The Economics of the Bitcoin Payment System

Jacob Leshno, Chicago Booth
Based on work with Ciamac Moallemi and Gur Huberman, Columbia Business School
The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics†

Alvin E. Roth


Abstract

Economists have lately been called upon not only to analyze markets, but to design them. Market design involves a responsibility for detail, a need to deal with all of a market's complications, not just its principle features. Designers therefore cannot work only with the simple conceptual models used for theoretical insights into the general working of markets. Instead, market design calls for an engineering approach. Drawing primarily on the design of the entry level labor market for American doctors (the National Resident Matching Program), and of the auctions of radio spectrum conducted by the Federal Communications Commission, this paper makes the case that experimental and
Who Gets What—and Why

ALVIN E. ROTH

Winner of THE NOBEL PRIZE IN ECONOMICS
<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Market Cap</th>
<th>Price</th>
<th>Volume (24h)</th>
<th>Circulating Supply</th>
<th>Change (24h)</th>
<th>Price Graph (7d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bitcoin</td>
<td>$203,918,783,289</td>
<td>$11,410.73</td>
<td>$15,705,918,263</td>
<td>17,870,787 BTC</td>
<td>0.09%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>2</td>
<td>Ethereum</td>
<td>$22,919,531,662</td>
<td>$213.64</td>
<td>$6,292,005,275</td>
<td>107,278,818 ETH</td>
<td>3.88%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>3</td>
<td>XRP</td>
<td>$13,040,650,220</td>
<td>$0.304172</td>
<td>$849,774,753</td>
<td>42,872,646,068 XRP</td>
<td>2.31%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>4</td>
<td>Bitcoin Cash</td>
<td>$5,960,916,360</td>
<td>$332.24</td>
<td>$1,170,302,065</td>
<td>17,941,688 BCH</td>
<td>6.78%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>5</td>
<td>Litecoin</td>
<td>$5,675,202,358</td>
<td>$90.06</td>
<td>$3,121,584,226</td>
<td>63,014,981 LTC</td>
<td>5.67%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
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<tr>
<td>6</td>
<td>Binance Coin</td>
<td>$4,654,460,896</td>
<td>$29.93</td>
<td>$266,480,436</td>
<td>155,536,713 BNB</td>
<td>1.44%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>7</td>
<td>Tether</td>
<td>$4,048,830,914</td>
<td>$1.00</td>
<td>$16,109,366,785</td>
<td>4,043,425,265 USDT</td>
<td>0.21%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>8</td>
<td>EOS</td>
<td>$3,869,415,583</td>
<td>$4.17</td>
<td>$1,588,267,781</td>
<td>927,033,053 EOS</td>
<td>3.99%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>9</td>
<td>Bitcoin SV</td>
<td>$2,594,547,889</td>
<td>$145.31</td>
<td>$303,608,935</td>
<td>17,854,986 BSV</td>
<td>3.09%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
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<td>10</td>
<td>Monero</td>
<td>$1,571,885,968</td>
<td>$91.66</td>
<td>$76,016,856</td>
<td>17,148,987 XMR</td>
<td>0.26%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
</tr>
<tr>
<td>11</td>
<td>Stellar</td>
<td>$1,547,268,940</td>
<td>$0.078812</td>
<td>$77,262,899</td>
<td>19,632,397,508 XLM</td>
<td>8.09%</td>
<td><img src="https://coinmarketcap.com/" alt="Price Graph" /></td>
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Traditional Payment Systems

- Require trust
Traditional Payment Systems

- Require trust
- Monopoly deadweight loss
  - Price too high, potential users excluded
- Hold-up
  - Price will increase if users are lock in
  - Prevents ex-ante adoption

Huberman, Leshno, Moallemi – Economic Analysis of Bitcoin
Traditional Payment Systems vs. Bitcoin

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Traditional Payment Systems vs. Bitcoin

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<td>Fees set by firm/org</td>
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<td>Balancing supply and demand</td>
<td>Firm’s incentives</td>
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Huberman, Leshno, Moallemi – Economic Analysis of Bitcoin
Traditional Payment Systems vs. Bitcoin

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<td>Procured by firm/org</td>
<td>Entry/Exit, Revenue</td>
</tr>
<tr>
<td>Pricing</td>
<td>Fees set by firm/org</td>
<td>Equilibrium congestion pricing, Miners do not set prices</td>
</tr>
<tr>
<td>Balancing supply and demand</td>
<td>Firm’s incentives</td>
<td>??</td>
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Huberman, Leshno, Moallemi – Economic Analysis of Bitcoin
Bitcoin as a Two-Sided Market – key properties

- Users choose transaction fees
- Miners choose pending transactions to include in their block
- System’s capacity is independent of number of miners
  - One miner selected at random to process transactions
  - Block size and block rate fixed by protocol
- New blocks are added as a Poisson process
- Free entry and exit of miners
  - Approximate (ignoring ASICs etc)
  - Assume there are many small miners with a cost $c_m$
Simplified Economic Model

- $N$ computing units of miners
  - Many potential small miners whose cost is $c_m$
  - Free entry/exit
- Blocks added at rate $\mu$, each can process $K$ transactions
  - System’s capacity is $K \cdot \mu$
- Users/transactions
  - Receive utility from service $R - c \cdot W - b$
  - Heterogeneous delay cost $c$
  - Willingness to pay $R_H$ or $R_L$, equal prob (ind of $c$)
  - Arrive at Poisson rate $\lambda < K \cdot \mu$ (excess capacity)
Benchmark: Dead-weight Loss Under a Profit Maximizing Firm

A profit maximizing firm sets a high transaction fee excluding low WTP customers, processes transactions without delay.

