

This PDF includes a chapter from the following book:

Distributed Ledgers

Design and Regulation of Financial Infrastructure and Payment Systems

© 2020 Massachusetts Institute of Technology

License Terms:

Made available under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International Public License

<https://creativecommons.org/licenses/by-nc-nd/4.0/>

OA Funding Provided By:

The open access edition of this book was made possible by generous funding from Arcadia—a charitable fund of Lisbet Rausing and Peter Baldwin.

The title-level DOI for this work is:

[doi:10.7551/mitpress/13382.001.0001](https://doi.org/10.7551/mitpress/13382.001.0001)

Index

- Accrual income method, 39
- Agents, 24, 185n1
 - in Ostroy-Starr model, 138–139
 - small and medium-sized enterprises as, 25
 - smart contracts and, 25, 26, 80
 - waterfall payment and, 119
- Agrello, 94
- AirSwap, 58
- Algorand, 16, 75
- Alibaba/Ant Financial, 89
- Allocations, 12, 24
- Amazon Cloud, 44
- Anchors, in Stellar, 74–75, 149
- Asian Development Bank, 115, 174
- Asset-backed off-chain, 160–161
- Asset-backed on-chain, 161
- Assets, 74, 93
- Association of Banks, in Singapore, 184n3
- Association of Southeast Asian Nations (ASEAN), 116
- Asynchronous systems, 14, 46
- Auctions, collusion and, 92
- Auditor, role of, 112–113
- Australian Stock Exchange, Digital Asset and, 37, 46
- Autarky, 159, 178
- Availability, distributed ledgers and, 44–45
- Axoni, 7
- Backing mechanisms, cryptocurrency, 160–163, 179
- Back-loading, 107, 174
- Balance of payments accounts, village financial accounts and, 40–41
- Balance sheet, 27
 - changes in income statement and, 39
 - creation of financial statements and, 38
 - cryptocurrency on, 38
 - items on, 38
 - as a ledger, 31–38
 - in village economies, 31, 32–33, 36
- Banishment penalty, 90
- Bankers Clearing House, 13

- Bank for International Settlements, 2, 3, 181n5
- Bankgirot system, 52
- Bank of Canada, 127, 128, 129, 175–176
- Bank of England, 129
- Banks. *See also* Central banks
 - digital reserve, 20, 163–165
 - mitigating runs on, 133–135
- Bargaining, 94
- Base account, in Stellar, 74
- Bayesian Nash equilibrium, 81, 92, 134
- Bills of exchange, 143, 149
- Binance, 58
- Bitcoin
 - absence of central authority, 9
 - bubble in, 159
 - coloring coins and, 184n3
 - controversy over, 178
 - distributed ledger technology, blockchain, and, 1
 - double-spending and, 68, 70
 - encryption and, 68–71
 - as innovation or invention, 4, 10
 - miners and, 67, 68–70
 - proof of work and, 65–66, 67, 171
 - security and, 44
 - two keys to, 69
 - user fees for, 181n5
 - validation and, 8, 77
- Bitcoin cryptography, 16
- Bitfinex, 161
- Bit gold, 10
- Blockchain protocol, proof-of-work, modeled as stochastic game, 70
- Blockchains, 1
 - contracts and, 2–3
 - permissioned or private, 46–47
 - resolution of hold-up problem in, 92–93
 - security and, 44
 - smart contracts and, 67
- Blockdata.tech, 160
- Bond market, 153
- Broker-dealers, e-money shortages and, 56–58
- Bubbles, 159, 179
- Bureau of Economic Analysis, 40
- Byzantine Agreement, 66
- Byzantine Fault Tolerant (BFT), 16, 66, 67
- Byzantine Generals Problem, 65, 79, 98–102
- Canada, Project Jasper, 20, 127–129, 175–176
- CAP (consistency, availability, partition tolerance) theorem, 44–45, 46
- Capital One, 44
- Cash flow method, 39
- Cash flow statement, 27
 - creation of financial statements and, 38
 - as a ledger, 31, 35, 36
 - similarities/differences with income statement, 38–39
 - for United States, 42
- Cash in advance, value of money and, 156–157
- Cash mismanagement, cost of, 51
- Cash transactions, recorded on ledgers, 31, 36

