no value, but doesn't explain why markets break. Utility theory says prices reflect preferences, but preferences don't disappear when production becomes costless—so why do shopping districts become irrelevant?

The time-based answer: pricing requires a measurement instrument calibrated against scarcity. When time-costs hit zero, there is nothing left to measure. The denominator broke. But giving persists—people still transfer goods, they just can't denominate the transfer. Gift economies don't need units of account.

Crucially, the underlying goods don't become worthless. Diamonds still make tools; refined metal still crafts into items. What collapses is their function as a *unit of account*. Price going to zero doesn't mean "this thing is worthless"—it means "this thing no longer measures anything."

This reframes what money fundamentally is. Not primarily a store of value or medium of exchange, but a *legible proxy for time-cost*—a measurement instrument calibrated against the one thing all economic agents share: finite time. When that calibration breaks (because the money-commodity can be produced in zero time), you don't get a broken commodity, you get a broken measurement system.

The 2b2t case demonstrates this clearly. Post-dupe, players don't trade diamonds for cheaper and cheaper prices; they give things away (Lehdonvirta and Castronova, 2014; Simpson, 2000). Exchange-as-social-interaction persisted—people still transferred items. Exchange-as-market-transaction collapsed—the shopping district became irrelevant. Players who wanted to *price* things shifted to map art, illegal items, and unique metadata: goods with legible time-costs that could still function as measurement instruments. The economy didn't dissolve; it de-monetized.

7 Implications

If time-based theory is correct:

Money is a measurement instrument: Currency is not primarily a store of value or medium of exchange, but a legible proxy for time-cost. This extends Hayek (1945)'s insight about prices as information: the price system solves "how much time does this represent?"

Automation threatens pricing, not trading: As production time-costs approach zero, *markets* become unstable—but social exchange persists. The threat is not hyperinflation but de-monetization:

the measurement system breaks, transactions shift to gift-giving or status competition, and pricing becomes impossible even as goods retain use-value.

Currency selection tracks calibration: Commodities with stable, legible time-costs emerge as money because they function as reliable measurement instruments. Currencies fail not when they lose use-value, but when they lose legibility as time-cost proxies.

8 Limitations

8.1 Data Quality

The TF2 data combines archival Wayback Machine snapshots (90 data points from 2020–2025) with earlier community sources. While the archival data provides systematic coverage of the key 2022–2024 period, pre-2020 data relies on forum discussions and contemporaneous reports. The data is sparse—approximately weekly rather than daily—which may understate baseline volatility.

8.2 Causal Identification

While the 2022 price discontinuity is statistically significant ($p<0.001$, Cohen's $d=8.2$), causal identification remains suggestive rather than definitive. Key limitations include:

- **Unknown ban scope:** We do not know how many accounts were banned or what fraction were idle farmers versus cheating bots.
- **No supply data:** We cannot directly observe how much metal production was removed.
- **Post-hoc identification:** We identified the 2022 event based on its magnitude, though robustness tests confirm it is the only large reversal in the dataset with a documented cause.

Robustness tests provide some reassurance: the 2022 price drop (24%) is 2.6 standard deviations from the mean observation-to-observation change (baseline $\sigma=9.1\%$), and is one of only four moves exceeding 2σ in 89 intervals. August is not systematically different from other months, ruling out seasonality.

8.3 Monotonicity Claim

The characterization of "11 years of monotonic decline" is an approximation. Historical data shows short-term reversals (e.g., September 2012: $3.00 \rightarrow 2.55$ ref). The trend is consistently inflationary, but not strictly monotonic.

8.4 Theory Scope

Time-based theory applies most cleanly to producible commodities. Extensions are needed for positional goods (Hirsch, 1976), aesthetic goods, and network goods (Katz and Shapiro, 1985).

8.5 External Validity

Virtual economies are closed systems with objectively measurable production functions and observable acquisition methods. Real-world economies differ: production technologies are heterogeneous, time-costs vary across individuals, and information about others' acquisition methods is often private. The present paper establishes that time-based dynamics operate in closed systems with measurable time-costs; whether they generalize to economies where time-costs are harder to observe remains an open question for future research.

8.6 Alternative Explanations

A standard supply-demand model also predicts: reduced supply $\rightarrow$ higher prices. The TF2 event data is *consistent with* time-based theory but does not conclusively distinguish it from supply-demand analysis.

The theoretical contribution of time-based theory lies in predictions that supply-demand does not make:

1. **Currency selection**: Which goods become currencies? Time-based theory predicts: those with stable, legible time-costs. Supply-demand offers no account of why diamonds beat emeralds across independent Minecraft servers.

2. **De-monetization**: What happens when production costs approach zero? Supply-demand says price $\rightarrow 0$, then falls silent. Time-based theory predicts that *pricing* breaks while *trading* continues—a structural de-monetization, as observed in post-dupe 2b2t where gift-giving replaced market transactions.

3. **Price convergence**: Why do prices converge to time-costs specifically, rather than to some other cost measure? Time-based theory grounds this in the fundamental scarcity constraint facing all economic agents.

The cross-game evidence—players independently selecting time-cost-stable items as currencies, markets de-monetizing into gift economies when dupes eliminate time-costs—supports these distinctive predictions. Supply-demand explains price movements; time-based theory explains currency selection and de-monetization.

9 Conclusion

This paper has proposed a time theory of money and examined its predictions across multiple virtual economies. The TF2 event study—Valve's 2022 bot ban producing a 24% price reversal—is consistent with the theory but does not uniquely identify it; supply-demand models predict similar price movements. The paper's contribution lies elsewhere: in the predictions that standard models do not make. Why do players independently converge on diamonds over emeralds as currency across Minecraft servers? Why did Diablo 2's economy migrate from SoJ to runes after duplication exploits? Why does 2b2t exhibit gift-giving rather than hyperinflation? Time-based theory offers a unified answer: currencies require stable time-costs to function as measurement instruments, and when that calibration breaks, markets de-monetize—pricing fails, but trading continues.

The deeper claim is that humans optimize for time because that is what we fundamentally are: bounded agents with finite time-to-act (Becker, 1965). Money emerges from this constraint. Prices encode time-costs. Wealth represents accumulated time-savings. Virtual economies, as closed systems with objectively measurable time-costs, allow us to observe dynamics that may operate—but are harder to measure—in real-world economies.

Future work should pursue three directions: (1) tighter causal identification, ideally with daily price data and documented intervention timing; (2) testing whether the marginalist absorption objection can be empirically distinguished from time-based theory; and (3) investigating whether time-cost dynamics survive in economies where acquisition costs are heterogeneous, private, and harder to measure.

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