- Monopoly dead-weight loss
  - Not serving low willingness to pay users, although it can efficiently do so
  - Prices go up if users are locked in and their WTP increases

Huberman, Leshno, Moallemi – Economic Analysis of Bitcoin
Bitcoin Miners: No Pricing Power

Suppose that some small miners are active. Then no miner can profitably affect transaction fees, including large miners.

- All miners select highest paying transactions
- That is, in equilibrium miners are price takers
- Large miners can affect transaction fees, but that will spur entry and won’t raise their revenue
Total payment to miners is equal to total transaction fees $Rev$ plus the value of minted coins $s \cdot e$ (both in USD).

Expected payment per mining unit is $(Rev + s \cdot e)/N$.

Free entry of small miners with cost $c_m$ implies small miners break even.

The equilibrium number of miners is

$$N = \frac{Rev + s \cdot e}{c_m}$$
Data: Miners Costs and Revenue Oct 2015

Approx. total miners’ cost (Croman et. al. 2016):

\[ 1.6 \frac{tx}{sec} \cdot \$6/tx \approx \$10/sec = \$6,000/10\text{min} \]

- Approx. $325M annually

Approx. total reward:

\[ 25 \frac{btc}{10\text{min}} \cdot \$300/btc = \$7,500/10\text{min} \]

- [http://www.coinwarz.com/cryptocurrency](http://www.coinwarz.com/cryptocurrency)
Bitcoin Users: Choice of Transaction Fees

- Users choose transaction fees $b_i$ to maximize

$$u(c_i) = R - c_i \cdot W(b_i|G) - b_i$$

where $W(b_i|G)$ is expected delay given distribution of others’ bids $G$

- Users play a congestion queueing game
  - Participate or not
  - Trade off transaction fees $b_i$ and delay $W(b_i|G)$
  - Independent of number of miners
Expected Delay for Lowest Priority Transaction given Congestion $\rho$

\[ \rho = \frac{\lambda}{K\mu} \]
Assuming WTP sufficiently high and the system has excess capacity, in equilibrium:

- All users participate
- Impatient users costs pay higher transaction fees, receive higher priority and lower delay
- Transaction fees equal to the delay externality imposed on other transactions
- Transaction fees independent of WTP, but depend on congestion
Data: Total Transaction Fees vs Congestion

Model curve parameters: $K = 2,000$, and delay costs $c \sim U[0,0.1]$ for 10min.

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Transaction Fees

- Positive revenue, without excluding transactions
  - Even transaction that pay no fee are processed
- Strictly positive net reward to all users
  - Not possible under a profit maximizing firm
- Payments do not depend on willingness to pay, if it is sufficiently enough
  - No monopoly pricing, even if the system is a monopoly
  - No hold-up

But:
- Fees vary with congestion $\rho$
- Fees independent of need for infrastructure
Revenue and Delay Costs Given $\rho$

Parameters: $K = 2,000$, delay costs distributed $c \sim U[0,1]$
Welfare Under Bitcoin

- Costly design
  - Redundancies, Tournament for random selection
- Delay costs are necessary to incentivize payment
- Infrastructure level likely to be suboptimal
  - Transaction fees vary with congestion
  - Block reward varies with exchange rate (currently the majority of the reward)

Welfare can be larger under Bitcoin if these are less than monopoly deadweight loss

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Controlling Congestion – Revenue vs. Delay

\[ \text{Delay Cost}_\infty (\rho) = \frac{\text{Rev}_\infty (\rho)}{\text{delay} \times \text{blocksize}} \]

- \( \rho = 0.5 \)
- \( \rho = 0.9 \)
- \( \rho = 0.95 \)
- \( \rho = 0.975 \)
The Tradeoff Between Congestion and Delay for Different Maximal Block Size

[Graph showing the tradeoff between congestion and delay for different maximal block sizes (K=20, K=200, K=2,000, K=20,000). The x-axis represents Revenue (USD/time), and the y-axis represents Delay Cost (USD/time).]
Summary

- Economic innovation of Blockchain is governance
  - No owner, commitment to rules
  - Fees determined in equilibrium, miners are price takers

- Congestion as a revenue generating mechanism
  - Can raise revenue without excluding users
  - Requires delay costs, inefficient at raising low amounts
  - Importance of stochastic block-arrival process

- Market fails to balance supply and demand
  - Can control congestion to target revenue
  - Benefit of smaller block size
Blockchain

- Blockchain blockchain blockchain blockchain blockchain, blockchain Bitcoin blockchain blockchain
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- Blockchain blockchain blockchain blockchain blockchain, blockchain blockchain blockchain blockchain, blockchain blockchain blockchain blockchain.
- Machine learning blockchain blockchain blockchain
- Decentralized blockchain blockchain blockchain blockchain
- Blockchain blockchain blockchain blockchain!