- Cell phone credits, M-Pesa and, 54–55, 56
- Central banks
 - cashless society and, 51–52
 - commitments and, 163
 - cryptocurrencies and, 181n5
 - mitigation of moral-hazard problem and, 135
 - motives for trade and, 140
 - payments and, 3
 - smoothing interest rate, 165
- Central counterparty (CCP) clearing, 184n3
- Centralization
 - delegation of portfolios to third party and, 105–107
 - Fischer Consensus Problem and, 46
 - smart contract and, 79
- Centralized platforms, 47
- Central warehouse, 140
- Certification in Bitcoin, 69
- Checks, paper, 148, 149
- China, regulation of delegation to platforms, 184n1
- Clearing House of New York, 13
- Coding costs, 94–97
- Coinbase, 58
- Coins. *See also* Tokens
 - coloring, 184n3
 - histories of, 18, 111
 - stable, 160–163, 179
- Collateral, 93, 119, 141
- Collateralized debt positions (CDPs), 161–162
- Collusion, 92, 122, 172
- Coloring coins, 184n3. *See also* Multiple colored tokens
- Commitment
 - built into communication protocol, 101
 - in cryptocurrency design, 163
 - in economics, 94
- Commitment savings accounts, 120
- Committee on Payments and Market Infrastructures (CPMI), 3
- Commodity space of an economy, 123
- Communication
 - fixed objective and naive, 99–100, 101
 - under smart contract, 79
- Communication systems, optimal design of, 17–18
- Community-level financial accounts, 40–41
- Competition
 - among distributed ledger providers, 20–21
 - limiting, for smart contracts, 135–137
- Complete-markets equilibrium real allocation, 141–142
- Complexity, novelty *vs.*, 3
- Computer science
 - economics *vs.*, 17
 - smart contracts in, 93–102
 - synchronization in, 45
- Concealment, partitioned ledgers and, 104–106
- Conditionality, savings products and, 120
- Consensus
 - asynchronous systems and, 14
 - Byzantine Generals Problem and, 65

- Consensus (cont.)
 - differences among protocols, 65–68
 - distributed, 64–68
 - e-systems and, 15–16
 - permissioned private ledgers and lack of unique, 111–113
 - regulation and, 177
 - on shared distributed ledger, 37
 - unique, 78, 108–109
 - validity, 78
- Consensus algorithms, 16
 - blockchain platforms and, 67–68
- Consensus categorization, 40, 168
- Consistency, distributed ledgers and, 44–45
- Constrained-optimal contract, 84, 85–86, 104
- Constrained-optimal solutions, 13
- Constraints, economic, 24
- Context, innovation and, 4
- Contract competition, 175, 177
- Contract node as planner, 173–174
- Contracts. *See also* Smart contracts
 - blockchain and, 2–3
 - distributed ledger technology and, 13–14
 - money and, 25
 - to purchase and sale of commodity or asset, 89
 - time line of events within given period under, 27, 28
- Coordination, circulating private debt and, 141–142, 143
- Corda
 - latency and, 45
 - notary service on, 80
 - as permissioned ledger system, 66, 67
 - Project Jasper and, 127, 128
 - smart contracts and, 6, 68, 77–78, 79
 - tokens and, 112
 - unique consensus and, 121
- Cost
 - of cash mismanagement, 51
 - of coding and implementation of smart contracts, 94–97
 - of decentralization, 173
 - transaction, 24
- Costly state verification, 88
- Credit, 140, 148
- Credit cards, 52, 148
- Credit derivatives, 7
- Cross-border payments
 - Lightnet and Velo and, 130–132
 - Project Jasper and, 129
- Crossley, Thomas F., 43
- CRUD (create, read, update, or delete), 44
- Cryptocurrencies, 21–22, 59, 145–165. *See also* Bitcoin
 - on balance sheet, 38
 - central banks and, 181n5
 - fiat money and, 178–179
 - hybrid model of positive token values, 157–158
 - incentives for compliance in, 94
 - interest rate policy for digital reserve bank, 163–165
 - as means of payment, 149–150

- mechanism design for tokens
 - and, 150–151
 - as media of exchange, 147–148
 - monetary theory in Walrasian competitive markets and, 151–156
 - multiple media, 148–150, 178
 - need for commitment in design, 163
 - number of, 8, 181n3
 - stable coins, 160–163
 - tokens and, 145–146, 157–158
 - value of money and, 156–160
- Cryptocurrency exchanges, 11, 58
- Cryptographic hash, 97
- Cryptography, 13, 170–171
- CSD (clearing house), 37
- Currency. *See also* Paper currency
 - elastic, 164–165
 - ghost, 150
- Currency infrastructure, in Sweden, 182n1
- Currency to GDP ratio, 49, 52, 169
- Custodians, third parties as portfolio, 105–107
- Cybersecurity, Project Jasper and, 128
- Dai coin, 163
- Database
 - distributed ledger technology *vs.* traditional, 44–47
 - Townsend Thai, 27–29
- Database management
 - advances in, 10
 - science of, 169
 - traditional *vs.* decentralized, 14–15
- Data integrity, 15
- Data synchronization, 45
- Debit cards, 52
- Decentralization, 1, 18, 173–174
- Decentralized Autonomous Organization (DAO), 11
- Decentralized exchange, 137–140
- Decentralized ledgers, synchronization of, 8
- Decentralized systems, impossibility theorems for, 169
- Denison, Erin, 9
- Depository Trust and Clearing Corporation (DDTCC), 6–7
- Design issues
 - delegation of portfolios to third party, 105–107
 - partitioned ledgers, 103–105
 - permissioned private ledgers, 111–113
 - private *vs.* public and the role of tokens, 107–111
- Developing countries, building financial infrastructure in, 115. *See also* Emerging markets
- Diamond-Dybvig model, 104, 134–135, 136
- Digital Asset, 5, 37, 46, 146
- Digital asset, 38
- Digital credit providers
 - in Kenya, 55
 - in Sweden, 51–52
- Digital reserve bank, 20, 163–165
- Digital reserve system, 145, 179
- Disintermediation, of distributed ledger technology, 8

- Distributed computing, advances in, 10
- Distributed consensus, 64–68
- Distributed ledgers
 - as accounts, 13
 - applications, 167
 - building financial infrastructure on, 115–125
 - categorizing transactions on, 39–40
 - components of, 13–14
 - decentralization and, 1
 - financial accounts and, 168
 - innovations making use of, 19–20
 - payment systems on, 127–132, 175–176
 - public information on, 21
 - regulation and, 176–177
 - role of tokens, 107–108
 - security and, 44
 - smart contracts on, 79, 83–84
 - stocks and flows on, 77
 - summary and conclusion, 167–179
 - use in village economies, 37
 - verification in, 64–65
- Distributed ledger technology (DLT), 1
 - disintermediation and, 8
 - emerging-market economies and, 23
 - enhanced measurement and, 43
 - financial services and markets and, 2
 - for freight shipping, 6
 - land-title projects and, 4–5
 - multiparty smart contracts and, 106–107
 - regulation and use of, 133–143
 - repurchase agreements and, 6–7
 - risk of using for payments, 3
 - TCP/IP and, 7
 - traditional database *vs.*, 44–47
 - used to create complete financial accounts, 43
- Double-entry bookkeeping, 39, 168
- Double-spending, Ripple and, 72–73
- e-assets as payment devices, 140
- Economics
 - computer science *vs.*, 17
 - incentives in, 93–102
 - trust in, 88–91, 93
- Economy
 - function of, 24–25
 - meaning of, 23, 24
 - technology tied to, 25
- e-credit, 132
- Electronic clearing systems, 52
- Emerging markets, 23
 - limited financial infrastructure in, 115–116
 - use of paper currency in, 15, 42, 49–51
- e-messages, 13, 15, 169–170
- e-money, 15
 - shortages faced by broker-dealers, 56–57
 - social gains and, 53–56
- Encryption, 59–75
 - Algorand, 75
 - Bitcoin, 68–71
 - contemporary, 63–64

- historical examples of, 59–63
- HotStuff, 74
- Ripple, 71–73
- Stellar, 73–75
- validated and distributed consensus, 64–68
- Endowments, of agent, 24
- e-payments, 15
- e-securities, 140
- e-systems, consensus and, 15–16
- Ether cryptocurrency, 11, 163
- Ethereum, 6, 17
 - computing costs, 95, 96–97
 - contract validation in, 160
 - cost of decentralization on, 173
 - Project Jasper and, 127, 128
 - proof of work and, 65–66, 78
 - smart contracts and, 67
- Ethereum Classic, 11
- e-tokens, 140, 170
- e-transfers, 13, 52, 169–170
 - cryptography and, 170–171
- EvryNet, 20, 124–125, 133, 175

- Fabric, 67
- Facebook, 161
- Facts on ledgers, 77
- Fault tolerance, 66–67, 98
- Federal Reserve Bank, 6, 109, 111, 164–165
- Federal Reserve Bank of Boston, 42–43, 148
- Federated Byzantine Agreement (FBA), 66, 67, 73
- Fiat money
 - cryptocurrencies and, 178–179
 - exchange in Lightnet, 127, 130–132
 - history of, 148
 - media of exchange by, 22
 - multiple-country, 185n4
 - role of tokens relative to fungibility of, 145–146
 - value of, 151–155, 179
 - velocity of, 147, 148
- Fiat tokens, 71–72, 149
- Financial accounts. *See also*
 - Ledgers as financial accounts
 - digital ledgers and, 168
 - as ledgers, 38–40
 - schemata of agent interaction and, 25, 26
- Financial infrastructure, building on distributed ledgers, 115–125
- Financial liberalization, tariffs *vs.*, 40–41
- Financial service providers, competition among, 124
- Financial services and markets
 - distributed ledger technology and, 2
 - EvryNet, 124–125
 - general equilibrium perspective on provision of, 122–124
 - mitigating runs on, 133–135
 - transaction time lines in, 5
- Fingerprint, 63
- Finite-horizon model, 156
- Fischer Consensus Problem of distributed computing, 45–46
- Fixed objective, communication protocol and, 99–100, 101
- Flow, 77
- Flow of funds accounts, 41
- Fractional reserve banking, Safaricom and, 56

- Freight shipping, distributed ledger technology for, 6
- Frequency of use in payment, money and, 147–148
- Front-loading, 106–107, 174
- Full commitment, 88–89, 171
- Fundamental welfare theorem, 158–159
- General equilibrium perspective on provision of financial services, 122–124
- General equilibrium theory, 11, 135–136
- Generalized statements of liquidity accounts in the US, 42–43
- Generations, model of money and overlapping, 155
- Ghost currencies, 150
- Government village fund intervention (Thai Baht Fund), 19, 117–118, 174
- Grain, as medium of exchange, 148
- Hacking events, 11, 44, 58
- Hash, cryptographic, 97
- Hashing, 63, 68, 70–71
- Hawaladars, 72
- Hawala system, 72
- Helix Institute of Digital Finance, 57
- Hold-up problem, 92
- Honest nodes, in Bitcoin, 69
- Hong Kong Monetary Authority, 5
- HotStuff, 16, 74
- Households running small and medium-sized enterprises (SMEs) and, 25
- Hybrid model of positive token values, 157–158
- Hybrid smart-contract systems, 16
- Hyperledger, 6, 66, 67
- Hyperledger Fabric, 47
- IBM, 6, 7, 64
- ICRISAT, 148
- Immutability of smart contracts, 82
- Implementation costs for smart contracts, 94–95
- Incentive compatibility, 171
- Incentives
 - full commitment *vs.*, 88–89
 - mechanism design and, 172
 - to tell truth in messages, 87
 - in validation, 93–102
- Income, money transactions and, 154
- Income distribution, paying interest and, 153–154
- Income statement, 27
 - accrued income concept and, 39
 - changes in balance sheet and, 39
 - creation of financial statements and, 38
 - in village economies, 31, 33–34
- Indemnity, community-level insurance and, 121
- India
 - media of exchange in, 148
 - TReDS in, 5
- Inefficiency, testing for, 155–156
- Inflation, 154, 163

- Information. *See also* Private information
 private monies and,
 140–143
 public, 21, 137
- Information asymmetry, 112
- Innovation
 Bitcoin and, 4
 context and, 4
 EvryNet example, 124–125
 invention *vs.*, 4, 10
 localization and, 4
 public sector and, 182n7
 smart contracts and, 6
- Insurance
 community-level, 120–121
 multiparty insurance agreement, 90–91
 multi-period, principal-agent problem, 85–87
 smoothing economy and, 154
- Integrated financial accounts, 27
- Integration, 17
- Interbank payments, Project Jasper, 127–129
- Interbank transfer system, Ripple as, 71–72
- Interest
 distribution of income and paying, 153–154
 token values and, 145
- Interest rate, digital reserve banks and, 163–165
- Intermediation, connectedness and, 9
- InterPlanetary File System (IPFS), 97
- Invention, 4, 10
- iOlive, 94
- Kenya. *See* M-Pesa
- Keys
 to Bitcoin, 69
 public-private, 64, 79
 to smart contracts, 80–81
- Kinship
 Million Baht Fund and, 118
 risk-sharing on basis of, 117
- Kraken, 58
- Land-title projects, distributed ledger technology and, 4–5
- Latency, 45, 47, 67, 135, 177
- Ledgers as financial accounts, 31–47
 counterfactual policy analysis, 41–42
 distributed ledger technology *vs.* traditional database, 44–47
 financial accounts as ledgers, 38–40
 generalized statements of liquidity accounts in the US, 42–43
 smart contracts and, 93
 statement of cash flow and balance sheet as ledger, 31–38
 use of village and community-level financial accounts, 40–41
- Letters of credit, 119
- Liabilities, measurement of, 38–39
- Libra, 16, 74, 161
- Lightnet, 20, 127, 130–132, 158, 159–160, 165, 176
- Lightning Network, 46–47, 169
- Limited commitment, 171–172
 trust *vs.*, 88–91

- Limited-commitment contract, 89–91
- Liquidity
 - cash flow statements and, 36
 - common concerns about, 56–58
 - distributed ledger technology and study of, 36, 43
 - Ostroy-Starr model and, 139–140
 - productivity *vs.*, 39
 - public debt and, 153
 - reserve bank, 165
- Liquidity accounts for multiple media of exchange, 40–41
- Liveness, 67
- Loans, community information on who should get, 121–122
- Localization, innovation and, 4
- Maersk platform, 6, 7, 146
- MakerDAO, 161
- Malicious leaders, Algorand and, 75
- Malicious nodes, 172
- Marginal rates of substitution, digital reserve banks and, 164
- Markov perfect equilibrium, 70
- Measurement
 - of economic activity, 27
 - of liabilities, 38–39
- Mechanism design, 12–13, 171–172
 - Corda and, 78
 - cryptocurrencies and, 178
 - key elements from, 82
 - meaning of trust in, 88–91
 - mitigating runs on banks and markets and, 134
 - smart contracts and, 81–93
 - tokens and, 21–22, 145–146, 150–151
- Mesh networks, 47, 74
- Mesopotamians, cryptography and, 59–62, 171
- Messages
 - encryption of, 63–64
 - limited space, 88
 - single period contract with, 82
 - in smart contracts, 81–83, 97–102
 - verification of, 170–171
- Metadata on distributed ledger, 39
- Microdata on transactions, 165
- Micropayments, Stellar and, 5–6
- Million Baht Fund (Thailand), 19, 117–118, 174
- Miners, Bitcoin, 68–70, 92
- Mint, 43
- Monetary Authority of Singapore, 129, 184n3
- Monetary exchange, Turnpike model of, 152
- Monetary models, interest rate policy for digital reserve banks, 163–165
- Monetary policy, role of liquidity in, 58
- Monetary solution, Ostroy-Starr model and, 139
- Monetary theory
 - cryptocurrencies and, 178
 - lessons for regulation of payment systems from, 137–143
 - Walrasian, competitive markets, 151–156

- Money. *See also* Fiat money;
 Paper currency
 contracts and, 25
 cryptocurrency and value of,
 158–160
 definitions of, 145, 147–148
 e-money, 15, 53–57
 endogenous valuation of,
 152–155, 157–158
 exogenous valuation of,
 156–157
 in Ostroy-Starr model, 138
 as store of value, 153, 154
 types of, 21
 as unit of account, 153
 value of, 22, 145, 156–157
- Money good, 139
- Money markets, Thai village,
 116–117, 174
- “Moneyness,” velocity and, 21
- Money transfer operator
 (MTO), 20, 130–132, 158,
 176
- Moral hazard, 85, 86–87, 135
- M-Pesa, 15, 53–56, 170
 liquidity shortages and, 56–57
 operational flows of, 54
 social value of, 55
 as stable coin, 54–55
 transfers and borrowing/
 lending among Safaricom
 agents, 57
- M-Shwari, 55
- Multiparty insurance agreement,
 90–91
- Multiparty mechanisms, in con-
 tracts, 13–14
- Multi-period, principal-agent
 insurance problem, 85–87
- Multi-period contracts, 82
- Multiple colored tokens, 107,
 109–111, 150, 174
- Multiple-country fiat monies,
 185n4
- Multiple media of exchange,
 147, 148–150, 178
 liquidity accounts and, 40–41
- Multiple media of exchange
 equilibria, 140–143
- Nakamoto, Satoshi, 9, 10, 44,
 69, 70
- Nash equilibrium, 81, 92, 134,
 177
- National currencies, e-money
 systems for, 71
- National income and product
 accounts (NIPA), 41
- National income data, 155–156
- Natural discount rate, digital
 reserve banks, 164
- Netting, 128, 175–176
- Nodes
 incentives to validate cor-
 rectly, 91
 malicious, 98, 101
 notaries and, 80, 175
 smart contract, 78–79, 80
 trusted or not, 17, 93
- Novelty, complexity *vs.*, 3
- “Off-chain” environment, 169
- Office for National Statistics
 (ONS) Economic Expert
 Working Group (EEWG), 43
- OmiseGO, 58
- Opaque computational systems,
 64
- Open-source banking services,
 20, 124, 175

- Oracle, 79
- Ostroy-Starr model, 137–140
- Over-the-counter (OTC) markets, 47, 138
- Over-the-counter (OTC) trade in securities, 104
- Panel Study of Income Dynamics (PSID), 43
- Paper checks, 148, 149
- Paper currency
 - transactions recorded as ledgers, 31, 36
 - use in Thailand, 15, 42, 49–51
- Pareto criterion, 11, 123
- Pareto optimal allocation, 24, 137, 142
- Parties to contract, 78
- Partition agents, risk-sharing arrangements for, 47
- Partitioned ledgers, 103–105
 - colored coins and, 110
 - concealment and, 104–106
 - contract node and, 173–174
- Partition tolerance, distributed ledgers and, 45
- Payment matrix, 147–148
- Payments, waterfall, 119
- Payments Canada white paper, 127, 128
- Payment systems, lessons from monetary theory for regulation of, 137–143
- Payment systems on distributed ledgers, 3, 127–132
 - Lightnet and Velo, 127, 130–132
 - Project Jasper, 127–129, 175–176
- Payoff, smart contract, 85
- Payout, insurance, 120–121
- PayPal, 89
- Permissioned blockchains, 46–47, 66
- Permissioned private ledgers, 103–105, 111–113
 - Project Jasper and, 127–129
- Physical tokens, 174
- Planner
 - contract node as, 174
 - of mechanism design, 12–13
- “Planner” problem of mechanism, 173
- Political economy of reform, 12
- Portfolios, delegation to third party, 105–107
- Postal Pay, 55
- Practical Byzantine Fault Tolerance (PBFT) algorithms, 66, 74–75
- Price-fixing schemes, cryptocurrencies and, 162–163
- Private blockchains, 46
- Private clearinghouses, private and public ownership of, 13
- Private debt, 140–143, 149, 177–178
- Private information
 - letting be public, 98
 - Ostroy-Starr model and, 139
 - partitioned ledgers and, 103–105
 - smart contracts and, 83–84
 - tokens and, 111–112
- Private monies, information problem with, 140–143
- Process synchronization, 45
- Productivity, liquidity *vs.*, 39

- Products/systems, valuation of, 12
 Project Jasper, 20, 127–129, 175–176
 Promise-keeping, 86–87
 Proof of stake (PoS), 66, 171
 Proof of work (PoW), 16, 65–66, 67, 78, 171
 Propy.com, 5
 Protocol, 58
 Public and private partnerships (PPPs) in Sweden, 182n7
 Public debt, liquidity and, 153
 Public information, on distributed ledgers, 21, 137
 Public ledgers, regulation and, 177
 Public-private keys, 64, 79
 Public sector, innovations and, 182n7
 Quorum, 66, 67–68
 R3, 6, 66, 128
 Randomization, partitioned ledgers and, 104–105, 173–174
 Rebalancing, in developing countries, 57
 Reconciliation, in Lightnet, 131
 Regulation and use of distributed ledger technology, 20, 133–143, 176–177
 limits of competition for contracts, 135–137
 mitigating runs on banks and markets, 133–135
 need for coordination of payment systems, 138–143
 Rehypotheication of collateral, 141
 Relationships, smart contracts and enduring, 83–84
 “Relayers,” 47
 Remittances in Southeast Asia, 5–6, 130–132, 176
 Reneging, 172
 Renegotiation, 94
 Repo transaction, 161–162
 Repurchase agreements, digital ledger technology and, 6–7
 Reputation, smart contracts and, 91–92
 Reserve bank liquidity, 165
 Retrading, 136–137
 Revelation principle, 81, 97
 Riksbank, 51–52, 182n1
 Ripple, 6, 16
 cryptography and, 71–73
 Federated Byzantine Agreement and, 66
 validation system of, 8
 Ripple Protocol Consensus Algorithm, 73
 Risk aversion, information disclosure and, 112
 Risk sharing, 19, 55, 116–117, 174
 Rotating savings and credit association (ROSCA) transactions, 50
 RTGS (real-time gross settlement) system, 184n3
 Runs on banks and markets, mitigating, 133–135
 Safaricom, 15, 54, 55–56, 170
 Safety, in encryption, 67
 Savings
 difference between revenues and expenses, 38
 mechanism design and, 150–151

- Savings/investment account, 41
- Savings products, 120
- Secrets, permissioned private ledgers and, 111–113
- Secure Hash Algorithm SHA-256, 63
- Securities
 - e-securities, 140
 - as payment devices, 140–141
 - tokenized, 146, 148
- Security, distributed ledgers and, 44
- Seigniorage-style algorithm, 162
- Sequential-service models, 134
- Shocks, 153
 - back- and front-loading, 174
 - customer needs and, 104
 - sharing risk to mitigate, 116–117
 - smart contracts and, 83, 105
 - tokens and, 18
- Small and medium-sized enterprises (SMEs), in Thailand, 25, 51, 116
- Smart contracts, 16, 77–81
 - blockchain platforms and, 67
 - capabilities of, 80
 - coding and implementation costs, 94–97
 - in computer sciences, 93–102
 - costly state verification, 88
 - distributed ledger technology and, 175
 - economics of collusion, 92
 - EvryNet and, 124–125
 - examples, 119–122
 - impact of enduring relationships and, 83–84
 - implementation through sequential play, 92–93
 - incentives to take appropriate action, 85–87
 - innovation and, 6
 - lack of immutability in, 11
 - ledgers of the financial accounts, 93
 - Lightnet and, 160
 - limits of competition for, 135–137
 - meaning of trust, 88–91
 - mechanism design, 81–93
 - messages, 81–83
 - multi-period, 82
 - payoff, 85
 - promised utility as the state, 85
 - reliability of messages, 97–102
 - reputation and, 91–92
 - schematic of financial accounts and agent interaction through, 25, 26
 - Seigniorage-style algorithm and, 162
 - summary of, 172–174
 - utility threats, 87–88
 - value of tokens and, 145
- Social gains, e-money and, 53–56
- Social security, money and, 154–155
- Southeast Asia (SEA). *See also* Thailand
 - innovations in, 175
 - limited financial infrastructure in emerging markets in, 115–116
 - money transfer operators in, 176
 - remittances in, 5–6, 130–132, 176

- Spot-trade condition, quid pro quo, 138
- Stable coins, 160–163, 179
- Star communication network, 74
- State, promised utility as the, 85
- Statement of cash flow in village economies, 31, 36–38
- State of the system, 77
- Stellar, 5–6, 8, 16, 66, 131, 132, 149
- Stellar Consensus Protocol (SCP), 73
- Stellar Development Foundation, 73–75
- Stock, 77
- Strategic reliability, 102
- Supermartingales/submartingales, Bitcoin prices and, 159
- Survey of Consumer Finances (SCF), 43
- Sweden
 - as cashless society, 15, 51–52
 - currency infrastructure in, 182n1
 - currency to GDP ratio, 52, 169
 - public and private partnerships in, 182n7
- Swift, 66
- Swish, 51, 182n7
- Synchronization of data and processes, 45
- Synchronous systems, 14–15
- Tally sticks, 62–63, 149, 171, 183n1
- Tally stock, 62
- Tariffs, real and financial liberalization *vs.*, 40–41
- Taxes
 - digital reserve banks and, 164
 - value of money and payment of, 156–157
- TCP/IP (transmission control protocol/internet protocol), 7, 59
- Technological change to fill in the gaps, 9–10
- Technology
 - agent access to, 24
 - difficulty of adopting transformative, 3
 - distributed ledger technology and, 2
 - ties of economy to, 25
- Tether, 161
- Thailand. *See also* Townsend Thai project
 - change in policy in, 42
 - currency to GDP ratio, 49, 169
 - e-money *vs.* paper currency in, 15
 - Lightnet in, 130–132
 - Million Baht Fund, 19, 117–118, 174
 - use of paper currency in, 15, 42, 49–51
- Thin markets, 57
- Third party, delegation of portfolios to, 105–107. *See also* Trusted third party
- Third-party custodian, 174
- Time lines
 - of events within given period under contract, 27, 28
 - schemata of financial accounts and agent interaction through smart contracts, 25, 26

- Tokens, 18, 74. *See also* Coins
 achieving unique consensus
 and, 108–109
 as communication devices, 109
 fiat, 71–72, 149
 hybrid model of positive
 token values, 157–158
 indeterminacy of value, 22
 mechanism design for,
 150–151
 Mesopotamian, 59–62
 multiple colored, 107, 109–
 111, 150, 174
 physical, 174
 private information and,
 111–112
 private *vs.* public and role of,
 107–111
 public verified histories of,
 111
 removing indeterminacy of
 values, 159–160
 role and value of, 21–22
 role relative to fiat money fun-
 gibility, 145–146
 taxation and, 164
 tokenized securities and, 146,
 148
 as units of account, 150
 utility, 146, 156, 160, 179
 value of, 145
- Townsend Thai project, 13, 167
 data for study of financial
 access, 19, 27–29, 49
 national income and product
 accounts, 40–41
 sharing of risk to mitigate
 shocks, 116–118, 174
 transaction log, 31, 36–37
- Trade credit, 149
- Trade Information Warehouse, 7
- Trade receivables, TReDS and, 5
- Trades
 history of, on immutable
 ledger, 177
 token system to keep track of,
 109, 111
- Transaction costs, 24
- Transaction log, in Thai village
 economies, 31, 36
- Transaction speed, encryption
 and, 67
- Transaction time lines, 5
- TReDS, 5
- Trust
 borrowing and lending and,
 89
 Byzantine protocols with, 16
 distributed ledger technology
 and alleviation of limitation
 of, 118
 in economics, 88–91, 93
 financial system and, 170–171
 implemented by “scoring,”
 91–92
 mechanism design and,
 171–172
- Trusted third party
 central banks as, 9
 contracts and, 171
 decentralized systems and,
 169
 M-Pesa and, 15, 170
 reputations of, 91
 Safaricom as, 55, 56
 security and, 44
 speed and cost and, 46
- Trust lines, in Ripple, 72
- Turnpike model of monetary
 exchange, 152

- Unique consensus, 78, 108–109
- United States
 - economic surveys in, 43
 - generalized statements of
 - liquidity accounts, 42–43
 - impact of tariffs in, 40, 42
 - liquidity management in, 57–58
 - multiple media of exchange in, 148
- Unit of account, money as, 153
- Universal Market Access (UMA), 6
- Utility threats, smart contracts and, 87–88
- Utility tokens, 146, 156, 160, 179

- Validation
 - alternative, 67–68
 - bad actors and, 67
 - of code, 17
 - distributed consensus and, 64–68
 - incentives in, 93–102
 - in Ripple network, 72–73
 - in Stellar protocol, 73
- Validators, in Bitcoin, 69–70
- Validity consensus, 78
- Velocity
 - of fiat money, 147, 148
 - “moneyness” and, 21
 - private debt and, 149
- Velo Labs, 20
- Velo network, 176

- Velo tokens
 - exchanges of, 184n4
 - Lightnet and, 130–132, 158, 159–160
- Verification, costly state, 88
- Village economies (Thailand)
 - balance of payments account, 40–41
 - statement of cash flow and balance sheet as ledger, 31–33, 36
 - use of distributed ledgers, 37–38
- Villages. *See also* Townsend Thai project
 - Million Baht Fund and, 19, 117–118, 174

- Walmart, distributed ledger
 - technology and supply chain tracking and, 6, 146
- Walrasian allocation, 138
- Walrasian competitive markets, 150, 151–156
- Walrasian equilibrium, 135, 137
- Walrasian optimum, 177
- Waterfall payment, 119
- Welfare metric, 11

- XRP coin, 71

- Zero-knowledge-proof systems, 64
- 0x, 58

